2015 International Year of Soils

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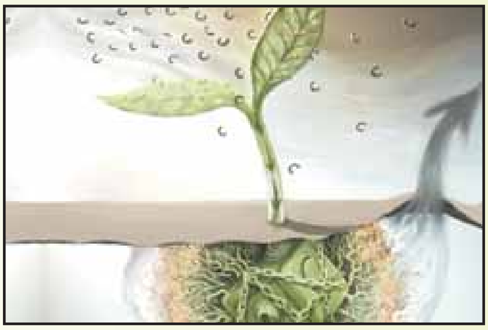
on

Climate Resilient Soil Management Strategies for Sustainable Agriculture

14th October to 3rd November, 2015



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"Healthy Soils for a Healthy Life"

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Preface

"Healthy soils for a healthy life"

The specter of climate change has been with us for a long time. As early as 1896, the Swedish chemist and Nobel Prize winner Svante Arrhenius published a paper discussing the role of carbon dioxide in the regulation of the global temperature and calculated that a doubling of CO_2 in the atmosphere would trigger a rise of about 5–6^{O}C. In more recent years we have moved to a better understanding of what this means for our planet and its people, and we have developed some plausible approaches to tackling the problem. However, we have yet to implement most of them.

In recent times, climate change has received the highest level of attention, however little has been achieved to arrest the increasing carbon emissions that are responsible for global warming. Agriculture, along with land use change, enjoys double distinction of being both a driver and a victim of climate change. On one hand, the carbon emissions related to each stage of the agricultural value chain–from seed to plate– contribute to climate change, while on the other hand, the negative impacts of climate change (e.g. growing frequency and intensity of rainfall, higher temperatures, shorter growing seasons, changing patterns of pests and diseases) may lead to crop damage, land degradation, and food insecurity.

As the future climate unfolds, more will be needed. Agriculture – and agricultural research will face a race against time.

Soils constitute the foundation of vegetation and agriculture. Forests need it to grow. We need it for food, feed, fiber, fuel and much more. The multiple roles of soils often go unnoticed. Soils don't have a voice, and few people speak out for them. They are our silent ally in food production. Soils also host at least one quarter of the world's biodiversity. They are key in the carbon cycle. They help us to mitigate and adapt to climate change. They play a role in water management and in improving resilience to floods and droughts. We need healthy soils to achieve our food security and nutrition goals, to fight climate change and to ensure overall sustainable development.

We now have adequate platforms to raise awareness on the importance of healthy soils and to advocate for sustainable soil management. Let us use them. The Sixty-eighth session of the United Nations General Assembly on December 20th, 2013 after recognizing December 5th as World Soil Day declared 2015 as The International Year of Soils, 2015 (IYS 2015) to increase awareness and understanding of the importance of soil for food security and essential ecosystem functions.

"Save soil save life"

Jabalpur **(A.K. Rawat)**
October, 2015 **Director, CAFT**

National Training Programme

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Climate change: Microbial contributions and responses

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What is climate change?

The Earth is surrounded by a thick layer of gases which keeps the planet warm and allows plants, animals and microbes to live. These gases work like a blanket. Without this blanket the Earth would be 20–30°C colder and much less suitable for life. Most scientists now agree that climate change is taking place. This is being demonstrated globally by the melting of the polar ice sheets and locally by the milder winters coupled with more erratic extreme weather such as heavy rain and flooding. Climate change is happening because there has been an increase in temperature across the world. This is causing the Earth to heat up, which is called global warming.

When the average long-term weather patterns of a region are altered for an extended period of time, typically decades or longer is known as climate change. Examples include shifts in wind patterns, the average temperature or the amount of precipitation. These changes can affect one region, many regions or the whole planet (Allison, 2010). Climate changes are caused by changes in the total amount of energy that is kept within the Earth's atmosphere. This change in energy is then spread out around the globe mainly by ocean currents as well as wind and weather patterns to affect the climates of different regions (Royal Society, 2010).

What are the causes of climate change /global warming?

Natural processes such as volcanic eruptions, variations in Earth's orbit or changes in the sun's intensity are possible causes. The Earth's climate has never been completely static and in the past the planet's climate has changed due to natural causes.

However, humans activities can also cause changes to the climate for example by creating greenhouse gases emissions or cutting down forests. The world population of 7.2 billion and the atmospheric CO_2 concentration of 400 ppmv in 2013 are increasing at the annual rate of 75 million people and 2.2 ppmv, respectively (*Greenhouse Gas Bulletin*, 2011). Indeed, there exists a strong correlation between the human population and CO_2 emission: growth in world population by one billion increases CO_2-C emission from fossil fuel consumption by 1.4 Pg (1 Pg = 1015, g = 1 Gt) (IPCC. Summary for Policymakers. In *Climate Change 2013;* Lal, R. , 2013). The blanket of gases that surrounds the Earth is getting much thicker. These gases are trapping more heat in the atmosphere causing the planet to warm up.

Global warming and the climate changes seen today are being caused by the increase of carbon dioxide (CO_2) and other greenhouse gas emissions by humans. Human activities like the burning of fossil fuels, industrial production, etc. increase greenhouse gas levels. This traps more heat in our atmosphere, which drives global warming and climate change (UNESCO, 2011). So while CO_2 and other greenhouse gases are naturally present in the atmosphere, emissions from human activities have greatly amplified the natural greenhouse effect. CO_2 concentrations in the Earth's atmosphere has increased significantly since the beginning of the Industrial Revolution, and most especially in the past 50 years (The World Bank, 2011).

Computer models, ice core evidence as well as fossilized land and marine samples show that CO_2 is at its highest level in the last 3 million years and that CO_2 concentrations have increased because of human activities like fossil fuel use and deforestation (Le Quéré et al, 2012; Van De Wal et al, 2011). Human activities have caused the Earth's average temperature to increase by more than 0.75°C over the last 100 years (The World Bank, 2011). Scientists have tracked not only the changes in the temperature of the air and oceans, but other indicators such as the melting of the polar ice caps and the increase of world-wide sea levels.

The impact of these shifts have an impact on all life-forms on our planet including their sources of food and water. Current impacts that are already being observed are desertification, rising sea-levels as well as stronger extreme weather events like hurricanes and cyclones.

Where are these extra gases coming from?

These gases are called greenhouse gases. The three most important greenhouse gases are carbon dioxide, methane and nitrous oxide and these have increased dramatically in recent years due to human activity. The complex and strong link between soil degradation, climate change and food insecurity is a global challenge. Increasing temperatures stimulate the decomposition of soil organic matter in the short term. But a shift in microbial carbon allocation could mitigate this response over longer periods of time.

Microbial decomposition of soil organic matter releases 60 Pg of carbon dioxide to the atmosphere each year. This constitutes about 25% of natural carbon dioxide emissions. “It’s a vicious circle,”. “Extreme weather as a result of the changing climate places plants under stress. In response to this stress, plants produce massive quantities of ethylene, initiating short term survival tactics such as leaf loss and reduced growth. In many cases, this reaction causes more damage to the plant than the stress itself. “However, ethylene also blocks a process in the soil where bacteria called methanotrophs break down methane. The result is that the soil cannot capture methane, leaving more in the atmosphere. With methane being a major cause of global warming, the extreme weather – plant stress–methane production cycle is accelerated.”

Methane is a potent greenhouse gas and although present in small concentrations is responsible for a large portion of global warming, second only to carbon dioxide (CO2). Any alterations to the methane concentration in the atmosphere will therefore have a considerable effect on global warming and weather conditions.

“There are many sources of methane – livestock, fossil fuel production and wetland emissions”. “But there are only two sinks – atmospheric oxidation and oxidation by these soil methanotrophs, which are found predominantly in forest ecosystems.”

Preserving the methanotrophs’ ability to capture methane when plants are subject to stress may prove a vital key to regulating the methane-global warming balance. The activity of a second group of “plant growth promoting bacteria” – so called due to their abilities to improve plant productivity - may provide the answer. These bacteria have the ability to slow down a plant’s production of ethylene by producing an enzyme referred to as ACC-D[1] (1-aminocyclopropane-1-carboxylate (ACC) deaminase) which reduces a plant's production of excess ethylene when under stress. Plants normally produce ethylene at low concentrations as part of their physiological processes. What we are interested in is being able to stop a plant producing excess ethylene when it is under stress. The enzyme ACC-D reduces a plant’s production of ethylene and allows it to respond to stress more effectively. This has been proven to increase plant’s tolerance to stress. It may also limit the amount of ethylene released into the soil, allowing methanotrophs to continue breaking down methane. There are some radiata pine strains that have greater levels of the ACC-D enzyme in the surrounding soil, suggesting there is some sort of signalling going on between those particular plants and the bacteria. This probably helps makes these strains more tolerant to certain stressful conditions like drought, for example. We don’t yet fully understand the complex relationship between plants, microbes, and soil systems. “It’s possible we may be able to harness these ACC-D producing bacteria not only to help plants cope better under stress, but also to address a significant piece of the global warming, helping future proof both planted forests and wider plant ecosystems against a changing climate.”

Microorganisms found in the soil are vital to many of the ecological processes that sustain life such as nutrient cycling, decay of plant matter, consumption and production of trace gases, and transformation of metals (Panikov, 1999). Although climate change studies often focus on life at the macroscopic scale, microbial processes can significantly shape the effects that global climate change has on terrestrial ecosystems. According to the International Panel on Climate Change (IPCC) report (2007), warming of the climate system is occurring at unprecedented rates and an increase in anthropogenic greenhouse gas concentrations is responsible for most of this warming.

Soil microorganisms contribute significantly to the production and consumption of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and nitric oxide (NO), and human activities such as waste disposal and agriculture have stimulated the production of greenhouse gases by microbes. As concentrations of these gases continue to rise, soil microbes may have various feedback responses that accelerate or slow down global warming, but the extent of these effects are unknown. Understanding the role, soil microbes contribute to and reactive components of climate change which can help us to determine whether they can be used to curb emissions or if they will push us even faster towards climatic disaster.

Microbial contributions to greenhouse gas emissions

Soil microorganisms are a major component of biogeochemical nutrient cycling and global fluxes of CO_2, CH_4, and N. Global soils are estimated to contain twice as much carbon as the atmosphere, making them one of the largest sinks for atmospheric CO_2 and organic carbon (Jenkinson and Wild, 1991; Willey et al., 2009). Much of this carbon is stored in wetlands, peatlands, and permafrost, where microbial decomposition of carbon is limited. The amount of carbon stored in the soil is dependent on the balance between carbon inputs from leaf litter and root detritus and carbon outputs from microbial respiration underground (Davidson and Janssens, 2006). Soil respiration refers to the overall process by which bacteria and fungi in the soil decompose carbon fixed by plants and other photosynthetic organisms and release it into the atmosphere in the form of CO_2. This process accounts for 25% of naturally emitted CO_2, which is the most abundant greenhouse gas in the atmosphere and the target of many climate change mitigation efforts. Small changes in decomposition rates could not only affect CO_2 emissions in the atmosphere, but may also result in greater changes to the amount of carbon stored in the soil over decades (Davidson and Janssens, 2006).

Methane is another important greenhouse gas and is 25 times more effective than CO_2 at trapping heat radiated from the Earth (Schlesinger and Andrews, 2000). Microbial methanogenesis is responsible for both natural and human-induced CH_4 emissions since methanogenic archaea reduce carbon into methane in anaerobic, carbon-rich environments such as ruminant livestock, rice paddies, landfills, and wetlands. Not all of the methane produced ends up in the atmosphere however, due to methanotrophic bacteria, which oxidize methane into CO_2 in the presence of oxygen. When methanogens in the soil produce methane faster than can be used by methanotrophs in higher up oxic soil layers, methane escapes into the atmosphere (Willey et al., 2009). Methanotrophs are therefore important regulators of methane fluxes in the atmosphere, but their slow growth rate and firm attachment to soil particles makes them difficult to isolate. Further exploration of these methanotrophs' nature could potentially help reduce methane emissions if they can be added to the topsoil of landfills, for example, and capture some of the methane that would normally be released into the atmosphere.

Not unlike their role in the carbon cycle, soil microorganisms mediate the nitrogen cycle, making nitrogen available for living organisms before returning it back to the atmosphere. In the process of nitrification (during which ammonia is oxidized to nitrate), microbes release NO and N_2O, two critical greenhouse gases, into the atmosphere as intermediates.

Evidence suggests that humans are stimulating the production of these greenhouse gases from the application of nitrogen-containing fertilizers (Willey et al., 2009). For example, *Nitrosomonas eutropha* is a nitrifying proteobacteria found in strongly eutrophic environments due to its high tolerance for elevated ammonia concentrations. N-fertilizers increase ammonia concentrations, causing *N. eutropha* to release more NO and N_2O in the process of oxidizing ammonium ions.

Since NO is necessary for this reaction to occur, its increased emissions cause the cycle to repeat, thereby further contributing to NO and N_2O concentrations in the atmosphere (Willey et al., 2009).

Microbial responses to global climate change

Microbial processes are often dependent on environmental factors such as temperature, moisture, enzyme activity, and nutrient availability, all of which are likely to be affected by climate change (IPCC, 2007). These changes may have greater implications for crucial ecological processes such as nutrient cycling, which rely on microbial activity. For example, soil respiration is dependent on soil temperature and moisture and may increase or decrease as a result of changes in precipitation and increased atmospheric temperatures. Due to its importance in the global carbon cycle, changes in soil respiration may have significant feedback effects on climate change and severely alter aboveground communities. Therefore, understanding the response of soil respiration to climate change is of great importance and will be discussed in detail in this report.

Microbial response to increased temperatures

One of the major uncertainties in climate change predictions is the response of soil respiration to increased atmospheric temperatures (Briones et al., 2004; Luo et al., 2001). Several studies show that increased temperatures accelerate rates of microbial decomposition, thereby increasing CO_2 emitted by soil respiration and producing a positive feedback to global warming (Allison et al., 2010). Under this scenario, global warming would cause large amounts of carbon in terrestrial soils to be lost to the atmosphere, potentially making them a greater carbon source than sink (Melillo et al., 2002). However, further studies suggest that this increase in respiration may not persist as temperatures continue to rise. In a 10-year soil warming experiment, Melillo et al. (2002) show a 28% increase in CO_2 flux in the first 6 years of warming when compared to the control soils, followed by considerable decreases in CO_2 released in subsequent years, and no significant response to warming in the final year of the experiment. The exact microbial processes that cause this decreased long-term response to heated conditions have not been proven, but several explanations have been proposed. First, it is possible that increased temperatures cause microbes to undergo physiological changes that result in reduced carbon-use efficiency (Allison et al., 2010). Soil microbes may also acclimate to higher soil temperatures by adapting their metabolism and eventually return to normal decomposition rates. Lastly, it can be interpreted as an aboveground effect if changes in growing-season lengths as a result of climate change affect primary productivity, and thus carbon inputs to the soil (Davidson and Janssens, 2006).

The effects of increased global temperatures on soils is especially alarming when considering the effects. It has already begun to have on one of the most important terrestrial carbon sinks: permafrost. Permafrost is permanently frozen soil that stores significant amounts of carbon and organic matter in its frozen layers. As permafrost thaws, the stored carbon and organic nutrients become available for microbial decomposition, which in turn releases CO_2 into the atmosphere and causes a positive feedback to warming (Davidson and Janssens, 2006). One estimate suggests that 25% of permafrost could thaw by 2100 as a result of global warming, making about 100 Pg of carbon available for microbial decomposition (Davidson and Janssens, 2006; Anisimov et al., 1999). This could have significant effects on the global carbon flux and may accelerate the predicted impacts of climate change. Moreover, the flooding of thawed permafrost areas creates anaerobic conditions favorable for decomposition by methanogenesis. Although anaerobic processes are likely to proceed more slowly, the release of CH_4 into the atmosphere may result in an even stronger positive feedback to climate change (Davidson and Janssens, 2006).

Microbial response to increased CO_2

Atmospheric CO_2 levels are increasing at a rate of 0.4% per year and are predicted to double by 2100 largely as a result of human activities such as fossil fuel combustion and land-use changes (Lal, 2005; IPCC, 2007). Increased CO_2 concentrations in the atmosphere are thought to be mitigated in part by the ability of terrestrial forests to sequester large amounts of CO_2 (Schlesinger and Lichter, 2001). To test this, an international team of scientists grew a variety of trees for several years under elevated CO_2 concentrations. They found that high CO_2 concentrations accelerated average growth rate of plants, thereby allowing them to sequester more CO_2. However, this growth was coupled with an increase in soil respiration due to the increase in nutrients available for decomposition by releasing more CO_2 into the atmosphere (Willey et al., 2009). This suggests that forests may sequester less carbon than predicted in response to increased CO_2 concentrations, however more research is needed to investigate this hypothesis.

Soil-borne pathogens and climate change

According to the IPCC (2007) report, climate change will alter patterns of infectious disease outbreaks in humans and animals. Soil pathogens are no exception: case studies support the claim that climate change is already changing patterns of infectious diseases caused by soil pathogens. For example, over the last 20 years, 67% of the 110 species of harlequin frogs (*Atelopus*) native to tropical regions in Latin America have gone extinct from chytridiomycosisthe, a lethal disease spread by the pathogenic chrytid fungus (*Batrachochytrium dendrobatidis*) (Willey et al., 2009). Research suggests that mid- to high-elevations provide ideal temperatures for *B. dendrobatidis*. However, as global warming progresses, *B. dendrobatidis* is able to expand its range due to increasing moisture and warmer temperatures at higher elevations (Muths et al., 2008). This expansion exposes more amphibian communities in previously unaffected or minimally affected areas, specifically at higher elevations, to chytridiomycosisthe. As seen in the case of *Atelopus* harlequin frogs, the spread of soil pathogens due to climatic changes can significantly affect life at the macro scale and ultimately lead to species extinction.

Microbes play an important role as either generators or users of these gases in the environment as they are able to recycle and transform the essential elements such as carbon and nitrogen that make up cells. Bacteria and archaea are involved in the ‘cycles’ of all the essential elements. In the carbon cycle methanogens convert carbon dioxide to methane in a process called methanogenesis. In the nitrogen cycle nitrogen-fixing bacteria such as *Rhizobium* fix nitrogen, i.e., they convert nitrogen in the at-mosphere into biological nitrogen that can be used by plants to build plant proteins. Other microbes are also involved in these cycles. For example, photosynthetic algae and cyanobacteria form a major component of marine plankton. They play a key role in the carbon cycle as they carry out photo-synthesis and form the basis of food chains in the oceans. Fungi and soil bacteria, the decomposers, play a major role in the carbon cycle as they break down organic matter and release carbon dioxide back into the atmosphere (Davidson EA, Janssens IA, 2006). Animal, especially ruminants contribute to green house gases. Ruminants have a special four chambered stomach. The largest compartment is called the rumen. This pouch is full with billions of bacteria, protozoa, moulds and yeasts. These microbes digest the cellulose found in the grass, hay and grain that the animal consumes, breaking it down into simpler substances that the animal is able to absorb (Angela RM, Jean-Pierre J, John N, 2000).

Animals can't break down cellulose directly as they don't produce the necessary digestive enzymes. The methanogens, a group of archaea that live in the rumen, specialize in breaking down the animal's food into methane. The ruminant then belches this gas out at both ends of its digestive system. Methane is a very powerful greenhouse gas because it traps about 20 times as much heat as the same volume of carbon dioxide (Panikov NS, 1999). As a result it warms the planet up to 20 times more than carbon dioxide. Around 20% of global methane production is from farm animals. Soil is home to a vast array of life ranging from moles to microbes which makes it a very active substance. As the climate heats up, the activity of microbes responsible for the breakdown of carbon based materials in the soil will speed up. If this happens then even more carbon dioxide will be released into the environment. This is because increased microbial activity results in an increase in respiration, which produces more carbon dioxide as a waste product (Panikov NS, 1999).

The soil respiration and carbon dioxide release can double with every 5-100^{O}C increase in temperature. A vicious cycle is set up as more carbon dioxide is released it causes global warming, which in turn speeds up the activity of the soil microbes again (Davidson EA, Janssens IA, 2006; Trumbore S, 2006). Soil microorganisms are vital to many of the eco-logical processes that sustain life such as nutrient cycling, decay of plant matter, consumption and production of trace gases, and transformation of metals. Although climate change studies often focus on life at the macroscopic scale, microbial processes can significantly shape the effects that global climate change has on terrestrial ecosystems (Willey JM, Sherwood LM, Woolverton CJ, 2009). According to the International Panel on Climate Change (IPCC) report, 2007 warming of the climate system is occurring at unprecedented rates and an increase in anthropogenic greenhouse gas concentrations is responsible for most of this warming. Soil microorganisms contribute significantly to the production and consumption of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and nitric oxide (NO), and human activities such as waste disposal and agriculture have stimulated the production of greenhouse gases by microbes.

As concentrations of these gases continue to rise, soil microbes may have various feedback responses that accelerate or slow down global warming. Thus, understanding the role of soil microbes as both contributors and reactive components of climate change can help us to determine whether they can be used to curb emissions or if they will push us even faster towards climatic disaster.

Conclusion

The complexity of microbial communities living below ground and the various ways they associate with their surroundings make it difficult to pinpoint the various feedback responses that soil microbes may have to global warming. Whether a positive feedback response results, in which microbial processes further contribute to climate change, or whether a negative feedback response slows its effects, it is clear that microbes can have a huge impact on future climate scenarios and ecosystem-level responses to climate change. Soil respiration plays a pivotal role in these effects due to the large amount of CO_2 and CH_4 emissions produced during respiration, the reliance of carbon stocks in soils on rates of respiration, and the initial sensitivity of soil respiration to increased atmospheric temperatures. Further studies in long term feedback effects of soil respiration on climate change can contribute to our understanding of the overall impacts of climate change, including the ability of terrestrial forests to uptake excess CO_2 from the atmosphere. As we attempt to mitigate greenhouse gas emissions and adapt to predicted climate change effects, turning towards microscopic life that lies below the surface can perhaps help us to become better equipped for future changes at the macroscopic and even global scale.

References

- Allison, Ian (2010). *The science of climate change: questions and answers*. Canberra: Australian Academy of Science.
- Angela R M, Jean-Pierre J, John N (2000). Methane production by ruminants: its contribution to global warming. Ann. Zootech. ; 9: 231-53
- Anisimov, O A, Nelson, F E, Pavlov, A V (1999). Predictive scenarios of permafrost development under conditions of global climate change in the XXI century. *Earth Cryology* 3, 15-25.
- Briones, M J I, Poskitt, J, Ostle, N (2004). Influence of warming and enchytraeid activities on soil CO2 and CH4 fluxes. *Soil Biology and Biochemistry* 36, 1851-1859.
- Davidson E A, Janssens I A (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature ; 440: 165-73.
- Greenhouse Gas Bulletin (2011). The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2011; World Meteorological Organization (WMO): Geneva, Switzerland, 2011; p. 4.
- IPCC. 2007. Climate Change 2007: Synthesis Report. Available at <http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm>.
- IPCC. Summary for Policymakers. In *Climate Change (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; *Stocker*, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK and New York, NY, USA, 2013.
- Jenkinson, D S , Adams, D E , Wild, A (1991). Model estimates of CO_2 emissions from soil in response to global warming. *Nature* 351, 304–306.
- Lal, R (2005). Forest soils and carbon sequestration. *Forest Ecology and Management* 220, 242-258.
- Lal, R (2013). *The Nexus of Soil*, *Water and Waste*; UNU-FLORES: Dresden, Germany.
- Le Quéré, C, A K Jain, M R Raupach, J Schwinger, S Sitch, B D Stocker, N Viovy, S Zaehle, C Huntingford, P Friedlingstein, R J Andres, T Boden, C Jourdain, T Conway, R A Houghton, J I House, G Marland, G P, Peters, G , Van Der Werf, A Ahlström, R M Andrew, L Bopp, J G Canadell, E Kato, P Ciais, S C Doney, C Enright, N Zeng, R F Keeling, K Klein Goldewijk, S Levis, P Levy, M Lomas, and B Poulter (2012). "The global carbon budget 1959–2011." *Earth System Science Data Discussions* 5, no. 2: 1107-1157.
- Luo, Y, Wan, S, Hui, D, Wallace, L L (2001). Acclimatization of soil respiration to warming in a tall grass prairie. *Nature* 413, 622-625,
- Melillo, J M, Steudler, P.A, Aber, J.D, Newkirk, K., Lux, H, Bowles, F P, Catricala, C, Magill, A, Ahrens, T, Morrisseau, S (2002). Soil Warming and Carbon-Cycle Feedbacks to the Climate System. *Science* 298, 2173-2176.
- Muths, E, Pilliod, D S , Livo, L J (2008). Distribution and environmental limitations of an amphibian pathogen in the Rocky Mountains, USA. *Biological Conservation* 141, 1484-1492.
- Panikov N S (1999). Understanding and prediction of soil microbial community dynamics under global change. Appl Soil Eco. ;11: 161-76.
- Schlesinger, W H, Lichter, J (2001). Limited carbon storage in soil and litter of experimental forest plots under increased CO2. *Nature* 411, 466-469.
- Schlesinger, W H, Andrews, J A (2000). Soil respiration and the global carbon cycle. *Biogeochemistry* 48, 7–20.
- The Royal Society. *Climate change (2010): A Summary of the Science*.: The Royal Society Science Policy Centre, London.
- The World Bank. *World Development Report (2010). Development and climate change*. Washington, DC: World Bank and Oxford University Press.
- Trumbore S. (2006). Carbon respired by terrestrial ecosystems, recent progress and challenges. Global Change Bio ;12: 141–53.
- UNESCO/UNEP (2011). *Climate Change Starter's Guidebook: An issues guide for education planners and practitioners*. Paris: United Nations Educational, Scientific and Cultural Organization and the United Nations Environment Programme.
- Van De Wal, R S W, Boer, B De, Lourens, L J, Köhler, P, Bintanja R (2011). "Reconstruction of a continuous high-resolution CO_2 record over the past 20 million years." *Climate of the Past* 7, no. 4; 1459-1469.
- Willey, J M, Sherwood, L M, Woolverton, C. J. (2009). Prescott's Principles of Microbiology. McGraw-Hill, New York, NY.

Seed priming: A tool in sustainable agriculture

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I. Sustainable agriculture (Gordon McClymont proposed in 1950's) is the act of farming using principles of ecology, the study of relationships between organisms and their environment. It has been defined as "an integrated system of plant and animal production practices having a site-specific application that will last over the long term". Thematically, sustainable agriculture is an approach that satisfies human food and fiber needs, enhancing environmental quality and the natural resource, using most efficiently the non-renewable resources and integrating on-farm resources, it has economic viability and enhances quality of life for farmers and society as a whole. The National Research Council (1989) of the US National Academy of Sciences advocated that soil quality is the "key" to a sustainable agriculture.

The alternative agriculture was defined as a system of food and fiber production that applies management skills and information to reduce costs, improve efficiency of input resources, and maintain production levels through practices like crop rotations, proper integration of crops and livestock, nitrogen fixing legumes, integrated pest management, conservation tillage, and recycling of on-farm wastes as soil conditioner and biofertilizers. In short, improving the efficiency of input resources is one of the prime factors in sustainable agriculture. Input like seeds of only good quality does not directly ensure for its uniform germination, establishment and growth of crops free from seed and soil pathogen and lack of proper soil management. Seed priming before sowing is one of the most important solutions to these problems.

II. Seed Priming

Priming could be defined as controlling the hydration level within seeds so that the metabolic activity necessary for germination can occur but radicle emergence is prevented. Different physiological activities within the seed occur at different moisture levels. The last physiological activity in the germination process is radicle emergence. The initiation of radicle emergence requires a high seed water content. By limiting seed water content, all the metabolic steps necessary for germination can occur without the irreversible act of radicle emergence. Prior to radicle emergence, the seed is considered desiccation tolerant, thus the primed seed moisture content can be decreased by drying. After drying, primed seeds can be stored untill time of sowing. Different priming methods have been reported to be used commercially. Among them, liquid or osmotic priming and solid matrix priming appear to have the greatest acceptance. However, the actual techniques and procedures commercially used in seed priming are proprietary.

Primed seeds are just like the pre-fabricated house, seed germination in the field takes less time, because part of the germination process is already complete.

Germination of tomato seeds

III. Importance of Prime Seed

Primed seed usually emerges from the soil faster, and more uniformly than non primed seed of the same seed lot. These differences are greatest under adverse environmental conditions in the field, such as cold or hot soils. There may be little or no differences between primed and non primed seed if the field conditions are closer to ideal. Some growers use seed priming during the earlier plantings in cold soil, and not later in the season when conditions are warmer.

Better seedling establishment under less than optimal conditions can be achieved. Priming alone does not improve percent useable plants; removal of weak, dead seeds is also needed.

IV. The subcellular basis of seed priming

Seed priming is a technique which involves uptake of water by the seed followed by drying to initiate the early events of germination up to the point of radicle emergence. Its benefits include rapid, uniform and increased germination, improved seedling vigour and growth under a broad range of environments resulting in better stand establishment and alleviation of phytochrome-induced dormancy in some crops. The common feature in these priming techniques is that they all involve controlled uptake of water. The metabolic processes associated with priming are slightly different, with respect to their dynamics from those which occur during germination, where the water uptake is not controlled. Also, the salts used during priming elicit specific subcellular responses.

i. Stages of water uptake during germination where priming is relevant

When a dry seed is kept in water, the uptake of water occurs in **three stages**. Stage I is imbibition where there is a rapid initial water uptake due to the seed's low water potential. During this phase, proteins are synthesized using existing mRNA and DNA, and mitochondria are repaired. In stage II, there is a slow increase in seed water content, but physiological activities associated with germination are initiated, including synthesis of proteins by translation of new mRNAs and synthesis of new mitochondria. There is a rapid uptake of water in stage III where the process of germination is completed culminating in radicle emergence.

Stages I and II are the foundations of successful seed priming where the seed is brought to a seed moisture content that is just short of radicle protrusion. The pattern of water uptake during priming is similar to that during germination but the rate of uptake is slower and controlled.

ii. Synthesis of proteins and enzymes during priming

A proteome analysis of seed germination during priming in the model plant *Arabidopsis thaliana* by MALDI-TOF spectrometry identified those proteins which appear specifically during seed hydropriming and osmopriming. Among these are the degradation products of the storage protein 12S-cruciferin-subunits. It has been reported that the accumulation of the degradation product of the β-subunit of 11-S globulin during seed priming by an endoproteolytic attack on the A-subunit. This suggests that enzymes involved in mobilization of storage proteins are either synthesized or activated during seed priming. Other reserve mobilization enzymes such as those for carbohydrates (α and β amylases) and lipids mobilization (isocitrate lyase) are also activated during priming. These results indicate that priming induces the synthesis and initiates activation of enzymes catalysing the breakdown and mobilization of storage reserves, though most of the nutrient breakdown and utilization occur post-germinative after the radical emergence.

The proteomic analysis also reveals that α and β tubulin subunits, which are involved in the maintenance of the cellular cytoskeleton and are constituents of microtubules involved in cell division, are abundant during priming. Accumulation of β-tubulins during priming has been observed in many species in relation with reactivation of cell cycle activity and is discussed later. Another protein detected by the proteomic analysis, whose abundance specifically increases during hydropriming is a catalase isoform. Catalase is a free-radical scavenging enzyme. It is presumed that hydropriming initiates an oxidative stress, which generates reactive oxygen species, and catalase is synthesized in response to this stress to minimize cell damage. In addition to catalase, levels of superoxide dismutase, another key enzyme quenching free radicals also increases during priming. Increased levels of these free radical scavenging enzymes due to the oxidative stress during priming could also protect the cell against membrane damage due to lipid peroxidation occurring naturally.

Shinde19 reported synthesis of a 29 kD polypeptide after 2–6 h of priming in cotton seeds.

The abundance of low molecular weight heat shock proteins (LMW HSPs) of 17.4 and 17.7 kD specifically increased in osmoprimed seeds in the MALDI-TOF spectrometry analysis10,11. LMW HSPs are reported to have molecular chaperone activity, these data suggested that LMW HSPs may act by maintaining the proper folding of other proteins during osmopriming, preventing aggregation and binding to damaged proteins to aid entry into proteolytic pathways. In osmopriming, seeds are soaked in osmotica, viz. polyethylene glycol (PEG) and mannitol, which result in incomplete hydration and an osmotic stress situation is created. This explains the abundance of heat shock proteins, which are known to accumulate in high amounts during any kind of stress. These HSPs synthesized during osmopriming in response to stress could also protect the proteins damaged by natural ageing. Similarly, the enzyme L-isoaspartyl protein methyltransferase, which repairs age-induced damage to cellular proteins, is reported to increase in response to priming. Thus, it appears that one of the ways in which priming is effective at the subcellular level is by conferring protection to the cellular proteins damaged through natural ageing.

iii. Gene expression and synthesis of new mRNA during priming

I has been reported that priming-induced synthesis of RNA in cotton seeds, corresponding to the actin gene, following a reverse transcriptase polymerase chain reaction (PCR) analysis. Studies on gene expression in osmoprimed seeds of *Brassica oleracea* on a cDNA microarray revealed that in primed seeds many genes involved in cellular metabolism are expressed (and synthesize mRNA) at a level intermediary between those in dry seeds and germinating seeds imbibed in water. These genes mostly code for proteins involved in energy production and chemical defence mechanisms. A few genes are expressed to the same extent in osmoprimed seeds as in germinating seeds. These include genes for serine carboxypeptidase (involved in reserve protein mobilization and transacylation) and cytochrome B (involved in the mitochondrial electron transport). This microarray analysis in combination with Northern analysis gives some idea of transcripts synthesized during priming. To obtain direct evidence for the synthesis of new mRNA, techniques which involve detection of premature RNA species before intron splicing should be integrated with the other methods.

iv. Effect of priming on protein synthesizing machinery

Priming improves the integrity of the ribosomes by enhancing rRNA synthesis. The microarray gene expression studies in *B. oleracea* seeds, reveal that RNA levels of genes encoding components of the translation machinery, such as ribosomal subunits and translation initiation and elongation factors, increase during osmopriming. Thus, one of the ways in which priming enhances protein synthesis is by improving the functioning of the protein synthesis machinery.

v. DNA repair during priming

Maintenance of the integrity of DNA by repairing the damages incurred naturally is important for generating error-free template for transcription and replication with fidelity. It has been reported that the damage to DNA which accumulates during the seed ageing is repaired by aerated hydration treatments as also during early hours of germination. DNA synthesis measured by the incorporation of ^{3}H thymidine in artificially aged seeds of *B. oleracea* L. was advanced by this treatment (compared to that in the untreated aged seeds) along with an improvement in germination. This recovery in DNA synthesis is attributed to pre-replicative repair of DNA damaged during ageing by the hydration treatment since treatment with hydroxyurea, which is an inhibitor of replicative DNA synthesis does not inhibit the synthesis. The exact mechanism of this repair is not yet known and needs to be investigated.

vi. Association between priming and the cell cycle

To achieve maximum benefits from priming, the process is stopped just before the seed loses desiccation tolerance, i.e. before the radicle emergence or stage III of water uptake. Radicle emergence involves cell expansion and is facilitated by an increased turgor pressure in the hydrated seed, whereas active cell division starts after radical emergence. So, it is expected that priming does not exert any major effect on cell division *per se*. However, priming advances the cell cycle up to the stage of mitosis.

Flow cytometric analyses of osmoprimed tomato seeds reveal that the improvement of germination associated with priming is accompanied by increase in 4C nuclear DNA indicating that priming enhances DNA replication allowing the advancement of the cell cycle from G_1 to the G_2 phase. It has been confirmed that an increase in the proportion of nuclear DNA present as 4C DNA in high vigour cauliflower seeds subjected to aerated hydration treatment. It has also been reported as a two-fold increase in total genomic DNA content in hydro-primed corn seed.

Immunohistochemical labelling of DNA with bromodeoxyuridine (BrdU) during seed osmoconditioning in tomato confirms the presence of cells in the S-phase of the cell cycle synthesizing DNA. The actively replicating DNA is tolerant to drying as incorporation of BrdU is detected in embryo nuclei before and after osmoconditioned seeds are re-dried. Although the frequency of 4C nuclei after the osmoconditioning treatment is higher than that of untreated seeds imbibed in water for 24 h, lower numbers of BrdU-labelled nuclei are detected in osmoconditioned embryos. This is because of the fact that though priming enhances DNA replication to some extent and facilitates the synchronization of DNA replication in all the cells of the embryo, DNA replication *per se* is lesser during priming under controlled hydration than during direct imbibition in water.

Following western analysis it has been observed that the level of β-tubulin, which is a cytoskeletal protein and is related to the formation of cortical microtubules increases in response to aerated hydropriming. It has also been observed that accumulation of β-tubulin in all tissues of the tomato seed embryo during osmopriming. After redrying β-tubulin appeared as granules or clusters. This is because microtubules are sensitive to dehydration and are partly depolymerized after drying. The amount of soluble β-tubulin detected after re-drying is relatively high because microtubules are dynamic structures and exist in an equilibrium between soluble tubulin subunits and the polymerized microtubules. During priming, the cell cycle is arrested at the G_2 phase allowing the synchronization of cells. Mitotic events and cell division occur earlier and to a greater extent in embryos of primed seeds upon subsequent imbibition in water than in the control seeds. Thus, the pre-activation of the cell cycle is one of the mechanisms by which priming induces better germination performance relative to untreated seeds. The regulation of the cell cycle by priming could be through the regulation of the activity of the cell cycle proteins such as cyclins, cyclin dependent protein kinases and proliferating-cell nuclear antigens (PCNA). Imbibition of maize seed in the presence of benzyladenine increases the amount of PCNA over control, which is associated with the acceleration of the passage of cells from G_1 to G_2. There is no information on the effect of priming on the cell cycle proteins and research needs to be initiated in this area.

vii. Effect of priming on energy metabolism and respiration

It has been observed that imbibition of tomato seeds in PEG results in sharp increases in adenosine triphosphate (ATP), energy charge (EC) and ATP/ADP (adenosine diphosphate) ratio. These remain higher in primed seeds even after drying than in unprimed seeds. During subsequent imbibition in water, the energy metabolism of the primed and dried seed is much more than that of the unprimed seed making the primed seed more vigorous. The high ATP content of the re-dried primed seed is maintained for at least 4–6 months when stored at 20°C. Maximum benefit of osmopriming is obtained when performed in atmospheres containing more than 10% oxygen. Priming treatment is totally ineffective in the presence of the respiratory inhibitor (NaN_3) at high concentration, suggesting that respiration is essential for priming to be effective. The beneficial effect of priming is optimal for values higher than 0.75 for EC and 1.7 for the ATP/ADP ratio.

Hydropriming improves the integrity of the outer membrane of mitochondria after 12 h of imbibition (estimated by the cytochrome C permeation assay), but there is no concomitant increase in the ability of the mitochondria to oxidize substrates. Significant increase in the number of mitochondria in response to priming has also been reported in osmoprimed leek cells, although these have not been correlated to respiration levels. The association between improvement in the mitochondrial integrity by priming and mitochondrial performance needs to be elucidated.

viii. Priming and seed dormancy

Priming also releases seed dormancy in some crops. In thermosensitive varieties of lettuce, germination is reduced or completely inhibited at high temperatures such as 35°C. The embryo in lettuce seed is enclosed within a two to four cell layer endosperm, whose cell walls mainly comprise galactomannan polysaccharides and hence the weakening of endosperm layer is a prerequisite to radicle protrusion, particularly at high temperatures. Endo-β-mannase is the key regulatory enzyme in endosperm weakening, which requires ethylene for activation. High temperatures reduce germination primarily through their inhibitory effect on ethylene production by seeds, which in turn reduces the activity of endo-β-mannase. Osmopriming of seeds with PEG (–1.2 MPa) at 15°C with constant light could overcome the inhibitory effects of high temperature in thermosensitive lettuce seeds in the absence of exogenous ethylene supply. Imbibition of seeds of lettuce in 1-aminocyclopropane-1-carboxylic acid (ACC, a precursor of ethylene) improved their germination at 35°C and also increases the activity of endo-β-mannase. Osmopriming of lettuce seeds had a similar effect as imbibitions in ACC, improving both germination and the activity of endo-β-mannase. This suggests that osmopriming is able to substitute the effect of ACC for breaking thermodormancy. Osmopriming in the presence of aminoethoxyvinylglycine (AVG), an inhibitor of ethylene synthesis (it inhibits ACC synthase) does not affect the enhancement of germination.

Thus, osmopriming is able to overcome the dormancy even when ethylene synthesis is interrupted. A possible explanation for this is that osmopriming helps in releasing the ethylene within the embryonic tissues encased by the endosperm and seed coat and this would be sufficient to allow seed germination. Priming in the presence of silver thiosulphate (STS), a putative specific inhibitor of ethylene action, which interacts with the binding site of ethylene, inhibits germination, suggesting that ethylene activity is indispensable for the release of dormancy. There are several studies that show an increased ability for primed seeds to produce ethylene. However, it is not clear whether ethylene production is integral to obtaining a priming effect in seeds or whether it is simply the result of high vigour displayed by primed seeds. In other species also such as tomato, carrot and cucumber which do not require ethylene, priming enhances the loosening of the endosperm/testa region that permits germination at suboptimal temperatures.

ix. Priming and seed longevity

In general, priming improves the longevity of low vigour seeds, but reduces that of high vigour seeds. The high vigour seed is at a more advanced physiological stage after priming nearly at stage III, and thus more prone to deterioration. When a low vigour seed is primed, it requires more time to repair the metabolic lesions incurred by the seed before any advancement in germination can occur, thus preventing further deterioration.

It has been observed that aerated hydration treatments improve storage potential of low vigour seeds and decrease the longevity of high vigour seeds. The improved longevity of low vigour seeds is associated with increased K_i (initial seed viability) after priming and a reduced rate of deterioration.

The most frequently cited cause of seed deterioration is damage to cellular membranes and other subcellular components by harmful free radicals generated by peroxidation of unsaturated and polyunsaturated membrane fatty acids. These free radicals are quenched or converted to less harmful products (hydrogen peroxide and subsequently water) by free radical scavenging enzymes and antioxidants. Hydropriming and ascorbic acid priming of cotton seed is reported to maintain germination and simultaneously the activities of a number of antioxidant enzymes such as peroxidase, catalase, ascorbate peroxidase, glutathione reductase and superoxide dismutase against the process of ageing. Also the accumulation of by-products of lipid peroxidation, such as peroxides, malonaldehyde and hexanals is decreased by osmopriming, which is correlated with decreased loss in viability of soybean seeds under storage. Solid matrix priming in moistened vermiculite reduces lipid peroxidation, enhances antioxidative activities and improves seed vigour of shrunken sweet corn seed stored at cool or subzero temperatures. Treatment of shrunken sweet corn seeds with 2,2′-azobis 2-aminopropane hydrochloride (AAPH), a water-soluble chemical capable of generating free radicals, damages the seeds by increasing lipid peroxidation. This damage is partially reversed by solid matrix priming which increases free radical and peroxide scavenging enzyme activity and subsequent reduction in peroxide accumulation.

As stated earlier, when high vigour seed lots are primed, their longevity gets adversely affected. Attempts have been made by several workers to develop methods to restore seed longevity after seed priming. Slow drying at 30^{o}C which reduces the moisture of osmoprimed *B. oleracea* to 25% in the first 72 h of drying, followed by fast drying at 20^{o}C to bring the moisture level down to 7% improved the performance of the osmoprimed seed in a controlled deterioration test compared to that of the osmoprimed seed subjected to fast drying. Concomitant with the improved longevity of slow dried-seeds is the enhanced expression of two stress tolerant genes during slow drying. These two genes namely *Em6* and *RAB 18*, which belong to the late embryogenesis abundant (LEA) protein groups, are also expressed to a large extent in mature seeds and are responsible for conferring desiccation tolerance during seed maturation. *Em6* belongs to group 1b LEA proteins and shares features with DNA gyrases or molecular chaperones which suggest a role for *Em6* in protecting DNA integrity during controlled deterioration treatments. *RAB 18* belongs to group 2 LEA proteins and encodes an abscisic acid (ABA)-inducible dehydrin. It accumulates in plants in response to drought stress and certainly has a protective role in stress tolerance but the exact mechanism is not known. These genes are expressed to a lesser extent in the fast dried seeds because the moisture content drops much too rapidly.

A post-priming treatment including a reduction in seed water content followed by incubation at 37^{o}C or 40^{o}C for 2–4 h restores potential longevity in tomato seeds. This treatment is accompanied by the increase in the levels of the immunoglobulin binding protein (BiP) an ER resident homolog of the cytoplasmic hsp 70. BiP is known to be involved in restoring the function of proteins damaged by any kind of stress and may function as a chaperone in the reactivation of proteins damaged due to the imbibition and drying processes involved in seed priming.

V. Seed priming – an overview

A broad term in seed technology, describing methods of physiological enhancement of seed performance through presowing controlled - hydration methodologies. Seed priming also describes the biological processes that occur during these treatments. Improvements in germination speed and/or uniformity common with primed seed lots.

Seed priming – hydration status

In primed seeds, Phase II is extended and maintained until interrupted by dehydration, storage. Phase III water uptake is achieved upon subsequent sowing and rehydration.

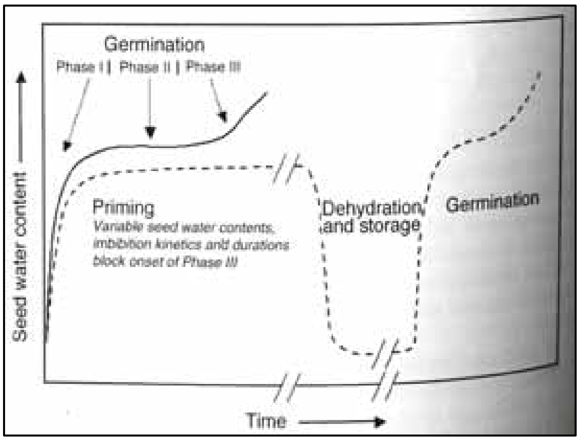


Fig. Phases during seed priming: Phase II is extended and maintained with interruption by dehydration and storage- In seed priming. Phase III is rehydration upon subsequent sowing

Seed priming – seedling establishment

Primed seed contributes to better seedling establishment especially under sub-optimal conditions at sowing (e.g. temperature extremes, excess moisture). Primed seed can also improve the percent useable seedlings in greenhouse production systems (e.g. plugs, transplants)

Seed priming

Currently used commercially in high-value crops where reliably uniform emergence is important:

- Field seeding/plug production of tomato, pepper, onion, carrots, leeks
- Potted/bedding plants like begonia, pansy (Viola spp.), cyclamen, primrose and many culinary herbs
- Large scale field crops (e.g. sugar beet) and some turfgrass species
- Also valuable in circumventing induced thermodormancy (e.g. some lettuce, celery, pansy cvs.) - priming can raise upper temperature limit for germination

Physiological mechanisms of seed priming

Key processes involved include:

1. **Hydrotime concept**
2. DNA replication, preparation for cell division (**cell cycle** studies)
3. **Endosperm weakening** for species with mechanical restraint

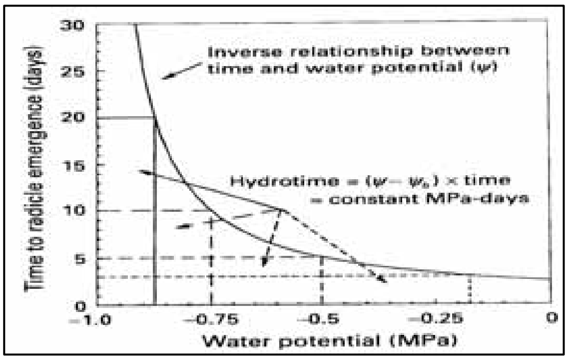


Fig. Relationship between effectiveness of priming to hydrotime

4. Hydrotime accumulated during priming

- Priming treatment effectiveness is linked to accumulated hydrotime
- Highest germination rate for broccoli seeds 'Brigalier' occurred after 218 and 252 MPa hrs
- When priming occurs at sub-optimal temps, **thermal time** can also be added to the equation.
- Goal is to provide a predictive tool for identifying optimal priming trts. for a seed lot without extensive empirical tests.
- General validity of hydrotime/hydrothermal models has spurred research on temps, H_2O potential thresholds and seed germination dynamics.

Priming - technologies

Three basic systems used to deliver/restrict H_2O and supply air to seeds, biopriming is the inclusion of beneficial organisms in addition to other basic priming. All can be conducted as batch processes. Commercial systems can handle quantities from tens of grams to several tons at a time.

1. Osmopriming

2. Matrix-priming

3. Hydropriming

4. Biopriming

After completion of priming seeds are re-dried. Slow drying at moderate temps is generally, but not always preferable. Controlled moisture-loss treatments (e.g. slow drying, or use of an osmoticum) can extend seed longevity by 10% or more in hydroprimed tomato, for example. Heat-shock is also used; keeping primed seeds under a mild H_2O and/or temp stress for several hrs (tomato) or days (Impatiens) before drying can increase longevity.

Osmopriming (Osmoconditioning)

- Seeds are kept in contact with aerated solutions of low water potential, and rinsed upon completion of priming.
- Mannitol, inorganic salts [KNO3, KCL, Ca(NO3)2, etc] are used extensively; small molecule size, possible uptake and toxicity a drawback.
- Polyethylene glycol (PEG; 6,000-8,000 mol. wt.) is now preferred; large molecule size prevents movement into living cells.
- For small amounts, seeds are placed on surface of paper moistened with solutions, or immersed in columns of solution.
- Continuous aeration is usually needed for adequate gas exchange with submerged seeds.

Matrix-priming (matriconditioning)

- Seeds in layers or mixes kept in contact of water and solid of insoluble matrix particles (vermiculte, diatomaceous earth, clay pellets, etc.) in predetermined proportions.
- Seeds are slowly imbibe reaching an equilibrium hydration level.
- After incubation/priming, the moist matrix material is removed by sieving or screening, or can be partially incorporated into a coating.
- Mimic the natural uptake of water by the seed from soil, or greenhouse mix particles.
- Seeds are generally mixed into carrier at matric potentials from -0.4 to -1.5 MPa at 15-20^{o}C for 1-14 days.
- Technique is successful in enhanced seed performance of many smaller and large seeded species.

Hydropriming (steeping)

- Currently, this method is used for both in the sense of steeping (imbibitions in H_2O for a short period), and in the sense of 'continuous or staged addition of a limited amount of water'.
- Hydropriming methods have practical advantages of minimal wastage of material (vs. osmo-, matripriming).
- Slow imbibition is the basis of the patented 'drum priming' and related techniques.
- Water availability is not limited here; some seeds will eventually complete germinate, unless the process is interrupted prior to the onset of phase III water uptake.
- At its simplest, steeping is an agricultural practice used over many centuries; 'chitting' of rice seeds, on-farm steeping advocated in many parts of the world as a pragmatic, low cost/low risk method for improved crop establishment
- Steeping can also remove residual amounts of water soluble germination inhibitors from seed coats (e.g. Apiaceae, sugar beets).
- Can also be used to infiltrate crop protection chemicals for the control of deep-seated seed borne disease, etc.

- Treatment usually involves immersion or percolation (up to 30^oC for several hrs.), followed by draining and drying back to near original SMC.
- Short 'hot-water steeps' (thermotherapy), typically ~ 50 ^oC for 10 to 30 min, are used to disinfect or eradicate certain seed borne fungal, bacterial, or viral pathogens; extreme care and precision are needed to avoid loss of seed quality.
- Drum priming (Rowse, 1996) – evenly and slowly hydrates seeds to a predetermined MC (typically ~ 25-30% dry wt. basis) by misting, condensation, or dribbling.
- Seed lots are tumbled in a rotating cylindrical drum for even hydration, aeration and temperature controlled.

Iopriming (e.g. Bacillus, Trichoderma, Gliocladium)

- Beneficial microbes are included in the priming process, either as a technique for colonizing seeds and/or to control pathogen proliferation during priming.
- Compatibility with existing crop protection seed treatments and other biologicals can vary.

Priming – promotive & retardant substances

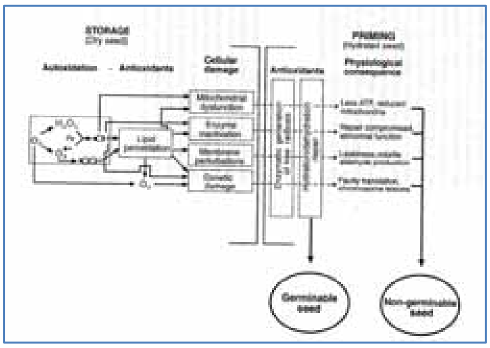
- Combination of priming with PGR's or hormones (GA's, ethylene, cytokinins) that may affect germination
- Transplant height control and seed priming with growth retardants (e.g. paclobutrazol) also effective.
- Other promoting agents, plant extracts can be included in future priming treatments.

Drying seeds after priming

- Method and rate of drying seeds after priming is important to subsequent performance.
- Slow drying at moderate temps is generally, but not always preferable.
- Controlled moisture-loss treatments (e.g. slow drying, or use of an osmoticum) can extend seed longevity by 10% or more in hydroprimed tomato, for example.
- Heat-shock is also used; keeping primed seeds under a mild H_2O and/or temp stress for several hrs (tomato) or days (Impatiens) before drying can increase longevity.

Priming and development of free space in seeds

- Hydropriming and osmopriming showed tomato seed free space development (8-11%), almost all at the cost of endosperm area
- When seeds are osmoprimed directly after harvest do not show free space change; dehydration prior to priming required.
- Facilitates water uptake, speeds up germination?



Seed priming and 'repair' of damage – a model

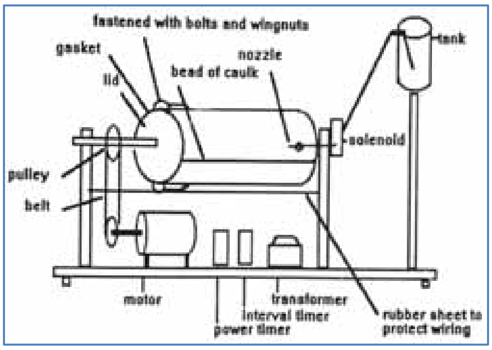


Fig. A model of seed deterioration and its physiological consequences during seed storage and imbibition

Seed priming - conclusions

- Clear benefits, especially for seedling establishment under less than optimal conditions.
- Seed longevity of primed lots is negatively affected (% RH oF = 80 or less, rather than 100%)
- Priming alone does not improve percent useable plants; removal of weak, dead seeds also needed.

VI. Seed priming- The pragmatic technology

Priming could be defined as controlling the hydration level within seeds so that the metabolic activity necessary for germination can occur but radicle emergence is prevented. Different physiological activities within the seed occur at different moisture levels. The last physiological activity in the germination process is radicle emergence. The initiation of radicle emergence requires a high seed water content. By limiting seed water content, all the metabolic steps necessary for germination can occur without the irreversible act of radicle emergence. Prior to radicle emergence, the seed is considered desiccation tolerant, thus the primed seed moisture content can be decreased by drying. After drying, primed seeds can be stored untill time of sowing.

Different priming methods have been reported to be used commercially. Among them, liquid or osmotic priming and solid matrix priming appear to have the greatest following. However, the actual techniques and procedures commercially used in seed priming are proprietary.

A. Types of seed priming commonly used:

1. Osmopriming (osmoconditioning)

This is the standard priming technique. Seeds are incubated in well aerated solutions with a low water potential, and afterwards washes and dried. The low water potential of the solutions can be achieved by adding osmotica like mannitol, polyethyleneglycol (PEG) or salts like KCl.

Seeds in contact with aerated solutions of low water potential is performed, and then rinsed upon completion of priming. Mannitol, inorganic salts [KNO_3, KCL, $Ca(NO_3)_2$, etc] are used extensively. However, salts of small molecule size may pose for possible uptake and toxicity as drawback. Polyethylene glycol (PEG; 6,000-8,000 mol. wt.) is now preferred; it is large molecular size that prevents movement into living cells.

Seed Priming: Seeds of a sub-sample were soaked in distilled water. Another sub-sample is pretreared with Polyethylene glycol 6000 (PEG) at a concentration of 253 g/kg water giving an osmotic potential of -1.2 MPa for 12 hours. Priming treatments were performed in an incubator adjusted on 20 ± 1^{o}C under dark conditions. After priming, samples of seeds were removed and rinsed three times in distilled water and then dried to the original moisture level about 9.5% (tested by high-temperature oven method at 130±2°C for 4 hours).

Laboratory germination test: Four replicates of 50 seeds were germinated between double layered rolled germination papers. The rolled paper with seeds was put into plastic bags to avoid moisture loss. Seeds were allowed to germinate at 10±1^{o}C in the dark for 21 days. Germination is considered to have occurred when the radicles are 2 mm long. Germinated seeds were recorded every 24 h for 21 days. Rate of seed germination (R) is calculated according to Ellis and Roberts. (1980).

2. Hydropriming (drum priming / Steeping)

This is achieved by continuous or successive addition of a limited amount of water to the seeds. A drum is used for this purpose and the water can also be applied by humid air. 'On-farm steeping' is the cheep and useful technique that is practised by incubating seeds (cereals, legumes) for a limited time in warm water.

Hydropriming can also be practised to infiltrate crop protection chemicals for the control of deep-seated seed borne disease, etc. Treatment usually involves immersion or percolation (up to 30^{o}C for several hrs.), followed by draining and drying back to near original SMC (seed moisture content). Short ‘hot-water steeps’ (thermotherapy), typically ~ 50^{o}C for 10 to 30 min, are used to disinfect or eradicated certain seed borne fungal, bacterial, or viral pathogens. Here extreme care and precision are needed to avoid loss of seed quality.

3. Matrixpriming (matriconditioning)

Matrixpriming is the incubation of seeds in a solid of insoluble matrix (vermiculite, diatomaceous earth, cross-linked highly water-absorbent polymers) with a limited amount of water. This method confers a slow imbibition.

Adoption of **Pregerminated seeds** is only possible with a few species. In contrast to normal priming, seeds are allowed to perform radicle protrusion. This is followed by sorting for specific stages, a treatment that re-induces desiccation tolerance, and drying. The use of pre-germinated seeds causes rapid and uniform seedling development.

In matriconditioning the use of sawdust (passed through a 0.5 mm screen) on seeds can be adopted to improve seed viability and vigour. The ratio of seeds to carrier to water used was 1: 0.4: 0.5 (by weight in grams). The seeds are conditioned for 18 h at room temperature, and air-dried afterwards for 5 h. The treatment significantly increases pod yield 1.5 times as much as the untreated.

Matriconditioning using either moist sawdust or vermiculite (210 μm) at 15^{o}C for 2 days in the light showed improvement in uniformity and speed of germination as compared to the untreated seeds. The ratio of seed to carrier to water used was 1: 0.3: 0.5 (by weight in gram) for sawdust, and 1: 0.7: 0.5 for vermiculite. However, there was no significant difference between the sawdust and vermiculite treatments. Uniformity increased from 42% in the untreated to 61.7% in the sawdust- and 60.3% in the vermiculite-matriconditioned seeds. Speed of germination increased from 17.3% to 20.0% (sawdust) or 19.7% (vermiculite). Even though there were no significant differences in germination and electrical conductivity between matriconditioned seeds and the untreated ones, matriconditioning treatments increased percent of germination and reduced seed leakage as shown by reduction in the electrical conductivity values of the soaked water, thus improvement in membrane integrity has occurred.

Study with hot pepper seed indicated that improvement in seed quality by sawdust-matriconditioning plus GA3 treatment was related with increase in total protein content of the seed. The seeds were conditioned for 6 days at 15^{o}C, and the ratio of seeds to carrier to water was 1: 2: 5.

Observations on blight disease incidence at 45, 60 and 75 days after sowing were recorded by scoring five plants in each treatment on a 0 to 9 scale of Mayee and Datar (1986) and percent disease index (PDI) was calculated using a formula given by Wheeler (1969).

$$\text{PDI} = \frac{\text{Sum of numerical disease ratings x 100}}{\text{No. of plants/leaves observed}}$$

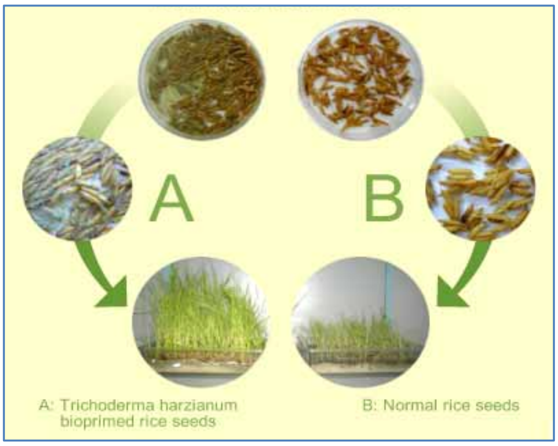
Maximum disease rating value, Head diameter, test weight (100-seed weight) and yield (quintal/ha) were also recorded.

4. Bio-priming or Biological Seed Treatment

Bio-priming is a process of biological seed treatment that refers combination of seed hydration (physiological aspect of disease control) and inoculation (biological aspect of disease control) of seed with beneficial organism to protect seed. It is an ecological approach using selected fungal antagonists against the soil and seed-borne pathogens. Biological seed treatments may provide an alternative to chemical control and balanced nutrient supplement.

Procedure

- Pre-soak the seeds in water for 12 hours.
- Mix the formulated product of bioagent (*Trichoderma harzianum* and/or *Pseudomonas fluorescens*) with the pre-soaked seeds at the rate of 10 g per kg seed.
- Put the treated seeds as a heap.
- Cover the heap with a moist jute sack to maintain high humidity.
- Incubate the seeds under high humidity for about 48 h at approx. 25 to 32 ^oC.
- Bioagent adhered to the seed grows on the seed surface under moist condition to form a protective layer all around the seed coat.
- Sow the seeds in nursery bed.
- The seeds thus bioprimed with the bioagent provide protection against seed and soil borne plant pathogens, improved germination and seedling growth (Figure)



Rice seed biopriming with *Trichoderma harzianum* strain PBAT-43

B. Priming – promotive & retardant substances

Many reports are available on combination of priming with PGR's or hormones (GA's, ethylene, cytokinins) that may affect germination. Transplant height control and seed priming with growth retardants (e.g. paclobutrazol) are also effective. Other promoting agents, plant extracts can be included in future priming treatments.

C. Drying seeds after priming

Method and rate of drying seeds after priming is important to subsequent performance. Slow drying at moderate temps is generally, but not always preferable. Controlled moisture-loss treatments (e.g. slow drying, or use of an osmoticum) can extend seed longevity by 10% or more in hydroprimed tomato, for example. Heat-shock is also used; keeping primed seeds under a mild H_2O and/or temp stress for several hrs (tomato) or days (Impatiens) before drying can increase longevity.

VI. Discussion and conclusions

Pre-sowing priming improves seed performance as the seed is brought to a stage where the metabolic processes are already initiated giving it a head start over the unprimed seed. Upon further imbibition, the primed seed can take off from where it has left completing the remaining steps of germination (stage III) quicker than the unprimed seed. Priming also repairs any metabolic damage incurred by the dry seed, including that of the nucleic acids, thus fortifying the metabolic machinery of the seed. Another beneficial effect of priming is the synchronization of the metabolism of all the seeds in a seed lot, thus ensuring uniform emergence and growth in the field.

The different ways in which priming could possibly be effective at the subcellular level in improving seed performance is depicted in Figure 1. This figure is an adaptation of the figure suggested by Bewley *et al.*7 to illustrate the metabolic events in the seed upon imbibition in water. Since hydration is also the key process in priming, albeit in a controlled fashion, and conforms to the triphasic pattern of water uptake, the original figure has been superimposed with the present one to describe the subcellular events specifically associated with priming. The figure also incorporates other aspects of priming discussed in the earlier sections such as its effect on dormancy release and seed longevity.

The most important ameliorative effect of priming should be the repair of damaged DNA to ensure the availability of error free template for replication and transcription. Since the water uptake is slower during priming than germination, the seed gets more time for completion of the process of repair. Unfortunately, there is no direct experimental evidence to support or corroborate this. One strategy (there could be other possible approaches) to specifically detect repair synthesis differentiating it from replicative synthesis is to artificially induce damage to DNA of the seed by UV irradiation. The damaged seeds can then be primed, the DNA labelled with BrdU, and ssDNA transients generated during repair in response to priming can be detected using an anti- BrdU antibody.

It is evident that priming advances the metabolism of the seed. Many proteins and enzymes involved in cell metabolism are synthesized to a level intermediary between the dry seed and the seed imbibed directly in water, while a few of these are synthesized to the same extent as the germinating seed.

Some proteins are synthesized only during priming and not during germination. For example, the degradation products of certain storage proteins (such as globulins and cruciferin) are detected only during priming and not when imbibed in water. A possible explanation is that the slight water stress situation created during priming (particularly osmopriming) can induce the breakdown of these proteins thus initiating the process of reserve protein mobilization earlier than in the unprimed seed. Similarly, low molecular weight HSPs is specifically synthesized during osmopriming and not during imbibition in water.

These proteins function as molecular chaperones and are synthesized to protect the cell from moisture stress occurring during the process of osmopriming but they could very well be effective in protecting those proteins also which are damaged naturally. Free radical scavenging enzymes such as catalase and superoxide dismutase are synthesized during hydropriming to protect the cell from damage due to lipid peroxidation, which occurs due to the oxidative stress induced by hydropriming. These enzymes could also be effective in quenching the free radicals generated by lipid peroxidation occurring naturally.

Priming synchronizes all the cells of the germinating embryo in the G2 phase of the cell cycle so that upon further imbibition, cell division proceeds uniformly in all the cells ensuring uniform development of all parts of the seedling. Priming also prepares the cell for division by enhancing the synthesis of β -tubulin which is a component of microtubules. These effects of priming are retained even after drying the primed seed. The exact mechanism by which priming regulates the cell cycle needs to be investigated. There is enhanced ATP production during priming, which is retained even after drying making the primed seed more vigorous than an untreated seed.

When a primed seed is stored under conducive conditions (low temperature and low moisture) most of the beneficial effects of priming are retained. However, the storability of the primed seed per se is either improved or adversely affected, depending upon the initial physiological status of the seed. Priming improves the storability of low vigour seeds, but reduces that of high vigour seeds. The longevity of seeds after priming can be extended by giving post-priming treatments involving subjecting the seed to slight moisture and temperature stress before drying the seed completely. These treatments are accompanied by the synthesis of stress related proteins (similar to those which are abundant when the seed undergoes desiccation during maturation) which protect the cellular proteins from damage and thus, in turn, extend the seed longevity.

Delivery system	*Technique*	*Purpose*	*Mode*
Seed treatment	Soaking of seeds in culture suspension 10 g/lit for 24 h	Sheath blight of rice	Establishment of rhizobacteria on chickpea rhizosphere
	Seed coating 4 g/kg seed	Chickpea wilt	Establishment of rhizobacteria on chickpea rhizosphere
Biopriming	Incubation of seeds with culture suspension at 25°C for 20 h	Increase germination and improve seedling establishment	Proliferation and establishment of bacterial antagonist
Seedling deeping	Root deeping in culture suspension (20 g/ltr) for 2 h	Rice sheath blight by *Rhizoctonia solani*	Prevents host-parasite relationships
Soil application	Braodcast culture 2.5 kg mixed with 25 kg FYM or 50 kg soil	Chickpea wilt by *Fusarium oxysporum*	Increases rhizosphere colonization of Pf
Foliar application	Foliar spay of culture 1 kg/ha on ground nut at 15 days intervals since 30 DAS	Leaf spot and rust of groundnut	Actively competes for amino acids on the leaf surface and inhibits spore germination
Fruit spray	Spray of 10% WP 10 g/lit over apple fruits	Blue and grey mold of apple	Population of antagonist Ps increased in wounds >10 fold during 3 months in storage (post harvest disease management)
Hive insert	Dispenser dusting over bee hive and nectar sucking bees are dusted / coated with powder formulation	*Erwinia amylovora* causing fire blight of apple infects through flower and develops extensively on stigma	Colonisation by antagonist at the critical juncture is necessary to prevent flower infection
Sucker treatment	Banana suckers were dipped in suspension (500 g/50 lit) for 10 min after pairing and pralinage and followed by capsule application (50 mg Ps/capsule) on third and fifth month after planting	Panama wilt of banana	Management of soil borne diseases of vegetatively propagated crops
Sett treatment	Setts are soaked in suspension (20g/l) for 1 h and incubated for 18 h prior to planting	Red rot of sugarcane	Acts as a predominant prokaryote in the rhizosphere
Multiple delivery systems	1. Seed treatment-4 g/kg of seed; followed by soil application-2.5 kg/ha at 0, 30, and 60 DAS 2. Seed treatment followed by 3 foliar application	1. Pigeonpea wilt 2. Rice blast	Colonisation by antagonist in rhizosphere and phyllosphere

While we know that all the beneficial subcellular responses induced by seed priming occur between stages I and II of water uptake, we are not able to give the exact sequence of their occurrence at this point in time. Similarly, for optimization of priming technology, no suitable marker is reported, which can indicate the completion of stage II. This can be of immense practical use. More in-depth research on the physiology of seed priming would help us to refine the technique and develop better priming protocols to achieve maximum benefits.

VII. Biofertilizer Delivery Systems

In seed biopriming, plant growth promoting rhizobacteria are delivered through several means based on survival nature and mode of infection of the pathogen. It is delivered through

1. Seed treatment
2. Bio-priming
3. Seedling dip
4. Soil application
5. Foliar spray
6. Fruit spray
7. Hive insert
8. Sucker treatment
9. Sett treatment
10. Multiple delivery systems

VIII. Benefits of seed priming

For practical purposes, seeds are primed for the following **reasons**:

1. **Reasons of priming**
   - To overcome or alleviate phytochrome-induced dormancy in lettuce and celery,
   - To decrease the time necessary for germination and for subsequent emergence to occur,
   - To improve the stand uniformity in order to facilitate production management and enhance uniformity at harvest.
2. **Extension of the temperature range at which a seed can germinate**
   - Priming enables seeds to emerge at supra-optimal temperatures
   - Alleviates secondary dormancy mechanisms particularly in photo-sensitive varieties

One of the primary benefits of priming has been the extension of the temperature range at which a seed can germinate. The mechanisms associated with priming have not yet been fully delineated. From a practical standpoint, priming enables seeds of several species to germinate and emerge at supra-optimal temperatures. Priming also alleviates secondary dormancy mechanisms that can be imposed if exposure to supra-optimal temperatures lasts too long or in photo-sensitive lettuce varieties.

3. **Increases the rate of germination at any particular temperature**
   - Emergence occurs before soil crusting becomes fully detrimental,
   - Crops can compete more effectively with weeds, and
   - Increased control can be exercised over water usage and scheduling.

The other benefit of priming has been to increase the rate of germination at any particular temperature. On a practical level, primed seeds emerge from the soil faster and often more uniformly than non-primed seeds because of limited adverse environmental exposure. Priming accomplishes this important development by shortening the lag or metabolic phase (or phase II in the triphasic water uptake pattern in the germination process. The metabolic phase occurs just after seeds are fully imbibed and just prior to radicle emergence. Since seeds have already gone through this phase during priming, germination times in the field can be reduced by approximately 50% upon subsequent rehydration. The increase in emergence speed and field uniformity demonstrated with primed seeds have many practical benefits:

4. **Eliminates or greatly reduces the amount of seed-borne fungi and bacteria**

Lastly, priming has been commercially used to eliminate or greatly reduce the amount of seed-borne fungi and bacteria. Organisms such as *Xanthomonas campestris* in *Brassica* seeds and *Septoria* in celery have been shown to be eliminated within seed lots as a by-product of priming. The mechanisms responsible for eradication may be linked to the water potentials that seeds are exposed to during priming, differential sensitivity to priming salts, and/or differential sensitivity to oxygen concentrations.

IX. Seed priming risks

The number one risk when using primed seed is reduced seed shelf life. Depending on the species, seed lot vigor, and the temperature and humidity that the seed is being stored, a primed seed should remain viable for up to a year. If the primed seed is stored in hot humid conditions, it will lose viability much more quickly. In most of the cases however, primed seed has shorter shelf life than the non primed seed of the same seed lot. For this reason, it's best not to carry primed seed over to the next growing season.

Soil management strategies for climate mitigation and sustainable agriculture

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Introduction

Soil, a dynamic living matrix, is an essential part of the terrestrial ecosystem. It is a critical resource not only to agricultural production and food security but also to the maintenance of most life processes. Soil health is the key property that determines the resilience of crop production under changing climate. The most important process associated with soil health is the accelerated decomposition of organic matter, which releases the nutrients in short run but may reduce the fertility in the long run. A number of interventions are known to build soil carbon, control soil loss due to erosion and enhance water holding capacity of soils, all of which build resilience in soil. Soil testing needs to be done to ensure balanced use of chemical fertilizers matching with crop requirement to reduce GHGs emission. The high productivity levels to meet the challenges of feeding the emergent population has been achieved during post green revolution through introduction of high yielding inputs responsive crop varieties use of high analysis fertilizers and superior pest management practices. Long term continuous application of high analysis fertilizers led to degradation of soil health as a result of imbalanced mining of essential plant nutrients which necessitates the relooking on production system in terms of soil health (physical, chemical & biological) for sustaining the productivity. Campbell (2008), stated that time have arrived to refocus on soil stewardship as a key to improve water productivity, energy productivity and food security while reducing net greenhouse gas emissions from agriculture. Undoubtedly, with an estimated global carbon content of 1,500 Pg (10^{15} g), soil represents the biggest carbon sink on our planet (Amundsen 2001) and, as about 99 per cent of the world's food and fibers are produced on soil/land, a systematic understanding of how soil can be manipulated to increase carbon sequestration is crucial for mitigating greenhouse gas (GHG) emissions and climate change. Furthermore, alteration in agricultural management practices could potentially mitigate climate and reduce emissions directly or relocate emissions from other sources (Smith et al. 2008). However, there is increasing awareness of the restrictions of biomass production set by the other soil functions, in particular the soil's ability to filter water, sequester carbon, and satisfy nutrients as well as the need to maintain biological diversity.

A number of soil management strategies has been identified which may be applied to reduce GHG emissions, climate mitigation and making agriculture sustainable (Smith et al. 2007). Nevertheless, before deciding which of these strategies are most appropriate in a given condition, it is important to assess how these strategies affect other aspects of sustainability. It is evident that although some of the soil management strategies available may have positive effects, others may have negative social, economic, and environmental effects (Hussey and Schram, 2011). The key components of soil management strategies for climate mitigation and sustainable agriculture are summarized here.

Key soil management strategies to mitigate climate

When identifying soil management strategies with the potential to mitigate climate and diminish GHG emissions, it is useful to divide them into different categories, depending on their focus, i.e., crop management, nutrient management, tillage and residue management, water management and soil restoration. Soil management strategies under each of these categories are elaborated and assessed under the following heads.

Crop Management

Crop production is primarily the functions of crop genetics, climatic conditions and more importantly the management practices. Crop management practices includes precise uses of inputs, cropping sequence, tillage, intercultural operations etc. which directly or indirectly influences the natural resources in the vicinity, especially soil and water. Crop management practices affect not only the productivity but also contribute to fate of natural resources and climate change. The mean estimate of the GHGs mitigation potentials of improved crop management options range from 0.39 to 0.98 t CO_2-equivalant per hectare per year in dry and moist climatic zones (Smith et al. 2007). There are numerous ways to improve crop management for climate mitigation of which the more important are as blow:

1) Optimizing crop rotations for carbon sequestration by increasing the fraction of perennial crops, leguminous crops, and crops with high carbon content in crop residues.
2) Increasing energy efficiency by adopting high yielding varieties.
3) Replacing uncovered fallow with fallow crops.
4) Introducing cover crops.

Studies show that a complete conversion of arable land to permanent grass is estimated to increase soil carbon by 0.5 t/ha^{-1}/yr^{-1} (Conant et al. 2001), whereas temporary grass may increase soil carbon by 0.35 t/ha^{-1}/yr^{-1} (Soussana et al. 2004). The water requirements for leguminous crops are 10-40 per cent lower than most cereal crops (FAO 1991). Furthermore, a higher level of soil organic matter added by leguminous crops will also increase the water-holding capacity of the soil and thereby reduce losses from drainage. Growing of legumes (clover, lentil, pea, and bean) has the potential to reduce GHGs emission because they do not need N-fertilization and therefore save 50-200 kg N ha^{-1} depending on the crop they replace. Leguminous crops also have a pre-crop effect of 10-100 kg N ha^{-1} on the subsequent crops. Estimates of GHGs emissions from inorganic fertilizer production and application show that total GHGs emission range from 0.8 to 10.0 kg CO_2-equivalent kg^{-1} fertilizer-N produced and from 0.8 to 6.7 kg CO_2-equivalent kg^{-1} N applied in the field which means for every 100 kg fertilizer-N saved, the emission of 1.7 t CO_2- equivalent is potentially avoided. Therefore, increasing the fraction of crops with high carbon content in crop residues, adopting high yielding varieties and replacing bare fallow are crop management practices that will all increase the buildup of organic matter in the soil and thereby contribute to climate mitigation.

Nutrient Management

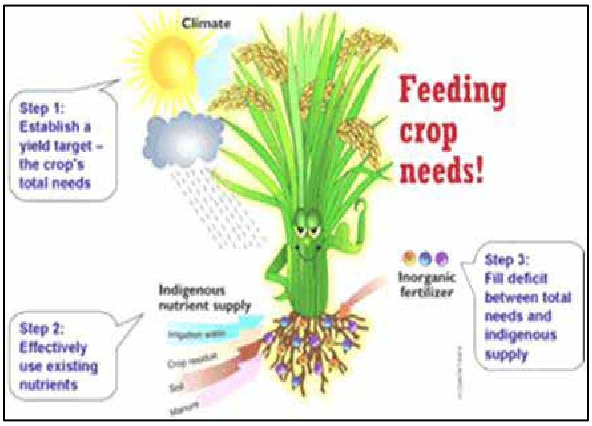
Managing soil health is an important component for sustainable crop production. In healthy soils, physical, chemical, and biological processes and functions drive the productivity of the soil. An important component of the soil that integrates these three aspects is the soil organic matter. The organic matter in the soil provides nutrition for the soil organisms and also regulates their diversity and functionality in soil. Soil management strategies should be focused on returning an amount of organic material that is sufficient to maintain or improve productivity and biological activity of the soil. It has been estimated that climate mitigation, in terms of GHG emission, potential of improved nutrient management in soil range from 0.33 to 0.62 t CO_2-equivalent $ha^{-1}yr^{-1}$ in dry and moist climatic zones (Smith et al. 2007). Production of inorganic fertilizers is responsible for around 1.2 per cent of global GHGs emission (Kongshaug 1998). Nitrogenous fertilizer production alone result in emission of GHGs to the tune of 0.8 to 10.0 kg CO_2- equivalent kg^{-1} of fertilizer-N depending on different aspects of fertilizer (Wood and Cowie 2004). The application of fertilizers in the field is estimated to emit N_2O to the extent of 0.25 to 2.25 kg per 100 kg N applied (Smith et al 1997). Total GHGs emissions from fertilizer production and application ranges from 1.5 to 16.7 kg CO2-eq/kg fertilizer-N in light of 296 times higher global-warming potential of N_2O as compared to CO_2. Therefore, escalating the fertilizer use efficiency and reducing the fertilizer inputs needs are the two primary ways to optimize nutrient management for reducing GHG emissions and climate mitigation.

Fertilizer efficiency can be increased by adjusting fertilizer amount, placement, and timing to minimize losses and meet actual crop demand. In recent past a number of nutrient management approaches have been evaluated and are being used by the end users for enhancing the nutrient use efficiency. Some of the important approaches are described below:

Integrated nutrient management (INM) is the maintenance or adjustment of soil fertility/ productivity and optimum plant nutrient supply for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients including locally available once in an integrated manner while ensuring environmental quality. Practically a system of crop nutrition in which nutrients need of plants are met through a preplanned integrated use of inorganic fertilizers, organic sources of plant nutrients (green manures, recyclable wastes, crop residues, FYM, vermicompost etc.), and bio-fertilizers. The appropriate combination of different sources of nutrients varies according to the system of land use and ecologies, social and economic conditions at the local level. Integrated use of inorganic, organic and biological sources of plant nutrients and their different management practices have a tremendous

potential not only in sustaining agricultural productivity and soil health but also in meeting a part of chemical fertilizers requirement for different crop and cropping systems.

Site-specific nutrient management (SSNM) provides a field-specific approach for dynamically applying nutrients to crops as and when needed. This approach advocates optimal use of indigenous nutrients originating from soil, plant residues, manures, and irrigation water. Fertilizers are then applied in a timely fashion to overcome the deficit in nutrients between the total demand by the crops to achieve a yield target and the supply from indigenous sources.



Tillage and crop residue management

Tillage is the agricultural preparation of the soil by mechanical agitation of various types, such as digging, stirring, and overturning. The tillage practices and management of crop residue are the key concern of today's agriculture. Conventional tillage (excessive tillage) requires more fuel consumption (more GHGs emission) on one hand while fasten the oxidation of soil carbon on other hand particularly in tropical and sub-tropical climate. Accelerated adoption of farm mechanization and climate variability / change escorts to practice of crop residue burning which results in higher GHGs emission from agricultural fields and also raises the temperature. It has been estimated that GHG-mitigation potential of improved tillage and residue management range from 0.17 to 0.35 t CO_2 - equivalent $ha^{-1}yr^{-1}$ in dry climatic zones and from 0.53 to 0.72 in moist climatic zones (Smith et al. 2007).

Conservation tillage practices (no tillage and reduced tillage) increases the buildup of soil organic matter and thereby mitigate GHGs emissions, especially if combined with the retention of crop residues (Holland 2004). Conservation tillage practices and the retention of crop residue on soil surface have significant synergistic effects on water resources, as the resulting improved soil structure increases the water-holding capacity of the soil and leaves the soil less prone to leaching. Conservation tillage provides an opportunity for carbon sequestration in soil and creating a nutrient-rich environment in plant rhizosphere. It has been reported that organic matter levels have increased from 1.9 to 6.2 percent after 19 years of continuous no-till experiment (Schertz and Kemper, 1994). In another study, Hargrove and Frye (1987) also found a buildup of organic carbon in soil under conservation tillage practice in (Figure 1). Also, there is a synergistic effect of conservation tillage practices on energy security, as a substantial amount of energy is saved by no-till the soil.

Water management

Water is one of the key inputs essential for crops production as crop plants need it continuously during their life and in huge quantities. Both its shortage and excess affect the performance of the crops. Changing climate results in erratic behavior in rainfall pattern causing floods and droughts alternately which resulted erosion soil having nutrients and soil carbon in the event of excess rainfall while on other hand reduces the CO_2 assimilation in terms of biomass production and necessitates excessive pumping of ground water in drought situations. Though, the farmers have several agronomic management options to face the situation of water scarcity and excessiveness, through choice of crops, cultivars, adoption of suitable irrigation schedules. But increased ground water utilization and pumping of water from deep tube wells is the major concern as it is the largest contributor to GHG emissions in agricultural water management. If surface storage of rainwater in dug out ponds is encouraged and low lift pumps are used to lift that water for supplemental irrigation, it can reduce dependence on ground water. Sharma About 28 M ha of rainfed area in Eastern and Central states of India has the potential to generate runoff of 114 billion m3 which can be used to provide one supplemental irrigation in about 25 M ha of rainfed area. This is one of the most important strategies not only to control runoff and soil loss but also contribute to climate mitigation.

The mean estimate of the GHG-mitigation potential of improved water management is 1.14 t CO_2-equivalent/$ha^{-1}yr^{-1}$ in all climatic zones (Smith et al. 2007). About 18 per cent of global arable land is irrigated, and more efficient irrigation schemes may save CO_2 used for irrigation and increase carbon sequestration through increased productivity. One of the most promising irrigation schemes that may be able to reduce GHG emissions and enhancing C concentration in the plant biomass is partial root-zone irrigation (PRI) which has great potential to increase water-use efficiency and to maintain yield (Shahnazari et al 2008, Davies and Hartung 2004 and Wang et al. 2010).

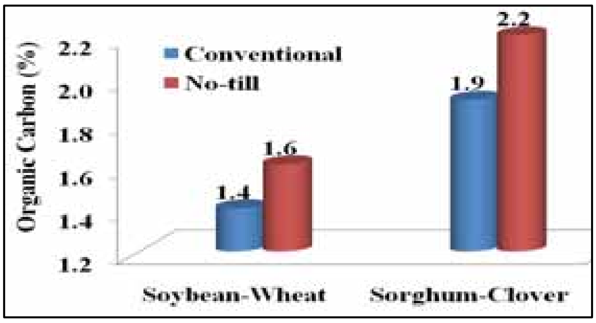


Fig 1: Effect of tillage practice and cropping systems on soil organic carbon.

Soil restoration

Soil degradation has adverse impacts on all soil functions, including agronomic/biomass production, soil-filter function (environmental), engineering and cultural functions. A large proportion of agricultural lands have been degraded by excessive disturbance, erosion, organic matter loss, salinization, acidification, and other processes (Smith et al.,2007). Additionally, both agricultural and non-agricultural soils, such as urban and periurban soils have lowered soil functionality given their pollution with organic chemicals and potentially toxic elements. Although only a few soil nondestructive methods exist for the treatment of persistent chemicals and non-degradable elements like heavy metals and metalloids, often soil functionality and carbon storage capacity can be partly restored by revegetation, applying organic substances such as manures, bio-solids, and compost; reducing tillage, and retaining crop residues. It has been estimated that GHG-mitigation potential of soil restoration of organic soils and degraded lands perceives improved nutrient management range from 37.96 to 70.18 t CO_2-equivalent $ha^{-1}yr^{-1}$ (Smith et al. 2007). Reestablishing a high water table is the primary mitigation measure for organic soils, while a combination of applying organic manures, reducing tillage, retaining crop residues, and conserving water is the primary mitigation measure for degraded land.

Conclusion

Soil is the key component of agricultural production system hence soil health need to be relooked in light of projected climate change for sustaining agricultural productivity. Evaluation and dissemination of climate resilient soil management strategies are required to mitigate the probable impacts of climate change on agriculture. Therefore, adoption of conservation agriculture (no-tillage, organic soil cover and crop diversification) with proficient CO_2 assimilating crops having potential use efficiencies of nutrient and water, high c-sequestration in soil, least fuel consumption and GHGs emission could be the effective strategies for climate mitigation and sustaining crop productivity.

References

- Amundsen R (2001). The carbon budget in soils. *Annual Review of Earth and Planetary Sciences* 29:535–562.
- Campbell A (2008). Food, energy, water: conflicting insecurities. *Journal of Soil and Water Conservation* 63:149A–151A.
- Conant R T, Paustian K and Elliott E T (2001). Grassland management and conversion into grassland: effects on soil carbon. *Ecological Applications* 11:343–355.
- Food and Agriculture Organization (1991). *Water harvesting–a manual for the design and construction of water harvesting schemes for plant production.* FAO, Rome, Italy.
- Hargrove W L and Frye W W (1987). The need for legume cover crops in conservation tillage production. *In*: J. F. Power (ed.). The role of legumes in conservation-tillage systems. Soil Conservation Society of America. Ankeny, IA. pp.1-5.
- Holland J M (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems and Environment* 103:1–25.
- Hussey K and Schram A (2011). Accounting for, and managing, the links between climate, energy, water and food in Europe: an opportunity for better policy integration and coordination. *In* P. Winland, and G. Pearman, editors. *Securing sustainable energy futures in Europe and Australia.* Peter Lang, Brussels, Belgium.
- Schertz D L and Kemper W D (1994). Crop residue management systems and their role in achieving a sustainable, productive agriculture. ISCO94 Conference. New Delhi.
- Shahnazari A, Ahmadi S H, Laerke P E, Liu F, Plauborg F, Jacobsen S E, Jensen C and Andersen M N (2008). Nitrogen dynamics in the soil-plant system under deficit and partial root-zone drying irrigation strategies in potatoes. *European Journal of Agronomy* 28(2) : 65–73
- Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M and Smith J (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society* 363:789–813.
- Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O’Mara F, Rice C, Scholes B and Sirotenko O (2007). Agriculture. Pp 499–532. *In:* B. Metz, O.R. Davidson, P. R. Bosch, R. Dave, and L.A. Meyer, editors. *Climate change 2007: mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, New York, USA.
- Soussana J F, Loiseau P, Vuichard N, Ceschia E, Balesdent J, Chevallier T and Arrouays D (2004). Carbon cycling and sequestration opportunities in temperate grasslands. *Soil Use and Management,* 20(2)219-230.
- Wang Y, Liu F, Andersen M N and Jensen C R (2010). Carbon retention in the soil-plant system under different irrigation regimes. *Agricultural Water Management* 98 (3):419–424.
- Wood S and Cowie A (2004). *A review of greenhouse gas emission factors for fertiliser production.* International Energy Agency (IEA) Bioenergy Task 38, IEA, Paris, France. URL: http://www.ieabioenergy-task38.org/publications/ GHG_Emission_Fertilizer%20 Production _ July 2004. pdf.

Climate change and mitigation strategies in India

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The task of producing adequate food, fiber and feed to meet ever- growing demand has now become even more challenging to sustain the agricultural productivity with dwindling natural resources and ecological constrains. In future, agricultural production may be severely constrained by other emerging threats to agricultural production like increasing climatic variability and number of biotic factors due to climate change which is mainly caused by human activities.

There are three aspects of climate change that are important from the agriculture point of view:

(i) Increase in greenhouse gas concentration, particularly Co_2 levels.
(ii) Rise in temperature
(iii) Increased climatic variability

Increase in CO_2 concentration is generally beneficial to biomass production and can even mitigate other abiotic stresses on some extent. However, its net impact on crop productivity is not always positive. Whereas, rise in temperature is beneficial to cooler regions, it will have detrimental effect on crop productivity in warmer regions. Crop specific assessments for some of the important Indian crops also support these observations e.g. soybean rice and wheat. But the net impact of climate change and the vulnerability of a particular agricultural system or agro ecosystem will ultimately depend on its sensitivity and adaptability to climate change and because of inherent characteristics, rain fed productions systems are particularly vulnerable where climatic variability seriously affects food security through its influence on investment, adoption of agricultural technology, aggregate production, market prices and ultimately economic development. Therefore, in future, climate change will have serious repercussions for the rainfed agriculture, impacting the live hood of millions of farmers.

Weather risk management: As a part of weather risk management, there is a need to train the farmers at different levels, viz. village, watershed and command areas of an irrigation project on weather impacts, water conservation, rainwater harvesting and climate change management. The trained people can be called climate managers. They should be trained at regular intervals through awareness programmes on weather related disasters and their management to minimize the ill- effects on crops. They are supposed to study and assess whether impact at watershed/farm level. The development of crop contingency plants to suit different rainfall patterns is an integral part of weather risk management.

A part of government policy, it is needed to create the District and State Crop Weather Watch Groups for providing compensation production programmes under different weather scenarios with multi- institutional involvement and with multi disciplinary approach. All related institutes with technical people form a team to help the farmers with contingency plants.

From the past experience, it is clear that no foolproof mechanism works in a weather related disaster like cyclone havoc and folds. In such a situation, only relief to farmers to some extent is weather insurance. Therefore, weather insurance schemes should be made mandatory, provided they are easily accessible to farmers and beneficial in an event of weather disasters and crops are devastated.

Early warning systems: A reliable system of short range, medium range, long range weather forecasts and seasonal/ climate forecasts is the need of hour for effective on farm planning and management practices such as cultivation of land, preparation of seed bed, planting, choice of crops in case of prolonged monsoon breaks, fertilizer management, harvesting of crops, post harvest storage and transportation to markets. The integrated along with site specific agro- climatic analysis.

Cyclone warning system: The India Meteorological Department (IMD), follows a four stage warming systems for issuing warnings for tropical cyclones. A Pre- cyclone watch is issued whenever a depression forms over the Bay of Bengal or Arabian Sea, followed by a Cyclone

Alert, issued 2-3 days in advance of commencement of bad weather along the coast. In the third stage, Cyclone warnings are issued 1-2 days in advance, which specify the expected place and time of landfall of the tropical cyclone.

Flood warning system : Scientific Flood Forecasting activities in India commenced in 1958 for the Yamuna, and now cover almost all major flood- prone inter- state river basins of India with 173 flood forecasting stations in nine major river system, and 71 river sub basins in 15 seats. The central water commission (CWG) is in charge of these systems.

Drought warning management: Contingency crop plan strategies have been evolved through research efforts since the mid 1970s to minimize crop losses in the waked of aberrant weather conditions like drought. Our experience in 2002 strikingly reveals that one of the major constraints in implementing contingency crop planning is the lack of advance weather information during the Kharif season, with reasonable lead time and sufficient specificity to enable farmers to modify their decisions before and during the cropping season.

Long range weather forecasting (LRF) / seasonal climate forecast: Long range weather forecasting is a forecast for more than 10 days a month and for a season. The India Metrological Department revived issuing the long range weather forecasting since the year 1988 onwards on total monsoon rainfall of the country by the end of May. These forecasts can be used for predicting likely trends in food grains production of India before beginning of the Kharif season as the food grains production depends mostly on the distribution and amount of monsoon rain across the country. The cultivable cropped are depends on monsoon rain and its distribution. These for casts can hold the food grain prices in check through buffer stock operations.

Climate/ Agro climate analysis: Climate analysis requires pat meteorological data for more number of years (30-35 years). The tends in rainfall, its variability and probability on distribution of rainfall over a season can be determined weekly using the historical data of rainfall for a given location. This information is useful to crop planners and farmers as crop growth periods can be adjusted under rain fed conditions depending upon rainfall probabilities.

Weather service to farmers: The crop weather calendars prepared for main crops lost their significance with fast changing varieties. As they contain limited information, there was a need to frame them in relation to crops on specific are wise. Thus, the concept of Agro meteorological Advisory Services (AAS) and it is in operation since 1977. However, the utility of the same is very much limited. Realizing the defects and to make the AAS more meaningful, the National centre for medium range weather forecasting (NCMRWF) took up the task in 1988 based on medium range weather forecasting, after the several all India drought during Kharif 1987.

Weather insurance: Agriculture production and farm incomes in India are frequently affected by natural disasters such as droughts, floods, cyclones, snowstorms, landslides, cool and heat waves. The question is how to protect farmers by minimizing such losses. Agricultural insurance is considered an important mechanism to effectively address the risk to put and income resulting from various natural and manmade events. Despite technological and economic advancements, the condition of farmers continues to be unstable due to natural calamities and price fluctuations. Weather insurance is one method by which farmers can stabilize farm income and investment and guard against disastrous effect of losses due to natural hazards or low market prices. Weather insurance not only stabilizes the farm income but also helps the farmers to initiate production activity after a bad agricultural year. It cushions the shock of crop losses by providing farmers with minimum amount of protection. It cushions the shock of crop losses by providing farmers with a minimum amount of protection. It speeds the corps losses over space and time and helps farmers make more investments in agriculture.

Regional Impacts

Climate change and climate variability are a matter of great concern to humankind. The recurrent droughts and floods threaten seriously the livelihood of billions of people who depend on land for most of their needs. The global economy has adversely been influenced by droughts and floods, cold and heat waves, forest fires, landslips and mud slips, ice storms and snowstorms, dust storms, hailstorms, thunder clouds associated with lightning and sea level rise.

Increase in aerosols (atmospheric pollutants) due to emission of greenhouse gases including black carbon and burning of fossil, chlorofluorocarbons (CFCs) hydro chlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), per fluorocarbons (PFCs) Ozone depletion and UV-B filtered radiation, eruptionof volcanoes, the “human hand” in deforestation in the form of forest fires and loss of wetlands are the causal factors for weather extremes. The loss of forest cover, which normally intercepts rainfall and allows it to be absorbed by the soil, causes precipitation to reach across the land, eroding top soil, causing floods and droughts.

The global warming is nothing but heating of surface air temperature due to emission of greenhouse, gases, thereby increasing global atmospheric temperature over a long period of time. Such changes in surface air temperature and rainfall over a long period of time are known as climate change.

Impact of Drought on food grains: The Indian economy Is mostly agrarian based and depends on the onset of monsoon and its further behavior. The year 2002 is a classic example of how Indian food grains production depends on rainfall of July. It was declared the all India drought, as the rainfall deficiency was 19% against the on period average of the country and 29% of the area was affected due to drought. (The all India drought is defined as the drought year when the rainfall deficiency for the country as a whole is more than 10% of the normal and more than 20% of the country’s area is affected by drought conditions) The Kharif food grains production was adversely affected, registering a whopping fall of 19.1%. Similar was the situation during all India drought in 1979, 1987 and 2009. It shows that the occurrence of droughts and floods during Southwest monsoon across the country affects food grains production.

Impacts of Regional Climate Change in India: Self – sufficiency in Indian food grain production and its sustainability is in ambiguity due to the climate variability and change that occurred in the recent past. About 43% of India’s geographical area is used for agricultural activities. Agriculture accounts for approximately 33% of India’s GPD and employs nearly 62% of the population. It accounts for 8.56% of India’s exports. About one third of the cropland in India is irrigated, but rain fed agriculture is central to the Indian economy. .Despite technological advances such as improved crop verities and irrigation systems, weather and climate are still playing a key role in Indian agricultural productivity, and influenced the national prosperity. Increasing evidence over the past few decades indicates that significant changes in climate are taking place worldwide due to enhanced human activities. The major cause to climate change has been ascribed to the increased levels of greenhouse gases due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants and changed land use patterns related practices. The atmospheric concentration of carbon dioxide is increasing at alarming rates. (1.9 ppm per year) in recent years than the natural growth- rate the global atmospheric concentration of methane was at 1774 ppb in 005 and nearly constant for a period of time. Nitrous oxide increased to 319 ppb in 2005 from pre-industrial value of about 270 ppb. Thus, warming of climate system is unequivocal, as is evident from the recent past trends of cloven warmest years out of twelve years (1995-2005) The increase in mean air temperature over last 100 year (1850-1899 to 2001-2005) is 0.76^0C , which is influencing reduction of snow cover and discharge of ricer water in addition to affecting the agricultural production system.

Other impacts of global warming include mean sea level rise as a result of thermal expansion of the oceans and the melting of glaciers and polar ice sheets. The global mean sea level is projected to rise by 0.09 to 0.88 meter over the next century. Due to global warming and sea level rise many coastal systems can experience increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh ground water and encroachment of tidal waters into estuaries and river systems. Climate change and global warming also affect the abundance, spawning, and availability of commercially important marine fisheries. Increase in sea surface temperature also adversely affects coral and coral associated flora (sea grass, sea weed, etc.) and fauna.

Climate change and Agriculture: The impact of climate change on agriculture will be one the major deciding factors influencing the future food security of mankind on earth. Agriculture is not only sensitive to climate change but, at the same time, is one of the major drivers for climate change. Understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. The inter-annual variations in temperature and precipitation were much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability.

Different crops respond differently as the global warming will have a complex impact

The tropics are more dependent on agriculture as 75% of world population lives in tropics and the main occupation of two- thirds of these people is agriculture. With low levels of technology, wide range of pests, diseases and weeds, land degradation, unequal land distribution and rapid population growth impact on tropical agriculture will affect their livelihood.

Rice, wheat, maize, sorghum, soybean and barley are the six major crops in the world and they are grown in 40% cropped area, 55% of non- meat calories and 70% of animal feed (FAO, 2006). Since 1961 there is substantial increase in the yield of all the crops. The impact of warming was likely offset to be minimized some extent, by fertilization effects of increased CO_2 levels, levels. At the global scale, the historical temperature-yield relationships indicate that warming from 1981 to 2002 is very likely to offset some of the yield gains from technological advance, rising CO_2 and other non- climatic factors (Lobell and field, 2007).

The Indian Scenario: India, being a large country, experiences wide fluctuations in climatic conditions with cold winters in the north, tropical climate in the south, arid region in the west, wet climate in the east marine climate in the coastline, and dry continent climate in the interior.

A likely impact of climate change on agricultural productivity in India is a matter of great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Food grain requirements in the country (both human and cattle) would reach about 300 mt in 2020.

The time of arrival and performance of the monsoon is very significant in India and is avidly tracked by the national media. This is because most of the states in the country are largely dependent on rainfall for irrigation. Any change in rainfall patterns poses a serious threat to agriculture, and therefore to the country economy and food security. Owing to global warming, this already unpredictable weather system could become even more undependable. Semi- arid regions of western India are expected to receive higher than normal rainfall as temperatures by the 2050s. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of rainfall. For instance, over the last few years, the Chattisgarh region has received less than its share of pre- monsoon showers in May and June. These showers are important to ensure adequate moisture in fields being prepared for rice crops,

Drought management strategies in rainfed agriculture: In the absence of any assured irrigation facility and with ever- growing changing patterns of temperature and precipitation, the rain water management technologies would play a greater role in rained areas Renewed focus with incentive measures for in situ, especially in low to medium rainfall regions, the farmers themselves taking the leadership in conservation should be the focal theme. The predominant interventions to overcome climate related

Impacts in rain fed areas include

- Soil and water conservation practices
- Agronomic interventions
- Nutrient management practices
- Livestock based interventions
- Development of alternate land use plans.

These interventions have a role to play in all agro- eco systems, except that their order of priority changes, which basically depends on rainfall, status of natural resources like soil, water etc.

Future work for adaptation and Mitigation of climate change in India: Agricultural productivity is sensitive to two broad classes of climate- induced effects; (i) direct effects from changes in temperature, precipitation, or carbon dioxide concentrations, and (ii) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases.

Projected Priorities

1. Altered agronomy of crops

2. Development of resource conserving technologies
3. Increasing income from agricultural enterprises
4. Improved land use and natural resource management policies and institutions
5. Improved risk management through early warning systems and crop insurance

Mitigation Options of GHG in Agriculture: Approaches to increase soil carbon such as organic manures, minimal tillage, and residue management should be encouraged. These have synergies with sustainable development a well.

1. Changing land use by increasing area under horticulture, agro- forestry could also mitigate GHG emissions.
2. Improving the efficiency of energy use in agriculture by using better designs of machinery
3. Improving management of rice paddies, for both water and fertilizer use efficiency could reduce emissions of GHGs.
4. Using nitrification inhibitors and fertilizer placement practices need further consideration for GHG mitigation.
5. Improving management of livestock population, and its diet could also assist in mitigation of GHGs.

Conclusion

Climate change, it appears, is now underway. It is a global problem and India will also feel the heat. Nearly 700 million rural people in India directly depend on climate- sensitive sectors (Agriculture, forests and fisheries) and natural resources (water, biodiversity, mangroves, coastal zone and grasslands) for their subsistence and livelihood. Under changing climate, food security of the country might come under threat. In addition, the adaptive capacity of dry- land farmers, forest and coastal communities is low. Climate change is likely to impact all the natural ecosystems as well as health. The increase in weather extremes like torrential rains, heat waves, cold waves and floods, besides year- to- year variability in rainfall affect agricultural productivity significantly and leads to stagnation/ decline in production across various agro climatic zones.

There is thus, an urgent need to address the climate change and variability issues holistically through improving the natural resource base, diversifying cropping systems, adapting farming systems approach, strengthening of extension system and institutional support. Latest improvements in biotechnology need to be used for better agricultural planning and weather based management to enhance the agricultural productivity of the country and meet the future challenges of climate change the dry land regions of the world.

References

- Anon, 2000, Climate and climate change in India, http: //www. Brown. Edu/ research/ Env. Studies- theses/ full9900 /creid/ climate_and _ climate_change_in. htm, as viewed on July 2, 200.
- Arora, m. Goel, N.K., Singh, Pratap 2005. Evaluation of temperature trends over India, Hydrological sciences Journal, vol. 50, NO. I, p. 81-93.
- Brooks, TJ., Wall, G.W., Pinter, PJ., Jr., Kimball, B.A., Lamorte, R.L., Leavitt, S.W., Matthias,A.D., Adamson, FJ., Junsaker, D.J., and Webber, A.N. 2001. Acclimation response of spring wheat in a free- air CO_2 enrichment (FACE) atmosphere with variable soil nitrogen regimes. Net Assimilation and stomatal conductance of leaves. Photosymthesis. Reserch 66: 97-108.
- Dai, A., Fung, I.Y. and Del Genio, A.D., 1997. Surface observed global land precipitation variations during 1900-1988. Journal of Climatology 10: 2943-2962.
- FAO (Food and Agriculture Organization of the United Nations) 2006. FAO statistical databases. Available fromhttp:// faostat . fao. Org.
- Fisher, G., Frohberg, K., Parry, M.L. and Rosenzweig, C., 1996. The potential effects of climate change on world food production and security. In: Bazzaz, F. and Sombrock, W. (Eds.) Global Climate Change and Agricultural Production. Food and Agriculture, Organization of the United Nations and John Wiley & Sons. Rome, P. 354.
- Fischer, G., Shah, M. and Harrij van Velthuizen., 2002. Climate change and Agricultural Vulnerability. A special report prepared by the Inter Institute for Applied Systems Analysis under UNICA No. 1113, World Summit on Sustainable Development, Johannesburg, 2002.
- Hingane, L.S. , Rupa Kumar, K. and Ramana Murty, B.V., 1985. Long-term trends of surface air temperature in India. Journal of climatology

5: 521-528.

Climate change effects on soil health and organic matter turnover in soils

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Emission of greenhouse gases (GHGs) viz. carbon dioxide (CO_2), methane (CH_4), oxides of nitrogen (nitrous oxide, N2O and nitric oxide, NO) and halocarbons, which emanate from human activities are bringing about major changes to the global environment. The concentration of these greenhouse gases (GHGs) in the environment has increased significantly with time. The atmospheric concentration of CO2 has increased globally by ~45% from about 275 ppm in the pre industrial era (AD 1000-1750) to 400 ppm at present. The emission of GHGs in the agriculture sector increased by 35%, from 4.2 Gt CO2 eq. yr-1 to 5.7 Gt CO2 eq. yr-1 during 1970 to 2010 (IPCC, 2013). Enteric fermentation was the largest contributor to methane emission followed by rice cultivation and manure management. During 1970 to 2010, emission of CH4 increased by 18% whereas emission of N2O increased by 73%. Though total global emission increased but per capita emission declined from 2.5 ton in 1970 to 1.6 ton in 2010 because of growth in population. Global emission of GHGs in 2010 was about 50 Gt CO2 eq. in which India contributed about 2.34 Gt CO2 eq. (~5% of the total emission). The energy sector in India contributed the highest amount og GHGs (65%) followed by agriculture (18%) and industry (16%) (Fig.1)

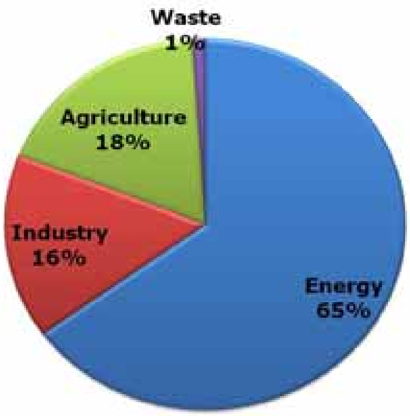


Fig. 1. Emission of greenhouse gases from various sectors in India in 2010

The increased concentration of GHGs cause global warming, deplete the concentration of ozone in the stratosphere that acts as a shield against excessive exposure to ultra violet (UV) rays at the Earth's surface, and also contribute to acid deposition. During the period 1906-2005, global mean surface temperatures have risen by 0.74°C ± 0.18°C and is expected to increase by another 1.1-6.4 ^{0}C by the end of this century (IPCC, 2007). However, the warming has neither been steady nor the same in different seasons or at different locations. The rate of warming during the last over 50 years is almost double (0.13°C ± 0.03°C per decade) than during the last 100 years (0.07°C ± 0.02°C per decade). In addition to temperature, atmospheric moisture, precipitation and atmospheric circulation have also changed. Increase in temperature influences evaporation, sensible heat and moisture-holding capacity of the atmosphere (at a rate of ~7% per °C). Together these effects alter the hydrological cycle, especially amount, frequency, intensity, duration, type and extremes of precipitation (Trenberth et al., 2003). The changes in temperature, moisture, increased CO_2 concentration and enhanced atmospheric deposition impact several soil processes, which influence soil health.

Effect of climate change on soil health

While several reports are available relating soil health to agricultural management, the studies describing the effect of climate change on soil health are rare. This is mainly because the changes in soil properties and the climate take place over a long-term. A change in soil quality can only be perceived when all the effects are combined over a period of time. Generally, biological processes in soil such as decomposition and storage of organic matter, C and N cycling, microbial and metabolic quotients are likely to be influenced greatly by climate change and have thus high relevance to assess climate change impacts

(Allen et al., 2011; Table 1). Physical indicators of soil quality such as porosity and available water capacity have high relevance and are occasionally used to assess climate change impacts. Chemical indicators of soil quality such as pH, EC and availability of macro-nutrients have medium relevance and are frequently used to assess climate change impacts (Table 2).

Table 1. Soil quality indicators and soil processes with high relevance to assess climate change impacts

Indicator	Soil processes affected
Soil organic matter fractions	Residue decomposition, organic matter storage and quality
Mineralizable C and N	Metabolic activity of soil organisms, mineralization-immobilization turnover
Total C and N	C and N mass and balance
Soil respiration, soil microbial biomass	Microbial activity
Microbial quotients	Substrate use efficiency
Microbial diversity	Nutrient cycling and availability
Porosity	Air capacity, plant available water capacity
Available water	Field capacity, permanent wilting pointing, water flow

Table 2. Soil quality indicators and soil processes with medium relevance to assess climate change impacts

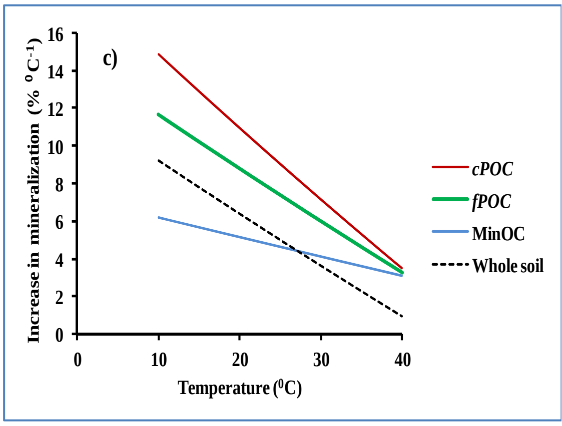
Indicator	Soil processes affected
Soil structure	Aggregate stability, soil organic matter turnover
pH	Biological and chemical activity thresholds
EC	Plant and microbial activity thresholds
Available N, P & K	Plant available nutrient and potential for loss

Effect of climate change on organic matter turnover

Soil organic matter has turnover times ranging from months to millennia, with much of it around several years and decades. Depending on the input-output balance, SOM can be both a source and sink of atmospheric CO_2. A soil source results when net decomposition exceeds C inputs to the soil, either as a result of human activities or because of increased decomposition rates due to global warming. Globally, soils contain 1500-2000 Gt organic C down to 1 m depth. The total quantity of CO_2-C exchanged annually between the land and the atmosphere as gross primary productivity is estimated at 120 Gt C yr^{-1} and about half of it is released by plant respiration giving a net primary productivity of 60 Gt C yr^{-1}. Soil respiration represents the second largest flux (~60 Gt C yr^{-1}) between ecosystems and the atmosphere and a small change in soil respiration could significantly intensify or mitigate atmospheric increase of CO_2. It is well-known that soil respiration is significantly influenced by temperature (Kirschbaum, 1995; Zhang et al., 2006; Benbi et al. 2014), and it is generally believed that 10^0C rise in temperature doubles the rate of decomposition, *i.e.*, Q_{10}=2. It is, therefore, speculated that increase in temperature due to global warming can accelerate the decomposition of soil organic matter (SOM) and consequently increase the release of SOC to the atmosphere (Davidson et al., 2000). These concerns have stimulated interest in understanding the temperature sensitivity of soil respiration and organic matter decomposition, especially with regard to the factors that determine the temperature dependence of C mineralization.

Several studies have shown that C mineralization increases with increase in temperature and the relative increase depends on reference temperature. The increase in mineralization is greater at low reference temperature than at high temperature. Q_{10} values ranging from about 8 at 0^0C to 2.5 at 20^0C have been reported (Kirschbaum, 1995; Zhang et al., 2006). However, these studies described decomposition temperature sensitivity of bulk soil organic matter rather than the temperature sensitivity for organic C fractions of different decomposability. A number of models and methodologies have been used to express relative temperature sensitivity of the decomposition of labile and stable SOM pools with contradictory results. Knorr et al. (2005) postulated that the dominant slow pools of organic carbon are more sensitive to temperature than the faster pools causing a larger positive feedback in response to global warming. On the contrary, Reichstein et al. (2005) argued that it is premature to conclude that stable soil carbon is more sensitive to temperature than labile carbon and there could be very similar responses of labile and stable SOM decomposition to temperature (Fang et al., 2005). The conflicting results may partially be attributed to the range of methods used to estimate SOM decomposition temperature sensitivity, and the inability to consistently define and quantify labile and stable SOM.

The SOM quality is generally described in terms of physical, chemical and biological pools. Studies published in the last three decades have shown that physical fractionation of SOM according to size provides a useful tool for the study of its functions and turnover in soil (Benbi et al., 2012). The availability of substrate to decomposers depends not only on the chemical nature of the substrate but also on the nature of its association with the soil's mineral components (Christensen, 2001). Soil organic matter is generally fractionated into *c*POM (size >250 µm), *f*POM (size 53-250 µm) and MinOM (size <53 µm). Coarse and fine particulate organic carbon (POC) fractions have been considered to represent active or labile and slow or relatively less labile pools of SOC, respectively. The mineral associated organic carbon (MinOC) that includes physically and chemically stabilized organic carbon is resistant to decomposition and is considered to represent passive pool of SOC (Benbi et al., 2012). Estimates of mean residence time (MRT) showed that *c*POM was most decomposable with MRT ranging between 490 days at 15^{0}C and 81 days at 45^{0}C (Benbi et al., 2014). The MinOM was least decomposable with MRT's of 1534 and 508 days at 15^{0}C and 45^{0}C, respectively (Table 3). The estimates of MRT show that the *c*POM was influenced by temperature to a greater extent as opposed to MinOM that was least affected by temperature. Unit degree Celsius increase in temperature enhanced decomposition of isolated SOM fractions and whole soil to a greater extent at low temperatures and the effect diminished with increase in temperature. It was shown (Fig. 2) that decomposition of *c*POM fraction is likely to be influenced to the greatest extent (7-15% increase) per ^{0}C rise in temperature between 10 and 15^{0}C followed by *f*POM (6-12% increase). The MinOM is likely to be least affected with about 4-6 per cent increase in its decomposition per ^{0}C increase in temperature between 10 and 15^{0}C. Carbon mineralization of whole soil will increase by 4-9 per cent at 10-15^{0}C temperature and the effect will diminish to about 2-3 per cent at 35^{0}C (Benbi et al., 2014).



Simulation models are increasingly used to generate scenarios and predict the possible effects of climate change on soil health. Soil organic matter models such as CENTURY and Roth-C are being used for regional and global analysis of soil C dynamics. Simulations with RothC model (Coleman and Jenkinson, 1996) has shown that the increase in global temperature will result in enhanced soil respiration rates and hence decreased soil carbon stocks, estimated at 54 Gt C by the year 2100 (Niklaus and Falloon, 2006). Similarly, Smith et al. (2005) estimated that soil carbon stocks in European croplands and grasslands will decrease due to enhanced decomposition but increased net primary productivity is likely to slow the loss.

Changes in climate are likely to influence the rates of accumulation and decomposition of SOM, both directly through changes in temperature and water balance and indirectly through changes in primary productivity and rhizodepositions. Atmospheric CO_2 concentration influences SOM storage through its effect on primary production. Generally, it is expected that increase in temperature will enhance the rate of SOM decomposition, which decreases SOC content. Increased temperature together with elevated CO_2 concentration will lead to increase in primary productivity, which provides input to SOC. The change in soil C storage represents the net effect of organic matter decomposition and primary production. Studies in the past have shown that soil organic C and N pools are positively correlated with precipitation and negatively correlated with temperature (Post et al., 1985). There are contradictory reports on the effect of temperature increase on SOC. Simulation studies of Kirschbaum (1993) showed that temperature increase could result in loss of SOC due to increased decomposition. On the contrary, Gifford (1992) predicted no loss of SOC due to temperature increase. Since SOC pools is influenced by rate of organic matter decomposition and primary productivity, the future trend in SOC pool will depend on the relative temperature sensitivities of the two processes. The temperature sensitivity of organic matter decomposition decreases with increasing temperature and at low temperature it is much greater than the temperature sensitivity of net primary productivity (Kirschbaum, 1995). However, to predict the fate of SOC stocks in relation to global warming it is essential to understand the temperature response of the processes that control substrate availability, depolymerization, microbial efficiency and enzyme production (Conant et al., 2011).

Fig. 2. Influence of one degree Celsius rise in temperature on mineralization of different soil organic matter fractions and whole soil

In conclusion, it may be stated that climate change could impact SOM and a number of processes that are strong determinant of soil health. To mitigate climate change effects, it is imperative that soil health is maintained so that it can sustain physical, chemical and biological functions and provide ecosystem resilience.

References

- Allen, D.E., Singh, B.P. and Dalal, R.C. 2011. Soil health indicators under climate change: a review of current knowledge. In: *Soil Health and Climate Change*. B.P. Singh *et al*. (eds.), Springer-Verlag Berlin Heidelberg. pp 25-45.
- Benbi DK, Boparai AK, Brar K. 2014. Decomposition of particulate organic matter is more sensitive to temperature than the mineral associated organic matter. *Soil Biol. Biochem* 70: 183-192
- Benbi, D.K., Toor, A.S., Kumar, S. 2012. Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. *Plant and Soil* 360: 145-162.
- Coleman, K. and Jenkinson, D.S. 1996. RothC 26.3- a model for the turnover of carbon in soil. in: Evaluation of Soil Organic Matter Models Using Existing Long-term Datasets, D. S. Powlson, P. Smith and J.U. Smith, eds. Springer, Berlin, pp. 237-246.
- Conant R., Ryan, M.C., Ågren, G.I. *et al*. 2011. Temperature and soil organic matter decomposition rates- synthesis of current knowledge and a way forward. *Global Change Biol.*17: 3392-3404.
- Davidson, E.A., Trumbore, S.E., Amundson, R., 2000. Soil warming and organic carbon content. Nature 408: 789-790.
- Fang, C., Smith, P., Moncrieff, J.B., Smith, J.U., 2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. Nature 433:57-59.
- Gifford, R.M. 1992. Implications of the globally increasing atmospheric CO2 concentration and temperature for the Australian terrestrial carbon budget: integration using a simple model. *Aust. J. Bot.* 40: 527-543.
- IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.
- IPCC (Intergovernmental Panel on Climate Change), 2014. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.
- Kirschbaum, M.U.F. 1993. A modeling study of the effects of changes in atmospheric CO2 concentration, temperature and atmospheric nitrogen input on soil organic carbon storage. *Tellus* 45B: 321-334.
- Kirschbaum, M.U.F. 1995. The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. *Soil Biol. Biochem*. 27: 753-760.
- Knorr, W., Prentice, I.C., House, J.I., Holland, E.A., 2005. Long-term sensitivity of soil carbon turnover to warming. Nature 433: 298-301.
- Niklaus, P.A. and Falloon, P. 2006. Estimating soil carbon sequestration under elevated CO2 by combining carbon isotope labelling with soil carbon cycle modelling. *Global Change Biol.* 12: 1909-1921.
- Post, W.M., Pastor, J., Zinke, P.J. and Strangenberger, A.G. 1985. Global patterns of soil nitrogen. N*ature* 317: 613-616.
- Reichstein, M., Kätterer, K., Andrèn, O., Ciais, P., Schulze, E.D., Cramer, W., Papale, D., Valentini, R. 2005. Temperature sensitivity of decomposition in relation to soil organic matter

pools: critique and outlook. *Biogeosciences* 2: 317-321.

- Trenberth, K.E., Dai, A., Rasmussen, R.M. and Parsons, D.B. 2003. The changing character of precipitation. *Bull. Am. Meteor. Soc.* 84: 1205-1217.
- Zhang, Xu-hui., Li, Lian-qing., Pan, Gen-xing, 2006. Topsoil organic carbon mineralization and CO_2 evolution of three paddy soils from south China and the temperature dependence. *J Environ. Sci.* 19: 319-326.

Climate change and disease management in chickpea: Challenges and strategies

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Summary

Climate variability and changing climate patterns are alarmimg the equilibrium of host-pathogen interactions resulting in either increased epidemic outbreaks or emergence of new pathogens or less known pathogens causing severe yield losses. Climate variables (temperature, humidity, and greenhouse gases) are the key factors for these changes. Plant pathogens inspite of sound management technologies still results in 10-16% of food yield losses due to the climate variability. The Indian sub-continent has witnessed a shift in cropping pattern in pulses last three decades. Chickpea has shifted from highly productive irrigated condition in Northern India to rainfed areas in Central and Southern India.This has made diseases viz., Ascochyta blight, Botrytis grey mould less frequent with wilt and root rots are becoming important in newer niches. Changing climatic conditions and abrupt rise in temperature at flowering and pod filling (March-April) accompanied by rains make the crop vulnerable to BGM attack. Efforts are being made to discuss the different climate variables on chickpea diseases , pathosystems and the mitigation strategies for their management.

Introduction

It is established fact that temperature, moisture and greenhouse gases are the major elements of climate change. Current estimates indicate an increase in global mean annual temperatures of 1ºC by 2025 and 3ºC by the 2100. The carbon dioxide (CO_2) concentration is rising @ of 1.5 to 1.8 ppm / year and is likely to be doubled by the end of 21st century. Variability in rainfall pattern and intensity is expected to be high. Greenhouse gases (CO_2 and O_3) would result in increase in global precipitation of 2 ± 0.5ºC per 1ºC warming. Overall, changes in these elements will result in: i) warmer and more frequent hot days and nights, ii) erratic rainfall distribution pattern leading to drought or high precipitation and iii) drying of rainfed semi-arid tropics in Asia and Africa.

Climate change may affect plant pathosystems at various levels viz. from genes to populations, from ecosystem to distributional ranges; from environmental conditions to host vigour/ susceptibility; and from pathogen virulence to infection rates These changes may show positive, negative and neutral impacts on host-pathogen interactions which could result: a) extension of geographical range; b) increased over-wintering and over summering; c) changes in population growth rates; d) increased number of generations; (e) loss of resistance in cultivars containing temperature-sensitive genes (f) extension of crop development season; (g) changes in crop diseases synchrony; h) changes in inter-specific interactions; i) increased risk of invasion by migrant pathogens; and j) introduction of alternative hosts and 'green bridges' or over-wintering hosts.

Climate variables

Temperature : Changes in temperature particularly increase in temperature are predicted to lead to the geographic expansion of pathogen and vector distribution, bringing pathogens into contact with more potential hosts. Higher minimum temperatures and reduced frequency or intensity of cold days will favor the survival of pathogens. Rust in chickpea were found to cause in areas of Karnataka where the pathogen could overwinter. Similarly cool and dry weather favoured the higher incidence of powdery mildew at Arnej, Gujrat where almost all the genotypes were having heavy infestation at pod filling stage .Change in temperature might lead to appearance of different races of the pathogens which are not active but might cause sudden epidemic.

Studies on temperature response of chickpea cultivars to races of FOC indicated that use of resistant cultivars and adjustment of sowing dates are important measures of management of Fusarium wilt. Greenhouse experiments indicated that the chickpea cultivar Ayala was moderately resistant to *F. oxysporum f.sp. ciceris* when inoculated plants were maintained at a day/night temperature regime of $24/21^0$ C but was highly susceptible at $27/25^0$ C. Field experiments in lsrael over three consecutive years indicated that the high level of resistance of Ayala to Fusarium wilt when sown in mid-to late January differed from a moderately susceptible reaction under warmer temperatures when sowing was delayed to late February or early March. Experiments in growth chambers showed that a temperature increase of 3^0

C from 24 to 27^0 C was sufficient for the resistance reaction of cultivars Ayala and PV-1 to race 1A of the pathogen to shift from moderately or highly resistant at constant 24^0 C to highly susceptible at 27^0 C. A similar but less pronounced effect was found when Ayala plants were inoculated with *F. oxysporum f. sp. ciceris* race 6. conversely, the reaction of cultivar JG -62 to races 1A and 6 was not influenced by temperature, but less disease developed on JG-62 plants inoculated with a variant of race 5 of *F. oxysporum f. sp. ciceris* at 27^0 C compared with plants inoculated at 24^0 C. These results indicate the importance of appropriate adjustment of temperature in tests for characterizing the resistance reactions of chickpea cultivars to the pathogen, as well as when determining the races of isolates of *F. oxysporum f. sp. ciceris*.

Studies indicated that dry root rot (*Rhizoctonia bataticola*) increased many folds in last 2-3 years due to prolonged moisture stress. Studying data in India after the rainy season from 2005 to 2010, showed that there is higher incidence of dry root rot in chickpea varieties that resist Fusarium wilt in years when temperatures exceed 33°C This is consistent with the greenhouse experiments where different soil moisture levels and temperatures were manipulated, showing that *R. bataticola* infected chickpea plants and caused dry root rot faster at 35 $^{\circ}$C with soil moisture levels ≤ 60% .Temperature may have important repercussions on the effectiveness of host plant resistance.. Increase in temperature can modify host physiology and resistance by changing gene expression and activity.

Moisture (rainfall)

Erratic rainfalls and rise in temperature have become more frequent under changing scenario of climate. As a consequence of drastic shift of chickpea, diseases have been recorded throughout the major chickpea growing regions in India and elsewhere. Dry root rot was found as a potentially emerging constraints to chickpea production than wilt. Increased incidence is directly correlated with the climate change variables viz. temperature and moisture on the disease development.

Prolonged moisture may create a new scenario of potential diseases as collar rot, wet root rot, anthracnose and Alternaria blight, and rusts. Other pathogens such as powdery mildew tends to strive in conditions with lower moisture

Carbon dioxide (CO_2)

The impact of increased CO_2 can be observed in several stages of the host-pathogen interactions. Elevated CO_2 and associated climate change have the potential to accelerate plant pathogen evolution, which may, in turn, affect virulence. The increased biomass due to increase in CO_2 may become more conducive for rusts, and blights etc..

Elevated CO_2 also have the potential to influence the effectiveness of host resistance also affect the soil microbial communities. However because of the great variation in interactions among microbial species,

Global climate change especially increased CO_2,, temperature and moisture levels are thought to influence or change all the elements of a disease triangle. This increase in temperature can modify host physiology and resistance,. Increase CO_2 would affect the physiology, morphology and biomass of crops by promoting the development of some rusts and other foliar disease. eg. Ascochyta blights, Stemphilium blight, Grey mould

Greenhouse gases

The greenhouse gases such as ozone, nitrous oxide, carbon monoxide are secondary pollutants and current climate change scenarios predict an increase of these greenhouse gases which will interfere with photosynthesis and growth process of plants Ozone can make plants sensitive for attack particularly for root rot fungi etc.

Integrated disease management

A single disease management strategy rarely provides complete disease control using a number of integrated disease management (IDM) techniques which aims to **:**

- Reduce background inoculum levels through paddock selection, control of volunteers and stubble management.
- Exclude pathogens through the use of clean seed and farm hygiene; and
- Protect the crop by using resistant varieties, seed treatments and strategically applied foliar fungicides.
- A fully integrated disease management program should be initiated before sowing and maintained through the growing season to greatly reduce disease impact. Disease monitoring should start at six to eight weeks after emergence if the crop is susceptible, as regular fungicide application are necessary in these varieties. Avoid sowing adjacent to old chickpea stubble, particularly downwind, and aim to separate by a distance of at least 500 metres. A break of at least four years between chickpea crops will minimise soil inoculum. Herbicide residues may increase susceptibility to disease.

- On-farm hygiene, paddock selection, varieties ,seed for sowing, seed dressing sowing date , seed rate , row spacing , fungicide treatments for AB and BGM are the major points besides the yield and marketability along with disease resistance .

Challenges and strategies

- Looking to the climate change on disease scenario management strategies will require adjustments. Although physiological changes in host plants may result in higher disease resistance under climate change scenarios, the durability of resistance may be threatened and may lead to more rapid evolution of aggressive pathogen races .
- The population dynamics of beneficial microorganisms such as rhizobia, biocontrol agents and mycorrhizal fungi may get affected due to increased temperature, moisture and CO_2. Arbuscular mycorrhizal fungi can modulate plant responses to elevated CO_2 by increasing resistance/tolerance of plants against an array of environmental stresses. Under elevated CO_2 conditions, mobilization of resources into host resistance through various mechanisms such as reduced stomata density and conductance greater accumulation of carbohydrates in leaves; more waxes, extra layers of epidermal cells and increased fiber content and increased biosynthesis of phenols increased tannin content have been reported.
- The efficacy of fungicides may change with changes in climate variables. For example more frequent rainfall events could make it difficult for farmers to use the fungicides on plants leading to more frequent applications.
- In addition to refinement in the existing management practices, there is a need for simulation models to assess the potential of emerging pathogens for a given crop production system and also shift in pathogen populations/fitness that may demand modifications in current production systems. Forecasting models which allows investigating multiple scenarios and interactions simultaneously will become most important for disease prediction, impact assessment and application of disease management measures. Recently, Geographic information system (GIS) is commonly used to evaluate and model the spatial distribution of plant disease in relation to environmental factors.
- Innovative methods may have to be adopted to develop adaptation strategies to overcome the impacts due to climate change and climate variability so that the food and livelihood security of rainfed farmers can be ensured. There is a need for a greater understanding of the effect of climate change on the efficacy of synthetic fungicides, their persistence in the environment, and development of resistance in pathogens populations to the fungicides.

Looking ahead

Due to highly variable nature of pathogens, resistant cultivars succumb to these diseases and consequently needs to be replaced with a new resistant cultivars. Further ,as climate change increases climate variability , the risk of drought and floods, diseases and pests ,and threats to agricultural productivity and production will escalate. Hence, the key to sustainable future lies in improving crop productivity through ecologically friendly farming systems that are more effective in harnessing nature, and that will go a long way in enhancing the livelihoods of the poor. Therefore. developing appropriate strategies for disease management effective under changing climate in future are critical. For example, four races of FOC (Race I, 2, 3, 4) has been reported from India in 1981. However, recent research indicated a change in the race scenario which do not restrict to a particular geographical location. Thus, due to the existence of several physiological pathogenic races FOC , control of wilt through resistance breeding has become a challenge. Therefore, there is a need to study the interaction of root rots and wilt and their sequential occurrence in sick plots.

- Under the climate change scenario, many of the conventional cultivation practices and strategies may no longer be relevant. Therefore, there is a need to recommend technologies to the farmers which respond well to climate change effects and give greater resilience against such shocks. Growing early maturing, photo-insensitive, high-tillering cultivars with optimal root traits and tolerant to abiotic and biotic stresses; mulching with crop residues; planting more seedling per hill for heat stress; better soil nutrient and water management, moisture conservation for late onset of monsoon and life-saving irrigation with stored rainwater for mid-season drought to harvest positive effects of the increased CO2 level are a few strategies recommended by ICRISAT to cope with the effects of climate change and variability on dry land agriculture . .As the dry land soils are critically low in soil organic matter, emphasis on improving soil organic matter status, an important driving force for biological activities in the soil, the source of food for soil flora and fauna with organic matter can minimize the climate change-induced water stress effects on crops by improving water-holding capacity of the soils and consequently enhancing LGP.

Breeding climate resilient soybean varieties

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Introduction

Global climate change is now already under way as evident particularly in terms of increasing temperature, increasing CO_2 concentration, widespread melting of snow and ice and rising global average sea level, erratic monsoon causing excessive or scarce moisture which has tremendous potential and some realized impact on Indian agriculture. This has more adverse effect on food production and food quality with the poorest farmers and in marginal environments. The adverse effect is a consequence of the expected or probable increased frequency of some abiotic stresses such as heat, excess moisture and drought, and of the increased frequency of biotic stresses (pests and diseases). For Indian region the IPCC has projected 0.5 to 1.2 ^{0}C rise in temperature by 2020, 0.88 to 3.16 ^{0}C by 2050 and 1.56 to 5.44 ^{0}C by 2080 depending upon the scenario of future development (IPCC, 2007). Despite the beneficial effects of higher CO_2 on several crops, associated increase in temperatures, increased variability of rainfall resultant variation in the growing of crop season available, change in the incidence, distribution and overall dynamics of pests and pathogens, soil degradation, quality deterioration in produce and other related direct and indirect effects may impact adversely on crop productivity/production and quality. Although temperature rise will cause a shift in planting dates, which may change the length of growing season yet benefit some areas and variability in rainfall is seen as potentially greater management challenges. The oilseed crops mostly grown in rainfed situations are seems to be more vulnerable to climatic changes than other high input receiving and well managed crops.

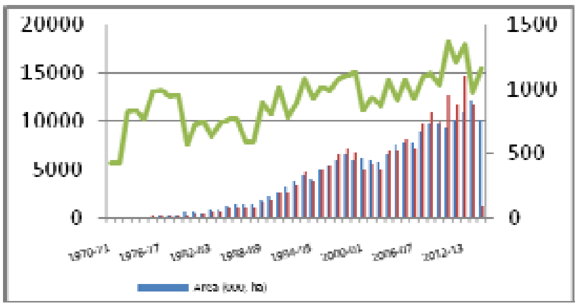

Fig.1: Area, production and productivity of soybean in India

Nevertheless, offset some of the negative effects of global warming particularly for C_3 crops like soybean that is often exposed to water stress. Studies conducted in India using CROPGROW-soybean model indicate that present temperatures are within the optimum range of soybean growth, development and yield and do not impede the productivity of soybean (Bhatia *et al*., 2008).

The simulation studies has projected increase in yield due to doubling of CO_2 in central India (Lal *et al*.,1999; Mall *et al*., 2004). However, a 3^{0}C rise in surface air temperature almost offset the positive effects of CO_2 concentration. Soybean yield increase ranging from 8-10% have been projected under different scenarios of climatic change in India depending on certain parameters such as demography, technology development, dependence on fossil fuel or other alternative sources.

The progress made in last four decades

(a) Regarding area, production and productivity: The advent of commercial exploitation of soybean in India is nearly four decades old. In this short spell of time, the crop has experienced unprecedented growth. The area and production under soybean has increased from a meager 0.03 m ha and 0.01 m tones to 10.02 m ha and 11.60 m tones in India (Figure-1) and 0.003 m ha and 0.001 m tones to 5.5m ha and 6.0 m tones in MP (Figure-2) from1970 to 2014-15, respectively. Mean national productivity has increased from 0.43 to1.20 t/ha of India and 0.46 to 1.1 t/ha of MP from 1970 to 2014-15 around 2.5 times which is admirable looking to rainfed situations. However, the vagaries of weather in several years adversely affected productivity and showed fluctuation. Soybean has established itself as a major kharif crop in the rainfed agro-ecosystem of central and peninsular India. Introduction of soybean in these areas has led to a shift in the cropping system from rainy season fallow followed by post-rainy season wheat or chickpea (fallow-wheat/chickpea) to soybean followed by wheat or chickpea (soybean-wheat/chickpea) system. This has resulted in an enhancement in the cropping intensity and resultant increase in the profitability per unit land area. In the commendable achievements, Jawaharlal Nehru Krishi Vishwa Vidyalaya and Madhya Pradesh contribution has always been largest and substantial in respect of area and production. Thus, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is known as the Bethlehem of Indian soybean and Madhya Pradesh as SOYA STATE.

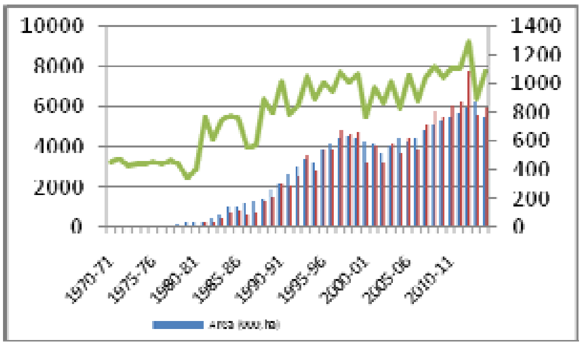

Fig. 2: Area, production and productivity of soybean in MP

In India, soybean will continue to remain a major rainfed oilseed crop. The simulation studies and on farm demonstrations have clearly indicated that with current varieties, the rainfed potential of soybean in India is about 2.1 t/ha against the national average productivity of just 1.2 t/ha. Hence, large yield gaps exist between the potential and the actual yields harvested by the farmers. Narrowing of this yield gap can lead to doubling of soybean production and productivity. However, to meet the growing demands by 2050 in terms of edible oil, food uses, meal for animal feed and various other industrial uses of soybean, we need to explore the untapped research areas, usher in new research methodologies. The present strategy needs revamping of soybean research programme and managements in future to tackle the challenges posed by changing demographics, climatic, agrarian and industrial requirements.

(b) Regarding breeding efforts

In India, soybean research and cultivation had minor contribution before 1965. Exotic lines received from USA were tested by conducting trials at the Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur and almost concurrently at the Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar and suitability of soybean cultivation in India was proved. The encouraging results led to the establishment of All India Coordinated Project in 1967 by ICAR. The breeding objectives were focused on germinability and longevity, resistance to shattering and lodging, early and medium duration, four seeded pods, profuse podding, quality and resistance to biotic and abiotic stresses. So far 100 improved soybean varieties possessing various traits in India applying hybridization and mutation breeding. Whereas, from JNKVV,15 popular and mega varieties viz., JS 72-44, JS 72-280, JS 2, JS 75-46, JS 76-205, JS 80-21, JS 71-05, JS 335, JS 90-41, JS 93-05, JS 95-60, JS 97-52, JS 20-34, JS 20-29 and JS 20-69 have been released which has ever covered more than 85 % area of country.

Important traits such as drought tolerance, photoperiod insensitivity, resistant to diseases such as rust, charcoal rot, and YMV, resistant to insects such as stem borers and defoliators, and food uses such as vegetable types, high oil content, high oleic acid content, low lipoxygenase content and null Kunitz Trypsin inhibitor were identified. To enhance the efficiency of breeding programmes using molecular tools, the QTLs for high seed longevity and markers for YMV resistance genes were identified. For harnessing the optimum productivity for a rainfed crop optimum phenology for harnessing maximum yield of rainfed soybean in central India has been worked out.

Future breeding objectives

Change in climatic patterns would compel major realignments in existing cropping pattern and systems. The projected change in climate may lead to emergence of new insect pests and diseases which assume menacing proportion and large segment of agricultural area could be under abiotic stresses. An increase in the number of outbreaks of a wider variety of insects, nematodes and pathogens and increased damage potential of existing and invasive pests and diseases is anticipated. To address these above mentioned future constrains of productivity, following strategies need to be followed.

Conventional breeding approaches

Breeding based on yield components: Soybean breeders have to be ready with necessary realignments to make crop extremely resilient to weather and climatic fluctuations and extremities.

There no alternative of conventional breeding but this needs reorientation or revamping. Yield potential may be built up by progressive assembling of positive genes including productivity, quality, resistance to biotic and abiotic stresses, simultaneously.

Soybean cultures having profuse podding crossed with four-seeded pod cultures may produce genotypes combining these two desirable characters and substantial yield increase can be achieved (Shrivastava, 2011). Hybridization programmes should be performed taking cultures having multiple attributes with multiple resistances for the future sustainability of varieties rather than improving single trait. Mutation breeding may also have place in breeding to create new variability for targeted traits.

Breeding based on physiological traits: It is imperative to consider yield components along with physiological characters simultaneously for substantial genetic gain in yield. The characters such as earliness, faster growth rates, photo-insensitivity, appropriate biomass, assimilate supply during seed filling period with high harvest index, per day productivity, high leaf photosynthesis, specific leaf weight, have been identified as important traits to be incorporated in future breeding programmes (Bhatia *et al.*, 1996). Identification of morphological and biochemical traits for drought, high temperature and excessive moisture tolerance and their use in breeding programme is required.

(a) Breeding for biotic stresses: Soybean diseases such as rust, yellow mosaic, charcoal root rot, Rhizoctonia aerial blight, rust, Rhizoctonia solani rot are collectively causing significant yield losses in soybean. Fortunately, sources of genic resistance for YMV are available in adapted genetic background that have 'PI 171443' (UPSM 534) in their pedigree as their main source (Singh et al. 1974 a,b; Ram et al., 1981). Screening and breeding work has to be intensified to combat future menace.

In the predominant soybean growing area, green semi-loopers, tobacco caterpillar, Bihar hairy caterpillar, girdle beetle, stemfly and whitefly are the major insect-pests of great concern. Breeding for insect-pests resistance is now receiving the impetus.

(b) Resistance for abiotic stress: Soybean suffers from drought and also excess water conditions. For improved and stable yields, it would be desirable to develop soybean varieties to cope with drought and excess water stresses prevalent in target environments. In India, soybean cultivars have not been specifically developed for drought and excess moisture stress conditions although tolerance in some lines is reported for these. Variety 'JS 97-52' has, however, been reported to be tolerant to excessive soil moisture. Systematic efforts are, therefore, needed for identifying sources of tolerance and associated physiological characters. Several morphological, physiological and biochemical characters have been associated with drought resistance in soybean. Sloane *et al.* (1990) reported that soybean line PI 416937 was less sensitive to drought than currently grown cultivars. The genotype had larger and thicker leaves and was superior in the ability' to maintain leaf turgor, transpiration and net C-exchange rates under severe drought stress. Canopy temperature depression, canopy growth and per cent growth cover at early stage (aided by image/ camera, photographic analysis) have also been found useful in several crops. Singh *et al.* (1973) and Sarkar *et al.* (1991) suggested some criteria for identification of drought resistance.

(e) Molecular Approaches: The identified genetic sources will be used for crop improvement using functional genomics, MAS, transgenic and allele mining approaches. Harnessing hybrid vigour and accumulation of yield, tolerance to drought and excessive moisture related QTLs to overcome genetic yield barriers will provide opportunities to enhance the genetic yield potential of soybean.

Soybean breeders would have the challenge of introgressing valuable traits from secondary and tertiary gene pools by utilizing widely available and established tools of modern biotechnology. Genetically modified soybean would possibly become a norm for effective biotic stress management (weeds, insect pests and diseases) and would widely be acceptable across globe thus making it imperative for India also to have GM soybean in the country. Researchers would have to be ready with production technologies compatible with GM soybean.

References

- Allen, H Jr, Boote K J, Jones J W, Jones P H, Valle R R, Acock b, Rogers H H and Dahlman R C. 1987. Response of vegetation to rising carbon dioxide: Photo-synthesis, biomass and seed yield of soybean. *Global Biogeochem Cycles*. 1-14.

- Bhatia V S, Tiwari S P and Joshi O P. 1996. Interrelationship of leaf photosynthesis, specific leaf weight and leaf anatomical characters in soybean. *Indian Journal of Plant Physiology New Series* 1:6-9.
- Bhatia V S, Singh P, Wani S P, Chauhan G S, Rao A V R K, Mishra A K and Srinivas K. 2008. Analysis of yield and yield gaps of rainfed soybean in India using CROPGRO-Soybean model. *Agriculture and Forest Meteorology* 148:1252-65
- IPCC. 2007. Climate Change 2007: Impact, Adaptation and Vulnerability. Contribution of working group II to the fourth assessment, Report of the Intergovernmental Panel on Climate Change, M L Parry, O F Canziani, J P Poluticof, P J van der Linden and C E Hanson (eds), Cambridge University Press, Cambridge, U K ,976 pp.
- Lal M, Singh K K, Srinivasan G, Rathore L S, Naidu D and Tripathi C N. 1999. Growth and yield response of soybean in Madhya Pradesh , India to climate variability and change. Agricultural and Forest Meteorology 93:53-70.
- Mall R K, Lai M, Bhatia V S, Rathore L S and Singh R. 2004. Mitigating climate change impact on soybean productivity in India: a simulation study. Agricultural and Forest Meteorology 121:113-25.
- Ram, H H, Pushpendra, Singh K and Verma, V D. 1981. Breeding soybean varieties for northern India. *Soybean Genetics Newsletter* 8:74-8
- Sarkar R K, Saini J P and Dubey S D. 19991. Testing of soybean genotypes for drought tolerance. *Indian Journal of Agricultural Sciences* 61:369-73
- Shrivastava A N, Shrivastava M K and Manjaiya J G. 2011. Significance of four-seeded pod trait in soybean yield improvement. *Soybean Research* 9:53-61.
- Singh B B, Gupta S C. and Singh B D. 1974. Sources of field resistance to rust and yellow mosaic diseases of soybean. *Indian Journal of Genetics and Plant Breeding* 34:400-4.
- Singh T N, Aspinall D, Paleg L G and Bergess S F. 1973. Stress metabolism II. Changes in proline concentration in excised plant tissue. Australian Journal of Biological Sciences 26:45-6.
- Sloane, R J, Patterson R P and Carter T E Jr. 1990. Field drought tolerance of a soybean plant introduction Crop Science 30:118-23.
- Specht J E, Hume D J and Kumudini S V. 1999. Soybean yield potential - A genetic and physiological perspective. *Crop Science* 39:1560-70.

Coping up with climate change through rainwater management

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Introduction

Significant changes in physical and biological systems across the globe in response to warming of the climate have been conclusively ascertained. Climate Change in India presents an additional stress on ecological and socio-economic systems which are already under tremendous pressures due to various factors like increasing population, rapid urbanization, industrialization and economic activities. India, naturally, becomes more vulnerable to climate change for its natural resources based economy. There are already evidences of negative impact yield of crops due to increase in temperature, water stress, reduction in number of rainy day and increase in heavy storm events. According to the study conducted by Asian Development Bank (2009), 'Addressing Climate Change in the South Asia', indicates that in South Asia, average yields in 2050 for crops will decline from 2000 levels by about 50 percent for wheat, 17 percent for rice, and about 6 percent for maize because of climate change. As per projections significant reduction in crops yields in the range 4.5 to 9.0 percent will occur due to climate change during 2010- 2039 (http://www.nicra-icar.in).

Agriculture being biggest user of water is likely to suffer most from the diminishing water resources and increasing competition for water from other users. It is anticipated that the total demand for fresh water in the year by 2050 would be 1447 Billion Cubic meter (BCM) as compared to 634 BCM in the year 2000. Per capita availability of utilizable water is going to decrease from 1020 in 2004 to 770 cubic meter/person in 2050. However, large opportunities exist to reduce the pressure on the limited resource by improve water use efficiency in all agricultural production systems. Producing more crops, livestock, fish and forest products per unit of water use holds a key to both food and environmental security. Building up of soil health, rainwater harvesting and water saving techniques are amongst the village level interventions towards climate resilient agriculture as suggested by NICRA, Hyderabad. Pandey et al (2003) while presenting worldwide review clearly stated that over thousands of years, people living in various geographical and climatic regions of the world have evolved diverse, indigenous rainwater harvesting and management regimes as an adaptation to climate change. They reported that Rainwater harvesting has a history of continuous practice for 8000 years in South Asia. Thus the antiquity of rainwater harvesting as an adaptation to climate change in India is deep. Under current financial constraints and ecological problems coupled with big projects, small-scale activities of water resource conservation seem to have an edge over big reservoirs. Rainwater offers advantages in water quality for both irrigation and domestic use. It is naturally soft, contains almost no dissolved mineral or salts, and is free of chemical treatment. Scientific use and management of rainwater, therefore, has become major focus of attention of the Government and scientific community in recent years.

Madhya Pradesh (MP), the second largest states of the Republic of India, is marked by a complex social structure, a predominantly agrarian economy, a difficult and inaccessible terrain, scattered settlements over a vast area, and a large population below poverty line, together pose several formidable problems to service delivery systems. The state is having diversified climate is divided into 11 agro climatic zones. Few states in India have expanded more efforts with more success than MP has done in developing its water resources. However it is well accepted fact that about three- fourth of created potential is actually being utilized in many of irrigation schemes. Even with fullest economic utilization of ultimate irrigation potential it is estimated that only three-fourth of cultivable land can be irrigated. Considering the above facts and climatic adversities the success has, therefore, to come not only through improvement in irrigation water management, but also by converting rainfed agriculture into partially irrigated land with the support of rainwater harvesting and conjunctive use and management of water resources. It is hypothesized that the adversities can be minimized through rainwater harvesting and its management by the way of excess rainwater storage and its delayed use, and eventually more land under double crop, enhancement in partially irrigated areas.

This article discusses climate change projections and associated problems, assessment of RWH potential and technological options and strategies for rainwater harvesting and management as a measure to cope up with the changing climatic scenario in central India.

The climate change-induced problem in MP

MPSPPCC (2012) projected the future climate risks for MP through **i**ncrease in maximum and minimum temperatures, increase in frequency and intensity of heavy precipitation events, change in onset of monsoon, increase in number of high intensity events and increase in number of hot days. Average surface daily maximum temperatures, in the period between 2021 to 2050s is projected to rise by 1.8-2.0 ^{0}C throughout Madhya Pradesh and the daily minimum temperature is projected to rise between 2.0^{o}C to 2.4^{o}C during (the same period).These adversities likely to increase magnitude of evapotranspiration due to rise in temperature and eventually diminishing crops yields.

About 70% of the rural population of Madhya Pradesh is engaged in agriculture and agri-based activities. The sector is highly vulnerable to the vagaries of climate and 60% farmers who work in the sector are small and marginal farmers. Shifting in onset of monsoon; shifting in temporal and spatial distribution pattern of monsoon rain fall, decreasing number of rainy days, and increasing intensity of rainfall during a short period of time likely to create drought in one part of the state, while excess rainfall in other parts of the state. Further, due to associated problems and practices of over exploitation of ground water with low capacity of soil for natural recharge; deterioration and depletion of water resources and minimal conservation and restoration of traditional water bodies; the perennial streams/ rivers have become seasonal. Extreme events like frost, excess rain and high temperatures cause huge losses in productivity. Shifting of the rainfall pattern seems to have affected cropping patterns and short term gains through mono-cropping reduces the crop diversity and adversely affects the soil health in the long term increasing vulnerability of the agriculture sector. Availability of water, extreme events such as hailstorms and storms can damage crops during flowering and fruit bearing stages and rainfall deficit and droughts can significantly impact agriculture production, which is predominantly rain fed. Increase in pests and diseases will also impact crops. Animal husbandry can potentially be impacted through an increase in vector borne diseases, reduced productivity, and impacts of heat and water stress. Fishing will be affected because of increasing temperatures that will affect the suitability of fish species to certain temperatures. A shift in breeding period and growth retardation of inland fish species is predicted. With 31% of area under forest cover, changing climate may affect the composition and distribution of types of forests impacting millions of livelihoods in the state. Drying up of water bodies could induce migration of wild animals, leading to an increase of alien invasive species. The situation of declining health of the population is likely to be aggravated by climate change. Increased heat waves and cold waves will also impact the health of the vulnerable population in the state. There are also climate change-induced problems affecting the major sectors and their performances in supporting national development programmes that need meticulous efforts to address them.

Rainwater harvesting: Adaptation to climate change is closely linked to water and its role in sustainable development. To recognize this reality and to respond accordingly presents development opportunities. Various necessary adaptation measures that deal with climate variability and build upon existing land and water management practices have the potential to create resilience to climate change and to enhance water security and thus directly contribute to development. Adaptation to climate change is urgent and RWHM plays a pivotal role in it, the political world and Govt. have recognized this notion and started many on-farm programmes , viz. NWDPRA, Rajiv Gandhi Mission and Balram tank etc.

The term rainwater harvesting (RWH) is used in different ways and, thus, no universal classification has been adopted (Ngigi, 2003). According to Critchley and Siegert (1991), water harvesting in its broadest sense is defined as the “collection of runoff for its productive use”. Runoff may be harvested from roofs and ground surfaces, as well as from intermittent or ephemeral watercourses. A wide variety of water harvesting techniques for many different applications is known.

Rainwater harvesting and management research has received emphasis across the country during the last three decades with the following objectives:

- Ensure maximum *in situ* rainwater conservation.
- Harvest rainwater for recycling as come-up supplemental irrigation and supporting establishment of tree crops.
- Integrate conservation and production technologies considering watershed as a unit of measurement

Potential for rainwater harvesting

Computation of rainwater harvesting potential (RWH) potential is complex and difficult as so many variables are involved. The rainwater surplus over evaporative demand, however, gives an approximation of RWH potential of a place. The climatic water balance analysis was carried out using 10-day rainfall at different probability level of rainfall (based on incomplete Gamma distribution function) and published records of PET were interpolated to arrive at 10-day values. Cumulative rainwater surplus potential thus estimated at 50 % probability level for some of the locations representing dryland tracts is given in Fig. 1.

Scientific investigations have recently demonstrated high potential of RWH (10-40% of annual rainfall) in dryland tracts of the country (Sastry *et al.* 1985; Rajput,1992; Rajput, 1997; Katyal *et al.*,1998). Studies showed that runoff percentage varied not only with Agro-climatic situations but also with changes in topographic, soil, vegetation and rainfall magnitude, intensity and temporal distribution at particular location.

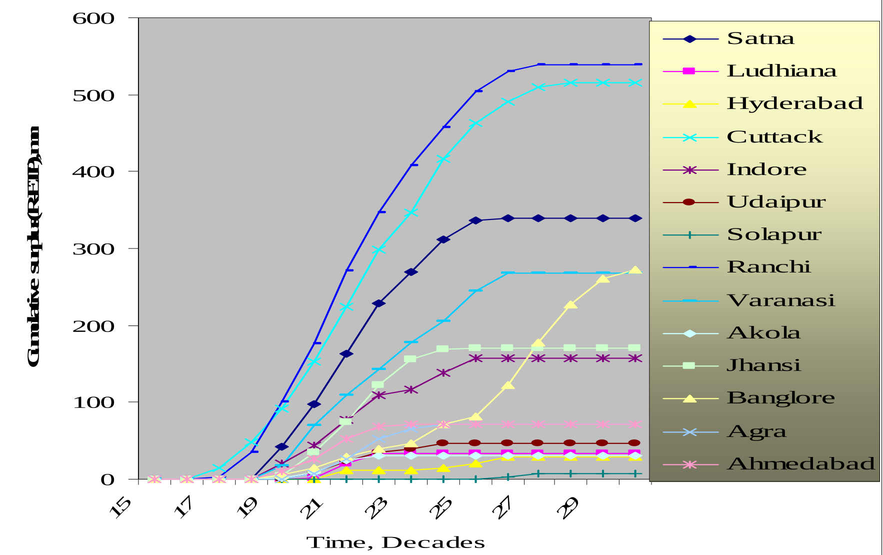

Fig.1 Cumulative rainwater harvesting potential at 50% probability, mm

Probable runoff at 50 % probability assessed for different part of MP are given in Table 1.

Table1: Estimated runoff potential and acreage can be irrigated (ha) once from dugout pond Under different agro-climatic zones of M.P.

Agroclimatic zone	Name of station	Probable runoff, mm	Per cent Area of pond per ha catchment		Area Irrigated once(ha) through pond with 1ha catchment	
			seepage@ 20mm/day	seepage@ 50 mm/day	seepage@ 20mm/day	seepage@ 50 mm/day
Jhabua Hills	Jhabua	60	1.3	1.0	0.53	0.32
	Dhar	98	2.2	1.4	0.91	0.53
Nimar valley	Khargone	82	1.8	1.2	0.74	0.44
	Khandwa	64	1.4	1.0	0.53	0.32
Malwa Plateau	Indore	111	2.5	1.6	1.04	0.63
Gird region	Gwalior	70	2.0	1.1	0.63	0.40
Vindhyan	Bhopal;	196	5.0	2.8	1.90	1.18
	Sagar	196	4.5	2.8	2.09	1.18
Central narmada valley	Powarkheda	212	5.0	3.1	1.04	1.25
Keymore plateau& satpura hills	Jabalpur	231	6.0	3.4	3.37	1.40
	Satna	144	4.0	2.0	1.90	0.85
Satpura plateau	Chhindwara	110	3.00	1.5	2.09	0.63
Chhattisgarh plain	Waraseoni	322	8.0	5.0	2.09	1.90

Note: Pond depth 3m, side slop 1:1, Irrigation depth 7cm(gross), pond catchment area 1.0 ha;

Technological Options

Rainwater harvesting (RWH) is in vogue since time immemorial in arid semi-arid and subhumid and humid climatic regions. Rainwater Cistern, *Khadin, Bhandaras, Anicut, Phad, Haveli, Tankas*, tanks and ponds in many part of India bear proof to this. Kerr and Sanghi (1992) and later Rajput and Singh (2004) presented a comprehensive review on indigenous Technical knowledge (ITK) of rainwater conservation and management. In the past no systematic rules were followed for RWH and deciding the catchment-storage area ratio for RMS. In most situations, in addition to reviving traditional water harvesting systems, there is need to have new or scientifically modified RWHM systems (Rajput et al, 2004.).

Sizes of farm ponds were designed using Krimgold's (1944) formula of water balancing inputs, viz. the catchment rainfall, surface runoff, seepage and evaporation losses, depth of storage, and out flow from the pond. The study showed large variation in runoff potential, pond size and area that can be converted into partially irrigated land using unit catchment area in Madhya Pradesh (Table 1). There are enough evidences to prove that conversion of rainfed areas into partially irrigated through recycling of harvested water resulted in to one additional legume crops and / or 15 to 20 % increase in yield of kharif crops. Depending on the prevailing site conditions the on-farm reservoirs can also be used as night storage reservoirs in the vicinity of canals and as structure for collection of drainage water for recycling or augmentation of supplies.

It is apparent that the technologies and objectives of RWH are highly location specific and sound RWHM system developed for a particular region might not be applied as such to other areas for technical, physiographical, environmental and socio-economic reasons.

Considering the fact that the RWH practices are most effective when implemented on watershed basis and in participatory mode, the Government at National and State level, has promoted number of schemes to promote conservation of this vital resource throughout the country. A number of social activists and voluntary organizations have shown growing interest in local watershed development, either in itself or as part of integrated development of a village or area. Sukhomajri, Tejpura, Nalgaon, Daltonganj, Ralegon Siddhi, Jawaja, Adgaon. Alwar, Chitrakoot, Khandwa, are well known examples and have been widely discussed and written about. Ram Babu *et al.*(1994), based on economic evaluation of various alternatives of soil and water conservation(SWC) programmes in India, concluded that water harvesting and recycling for productive purposes is the most attractive investment SWC option. Except a few success stories, however, the efforts did not prove as fruitful as originally envisaged. The benefits could not be sustained after withdrawal of advisory and financial support services. Hence there is need of reorientation of the current approaches of RWH in the light of indigenous technical knowledge (ITK). It is important to look for complementary opportunities among different types of small scale water storage systems in an integrated manner to improve conservation and productivity of water in the country. Among the alternatives available, combination of storage systems are most likely to produce superior results. However suitable combinations of storage types depend on number of factors, including topography, hydrology, and the existence of suitable aquifers. It has become imperative to wove the traditional knowledge into the modern techniques and; physical system into social system to get the maximum benefits.

Water storage: When objective of runoff water harvesting becomes recycling or prolonged storage it is essential to minimize seepage from the structure. Numerous materials are available for controlling seepage in water harvesting tanks or RMS. However effectiveness and durability of the lining materials still remain questionable. Some of the potential linning materials have been tried with partial success in small water bodies are HDPE film , LDPE film , Cipolin sheet, Cement concrete, Soil cement, soil-cowdung –straw etc.

Recycling: Recycling the harvested water is constrained with limited time of water availability for recycling because of associated seepage and evaporation losses. Best option of recycling of water is through gravity. However, in some of the situations the topographic and land ownership does not permit gravity flow, it becomes imperative to lift the water using manually operated , bullock driven or mechanically operated pumps or devices. Manually operated double diaphragm pump or electrically/ diesel operated centrifugal pump can be used for recycling the harvested water. Water application in the field can be facilitated using gravity methods (border /furrow/ basin) or pressurized irrigation techniques(sprinklers , drip system.) depending on the source, type of soil, field slope, availability of water and resource with farmer. Amongst various methods of supplemental irrigation, irrigating alternate furrow was found to be beneficial and practical technique for recycling of harvested water through dugout ponds, the diffusion of this technology has been quite low due to high initial investments, which are beyond the capacity of most small and marginal farmers.

Further research on controlling evaporative and seepage losses, water lifting devices, sealing materials and cost of dugouts need to be carried out to make the concept feasible and economically viable. Since watershed is an hydrologic unit and water is backbone of agriculture the base for natural resource management should be continued on watershed basis. Though the options reported in this paper are no matter location specific, never the less, those can be utilized as a tool for integrated water resource management in agriculture.

Strategy

The ultimate goal of RWH& M is to enhance water productivity at field level, village level and basin scale through the following:

(a) Improvement in rainwater use efficiency by blending ITK with improved practices

- Crop diversification & management practices
- Intercropping, Relay cropping
- Varietal substitution ,
- In *situ* water conservation & ground water recharging
- Runoff harvesting & recycling

(b)Possible conversion of rainfed areas into partially irrigated area through adoption of RWH&M

- Part of kharif fallow can be converted into double cropping
- Part of rabi fallow can be converted into double cropping
- Part of wasteland can be utilized for horticulture & medicinal plants

(c) Creating data base of natural resources at village/block/watershed level

(d) Promoting conjunctive use of harvested water and ground water

(e) Promoting peoples' participation in reality and public awareness in RWH&M

(f) Policy and political will to support RWH&M

Semi arid regions (western and central M.P.):

- Renovation of old and existing runoff management /storage structures (RMS) should be taken up on priority. Investigations should however be required catchment –storage area relationship under varying site conditions. Indigenous technical knowledge (ITK) should be evaluated and modified on scientific basis.
- Withdrawal of ground water should be within the safe yield of aquifer.
- Wasteland should only be brought under plough with appropriate measures of soil & water conservation .
- Measure for ground water recharge should be adopted

Sub –humid regions (central and eastern M.P.):

- Rainwater should be harvested as small scale water resource development projects. Incorporating conjunctive use of rainwater, surface water and ground water.
- Possibility of tranfering excess runoff deficit areas be investigated.
- ITK on surface storage to be promoted with suitable scientific improvement in perception of the farmers.
- Water yield potential of aquifers should be quantified and maintained to a safe limit of exploitation.

Policy issues

- The State water management and Agriculture policies should be revised in consideration of the following:
- Water resources in watersheds should be managed in totality based on water budgeting. Rainwater shold be conserved for efficient utilization for both, kharif and rabi crops using stored surface as well as ground water.
- Govt. should promote measures of water recharge in dark and gray ground water zones.
- Convergence of services of other sister department should farm part of the rainwater management programmes. All soil and water conservation programmes should be brought under a single agency/ department as being operative in neighbouring States of Maharashtra & Rajasthan.

Concluding remarks

There is huge RWH potential and technological options available for creating water resource through a network of RMS structures. The RWHM technological options are relatively low cost and can be managed with locally available skills. It has become imperative to wove the traditional knowledge into the modern techniques and; physical system into social system to get the maximum benefits and thereby ensuring water security. Holistic approach of integrated watershed development should be continued and a village can form a part of micro-watershed. Research efforts are required to intensify to develop methodologies for location specific designing the RWH network, land and water management practices compatible to the agro-climatic conditions, socio economic conditions and changing climate. Administrative infrastructure and beneficiaries are to be fine tuned to shoulder this responsibility with a changed mindset and accountability of final outcome.

References

- entral Research Institute for Dryland Agriculture, 1997, CRIDA Perspective Plan - Vision-2020.CRIDA (ICAR), Hyderabad, A.P., India, 80 pp.

- as, D.C. 1994. Water harvesting systems in watershed management and their cost effectiveness- Indian case studies. Indian J. Soil Conservation, 22(1-2): 236-250

- atyal, J. C., M. Narayan Reddy, K. Ramchandran and P.K. Mishra, 1998. Proc. National Seminar on " Water Management for Sustainable Agriculture- problem and perspectives for the 21st Century, IARI New Delhi, April 15-17, 1998, 221-234pp.

- err, J. and N. K. Sanghi, 1992.Indigenous soil and water conservation in India's Semi-arid Tropics. Gatekeeper Series No. 34, IIED, London.

- rimgold, D.B. and Honold, L.L. (1944), "Planning Farm Ponds to Ensure Ample Water Supply". Agricultural Engineering. Journal of SAE, 25: 372-374.

- am Babu, B.L. Dhyani and M. C. Agrawal, 1994. Economic evaluation of soil and water conservation programmes in India. Indian J. Soil Conservation, 22(1-2): 279-289.

- ajput, G.S. 1992. Water conservation in agriculture. Proc. Workshop on water conservation and Public Awareness, NIH, Roorkee, Sept.25-26, 1992.

- ajput, G.S. 1997. Rainwater harvesting potential and technology for Semi-arid regions. Abstract, Proc. International Conference on Rainwater Cistern, Tehran Iran.

- ajput, G.S. and A. Singh, 2004. *Madhya Pradesh mai versa Jal & bhumi Sanrakshan ki Desi Bidhiyan* (Hindi), JNKVV Tech.Bull.No.DRS/2004/15.

- ajput, G.S.,A. Singh, P. Shrivastava, M.L. Kewat,and S.K.Sharma, 2004. Indigenous haveli system of participatory rainwater management, JNKVV Tech.Bull.No.DRS/2004/10

- astry, G.; U.S. Patnaik and and V.V.D.Narayana 1985. Conservation engineering measures in watershed development project: problems and prospects. Proc. National Seminar, Soil Conservation and Watershed Management, ICAR, New Delhi, Sept. 17-18, 1985, 213-225pp.

- harma, S. and P.K. Mishra, 1995. Watershed Management in Dryland areas - Principles and Practices . In : Sustainable Development of Dryland Agriculture in India. (Singh, R.P., ed.) Jodhpur ,India: Scientific Publishers, 497-510 pp.

- harma, S. and P.K. Mishra, 1999. Watershed-based conservation technology in dry lands. *In* Fifty Years of Dry land Agricultural Research in India. H.P. Singh,Y.S. Ramakrishna, K.L. Sharma and B. Venkateswarlu(eds.), CRIDA Hyderabad, 281-289pp.

- ingh, A. and A.K. Bhattacharya, 1998. Watershed based water management-an emerging concept towards sustainable development. . Proc. National Seminar on " Water Management for Sustainable Agriculture-problem and perspectives for the 21st Century, IARI New Delhi, April 15-17, 1998, 486-491pp.

- ingh R. P. and Rao, B.V.R. (1988) Agricultural Drought Management in India- principles and Practices, CRIDA Hyderabad, India. Tech. Bull. 1., 45pp.

- ejwani, K.G.,1994. Soil and water conservation research in India -A historical and futuristic

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perspective. Indian J. Soil Conservation, 22(1-2):1-14.

The living soil: Importance of nematodes

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The creatures living within the soil are critical to soil health. They involved in soil structure and as a result soil erosion and water availability. They be capable of protect crops from pests and diseases. They are central to putrefaction and nutrient cycling and therefore influence plant growth and amount of pollutants in the atmosphere. Finally, the soil is home to a large proportion of the world's genetic diversity.

Soil health is an appraisal of how well soil performs all of its functions currently and how those functions are being preserved for future use. Soil health cannot be resolute by measuring only crop yield, water quality, or any other single outcome. Soil health cannot be measured honestly, thus appraise indicators.

Soil commotion is able to the result of physical, chemical or biological activities. Physical soil disturbance, such as tillage, results in bare and/or compacted soil that is destructive and disruptive to soil microbes, and it creates a hostile environment for them to survive. Misapplication of farm inputs can disrupt the symbiotic relationships between fungi, other microorganisms, and plant roots. Overgrazing, a form of biological disturbance, reduces root mass, increases runoff, and increases soil temperature. All forms of soil disturbance diminish habitat for soil microbes and result in a diminished soil food web.

Soil fertility is an input determinant of the accomplishment of a farming system. Management systems that rely on organic inputs as sources of fertilizer have different dynamics of soil nutrient accessibility than systems receiving mineral sources. Though biological processes control the availability of many soil nutrients, interest in the soil biological community has been ignored because high levels of mineral fertilizer surpass or inhibit biological activities. Heavy applications of pesticides also may alter the soil community and decline rates of certain key processes, for example N mineralization.

A perceptive of soil biology is predominantly important in cover crop systems where one relies on below-ground biota to liberate plant nutrients. Cover crops provide organic forms of C and N which are hastily metabolized to inorganic nitrogen and other nutrients, primarily by bacteria and fungi. N is also mineralized as

predators of bacteria and fungi, such as protozoa and microorganism eating nematodes, graze on preys which contain more N than required by the predators. Although more research attention is given to the plant parasitic nematodes, microbivorous organisms make up a large portion of the nematode community.

Excess N generated by grazing is released to the soil and becomes available for plant uptake. Four of every five multicellular animals on the planet are nematodes. Numerous species are well known as significant and devastating parasites of humans, domestic animals and plants. On the other hand, most species are not pests; they occupy several niches that provide an available resource of organic carbon in marine, freshwater and terrestrial environments. Nematodes are a quantitatively significant component of the soil microfauna: the number of individuals per m2 is measured in millions. They belong to the trophic level of the consumers, but they influence the processes of degradation and mineralization of organic matter, mostly due to the trophic relations which they establish with fungi and bacteria. Nematodes vary in sensitivity to pollutants and environmental disturbance. The species that feed on fungi are represented by nematodes which are furnished with a buccal stylet and, in meticulous, by Tylenchida.

Their role in the decomposition process of litter is essentially that of rendering the nutrients contained in fungi accessible to other organisms such as bacteria. In some cases they disseminate the spores of fungi. The nematode species that feed on bacteria have no buccal stylet. Their role consists in maintaining the demographic equilibrium in the bacterial population and in favouring the spreading and the proliferation of certain species. Nematodes constitute a small fraction in terms of biomass and respiration as compared to the total mass of soil organisms but their action appears significant when compared with that of other animals. Their mechanical action has no effect, yet it has been shown that they play a remarkable role in the production of CO2 in the soil and therefore in the decomposition of organic matter, doubtless due to their relation with fungi and bacteria.

Indirectly, nematodes can disseminate microbial propagules throughout the soil, which advances the colonization of substrates and mineralization of nutrients. Nematode metabolites may also stimulate specific bacterial growth by releasing growth-limiting nutrients (such as N and vitamins).Non-segmented worms typically 50 µm in diameter and 1 mm in length microscopic organisms have a great importance in soil health. However, few of them are also responsible for plant diseases have received a lot of attention, but far less is known about the majority of the nematode community that plays beneficial roles in soil. Incredible types of nematodes function at several trophic levels of the soil food web. Some of them feed on the plants and algae (first trophic level); others are grazers that feed on bacteria and fungi (second trophic level); and some feed on other nematodes (higher trophic levels).

Bacterial-feeding nematodes have a higher carbon :nitrogen (C:N) ratio (± 5.9) than their substrate (± 4.1), so that in consuming bacteria they take in more N than necessary for their body structure. The excess nitrogen is excreted as ammonia Bacterial-feeding nematode community in the top 15 cm of a field soil mineralized N at rates increasing to 1.01 µg-N g-soil-1 d-1 in the rhizosphere, the rate of N mineralization by bacterial-feeding nematode species of different body size ranged between 0.0012 and 0.0058 m g-N nematode-1 d-1, mainly as NH4+ The excess nitrogen is excreted as ammonia/ammonium, urea, peptides and amino acids (Thompson & Geary 2002). The assimilation of bacterial feeding nematodes is between 30-60 % of the consumption (Sohlenius, 1979), and it is estimated that the nematode grassing of bacteria would mobilise19-124 kg N ha-1yr-1 (Anderson et al. 1981) for uptake by plants and by microbes. In the presence of a suitable carbon source bacteria may out-compete plant roots for N, resulting in a microbiological immobilisation of N on the surface of growing root tips. By grassing on rhizoplane bacteria, nematodes may liberate N of bacterial cells and again make it available to plant roots.

Fungal-feeding nematodes have a C: N ratio closer to that of their food source. However, for nematodes of both feeding habits the grazing activity stimulates the growth and metabolic activity of the microflora (Trofymow & Coleman, 1982, Griffiths, 1994). The amount of N as NH_4^+ released from microcosms in which barley straw was colonized by the fungus *Rhizoctonia* sp. was always greater in the presence of the fungal-feeding nematode *Aphelenchus avenae*. Predatory nematodes contribute to nitrogen mineralization by feeding on other nematodes. Under field conditions bacterial feeding nematodes and predatory nematodes are estimated to contribute to 8% and19% of the nitrogen mineralization in conventional and integrated farming systems respectively (Beare, 1977). Nematodes respond rapidly to changes in their environment. Increased microbial activity first leads to an increased proportion of opportunistic bacterial feeders, which later are followed by general opportunists, which include fungal feeders and slower growing species of bacterial feeders (Bongers & Ferris, 1999). This succession is important for the decomposition of soil organic matter and mineralization of plant nutrients (Ingham et al. 1985, Hunt et al. 1987). The faunal composition may mirror the activity of decomposition pathways and give indications of nutrient status and fertility of soil (Bongers & Ferris, 1999).

Free-living nematodes are further divided into following broad groups based on their feeding behaviors.

1. Bacterial-feeders consume bacteria. *Eucephalobus*, *Acrobeles*, *Panagrolaimus*, *Rhabditis*, *Chronogaster*,*Monhystera*, *Plectus and Panagrolaimus* and *Cephalobusi* are the predominant bacterial feeders. As bacterivorous nematodes play important role in mineralization of soil (Wasilewska,1998), their abundance had a significant effect on productivity of soils. Enhanced carbon in form of CO2 can indirectly affect soil organisms through shifts in the quantity and qualityof plant litter returned to soil, the rate of root turnover, and the exudation of carbon and other nutrients into the rhizosphere.
2. Fungal-feeders puncture fungal cell wall and feed by sucking out the internal contents.
3. Predatory nematodes eat all types of nematodes and protozoa besides smaller organisms whole, or attach themselves to the cuticle of larger nematodes, scraping away until the prey's internal body parts extracted. The ecological roles of soil invertebrates include plant herbivory and the mineralization of nutrients in the detrital food web, both of which may be affected by change in carbon-flow patterns and, in turn have important impacts on ecosystems behaviour (Neher et al., 2004).
4. Omnivores eat a variety of microorganisms or may have a different diet at each life stage.

Root-feeders are plant parasites, and thus are not free-living in the soil. Out of the 20 000 nematodes described today some 4000 species are parasites of plants. The major characteristic of plant parasitic nematodes is the presence of a mouth spear (stylet),which is used to puncture plant cell walls, and inject nematode secretion, which changes plant physiology and facilitates food up-take by the nematode. Some species feed only on the outer tissue of the root (ectoparasites), others penetrate more deeply (migratory endoparasites), and some completely enter the host inducing the formation of a permanent feeding site (sedentary endoparasites)

What nematodes do in soil?

A. Nutrient cycling. Protozoa and nematodes are important in mineralizing, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium (NH4+) is released because bacteria and fungi contain much more nitrogen than the nematodes require.

B. Grazing. At low nematode population, feeding by nematodes seems to stimulates the growth rate of prey populations like bacterial-feeders stimulate bacterial growth, plant-feeders stimulate plant growth, and so on. However, by higher densities, nematodes will reduce the population of their prey resulting decreased plant productivity, might negatively impact mycorrhizal fungi, and able to reduce decomposition process furthermore immobilization rates by bacteria and fungi. Predatory nematodes possibly regulate populations of bacterial-and fungal-feeding nematodes, in consequence preventing over-grazing by those groups. Nematodes grazing possibly control the balance between bacteria and fungi, and the species composition of the microbial community.

C. Dispersal of microbes. Nematodes facilitate distribution of bacteria and fungi through the soil and along roots by carrying live and dormant microbes on their surfaces and in their digestive systems.

D. Food source. Nematodes are food usually intended for higher level predators, together with predatory nematodes, soil microarthropods, and soil insects. They are also parasitized with bacteria and fungi.

E. Disease suppression and development. Some nematodes effect disease. Others consume disease-causing organisms, such as root-feeding nematodes, or prevent their contact to roots. These may perhaps be potential biocontrol agents.

Where the nematodes concentrate?

Nematodes are concentrated in close proximity near their prey groups. Bacterial-feeders are plentiful near roots where bacteria gather together; fungal-feeders are near fungal biomass; root-feeders are concentrated in the region of roots of stressed or vulnerable plants. Predatory nematodes are additional to be profuse populations in soils with high numbers of nematodes.

Since of their size, nematodes be likely to be more common in coarser-textured soils. Nematodes move in water films in large (>50 µm) pore spaces.

Several characteristics of soil nematodes make them good candidates for bioindicators of the status and processes of an ecosystem. Nematodes possess the most important attributes of any prospective bioindicator environments, diversity of life strategies and feeding Habits short life cycles, and relatively well-de®ned sampling procedures. For these reasons, several researchers have attempted to develop relationships between nematode community structure and succession of natural ecosystems or environmental disturbance Conventional farming systems have been associated with many environmental ills. Common problems such as loss of soil fertility, soil erosion, reduction of soil biodiversity, and ground water pollution. may become crucial issues affecting production of sufficient amounts of food. A key to success of sustainable agriculture will be conservation of natural resources and higher dependence on natural ecosystem processes.

Agricultural soils usually support less than 100 nematodes in each teaspoon (dry gram) of soil. Grasslands may hold 50 to 500 nematodes, and forest soils in general embrace several hundred per teaspoon. The proportion of bacterial-feeding and fungal-feeding nematodes be related to the amount of bacteria and fungi in the soil. Universally, less disturbed soils contain more predatory nematodes, suggesting that predatory nematodes are highly sensitive to a wide range of disturbances. Recent development of indices that integrate the responses of different taxa and trophic groups to perturbation provides a powerful basis for analysis of faunal assemblages in soil as *in situ* environmental assessment systems. Application of nematode faunal composition analysis provides information on succession and changes in decomposition pathways in the soil food-web, nutrient status and soil fertility, acidity, and the effects of soil contaminants.

Nitrogen mineralization by *Aphelenchus avenae* and *Aphelenchoides composticola* feeding on *Rhizoctonia solani* and *Trichoderma* sp. Leachate more ammonium and nitrate concentrations. Average N-mineralized nematode^{-1} d^{-1} was 1.8 ng for *A. avenae* and 3.3 ng for *A. composticola* when feeding on *R. solani*. As the C-to-N ratios of organic substrates increased, total mineral N decreased with *R. solani* alone, but in general remained the same in the presence of nematodes. Initial and average nematode population densities were significantly higher in columns containing *R. solani* than in those with *Trichoderma* sp. Both nematode species reduced the fungal fatty acid 18:2 ω6c in *Trichoderma* columns on d 21. The fatty acid 18:2 ω6c was lower in columns containing both *R. solani* and *A. composticola* on d 0 and 7 and higher on d 14 and 21 than those in the absence of nematodes (Chen and Ferris,1999). In nematode communities the use of functional groups is inadequate for biodiversity studies. The four nematode species used in this study belong to the same functional group, but are clearly not functionally redundant since they all have a different influence on the cordgrass decomposition. This suggests that the relationship between nematode species diversity and ecosystem functioning may be idiosyncratic (De Mesel et al..2003).

Nematodes and water quality

Nematodes might be useful indicators of soil quality because of their incredible diversity and their participation in many functions at different levels of the soil food web. Several researchers have proposed approaches to assessing the status of soil quality by counting the number of nematodes in different families or trophic groups. In addition to their diversity, nematodes possibly will be useful indicators because their populations are relatively stable in response to changes in moisture and temperature (in contrast to bacteria), yet nematode populations respond to land management changes in predictable ways. Because they are quite small and live in water films, changes in nematode populations reflect changes in soil microenvironments.

1. Characterize nematode communities (taxonomic and ecological index description) in soils exposed to different agricultural management practices (under same physico-chemical soil properties, vegetation cover, and climatic conditions);
2. Evaluate whether soil ecosystem differences imposed by farming tactics can be reflected by nematode characterization (key taxa or indices)
3. Determine which measures of ecological characterization are the most useful in differentiating various agricultural regimes
4. Determine which of the ecological measures most adequately illustrate conditions of the soil environment exposed to different farming practices.

Enhancing water productivity - A compulsion in changing climate scenario

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Introduction

To feed a growing and wealthier population with more diversified diets will require more water for agriculture on an average annual basis. Evapotranspiration from agricultural land is estimated at 7,130 cubic kilometers and without increase in water productivity it could increase by 60%–90% by 2050. Agricultural water withdrawals from natural systems are estimated at 2,664 cubic kilometers, or about 70% of water withdrawn for human purposes. Additional water for agriculture will strain terrestrial and aquatic ecosystems and intensify competition for water resources. Improving physical water productivity in agriculture reduces the need for additional water and land in irrigated and rainfed systems and is thus a critical response to increasing water scarcity, including the need to leave enough water to sustain ecosystems and to meet the growing demands of cities and industries.

Water productivity is defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. In its broadest sense it reflects the objectives of producing more food, income, livelihoods, and ecological benefits at less social and environmental cost per unit of water used, where water use means either water delivered to a use or depleted by a use. But simply, it means growing more food or gaining more benefits with less water.

Increasing the productivity of Water

As can be seen above the productivity of water in India is quite low and causes concerns. There are many areas which need to be addressed for improving the productivity of water in the State. Thrust areas could be (I) Improving the institutional landscape, (II) ensuring the efficient delivery system, and (lll) following the management techniques.

The use of water is 80% for agriculture purposes and if efforts are made to reduce the water consumption in agriculture without jeopardizing the production area lot of water could be saved without reducing the total produce.

For example technological up gradation i.e. deficit, sprinkler and drip irrigation if adopted will save nearly 30-40% of water use. This in turn will increase our surplus water account and can be used elsewhere. Similarly the present supply management is based on resources available rather than being demand based.

By modernization of existing irrigation canal/conveyance system huge volume of water which otherwise is wastage could be saved and surplus water account is increased. Control structures in majority of distribution system are missing and if provided will lead to lot of water saving. Public awareness is one of the most effective tools which will demonstrate the remarkable improvement in the productivity of water. Similarly the provisions made in the state water policy regarding the water tariff provided in section 10 if adopted will indirectly also contribute in increasing the productivity.

The provision says that water rates should be such which conveys the beneficiary the scares value of water, 'its importance and motivates them for the economical use of water. Water rates necessarily shall be such that the project shall be self-supported. For the use of water for private purposes, rates shall be determined in such a manner so that the water can be used strictly in accordance to the prescribed priorities laid down in the policy. Due to the importance of the forest for protection of environment, concessional rates of water shall be fixed for forestation.

The method of cultivation, use of modem techniques, and use of less water requirement crops, intensification and diversification of crops are the effective tools for increasing the productivity. One of the field-level methods for increasing water productivity is deficit irrigation, where deliberately less water is applied than that required meeting the full crop water demand. For deficit irrigation to be successful, farmers need to know the deficit that can be allowed at each of the growth stages and the level of water stress that already exists in the root-zone. Most importantly, they need to have control over the timing and amount of irrigations.

For increasing the productivity of water the thrust areas and action agenda could be as below:-

Sr. No.	Thrust Area	Action Agenda
1	Institutiona l	To establish Rational Allocation Mechanism of water
		(Establishment of SWaRA, SWaRDAC)
		Improvement in the coordination of the line departments
		(Establishment of Empowered Committee etc.)
		Rationalization of water tariff. (Establishment of SWaTReC etc)
		Enforcing the revenue recovery mechanism.
		(Privatization of the activity)
		Extension Services.
		(Agriculture, Fisheries & Veterinary Horticulture etc.)
2	Efficient	Asset management (Creation of proper deli very System
	Delivery	including effective and planned control structures etc)
	System	Regular and Proper up-keep of the Canal System. (Systematic
		and effective maintenance activities to be carried out as per
		schedule)
		Adoption of Barabandi System. (Even by taking help of the law
		enforcing Agencies to stalt with)
		Leakage detection and preventive mechanism.
		(In Close Conduits viz. Domestic Water Supplies etc)
3	Manageme nt	Sustainable ground water development
	Techniques	Water conservation at household level
		Increasing the productivity of the fish.
		Creating awareness in the masses.
		Effective Drainage
		Re-cycling and reuse of water
		Adoption of new technology. Deficit, Sprinkler & Drip
		Irrigation etc.

Concepts of Water Productivity

Initially, irrigation efficiency or water use efficiency was used to describe the performance of irrigation systems. In agronomic terms, ‘water use efficiency’ is defined as the amount of organic matter produced by a plant divided by the amount of water used by the plant in producing it (De Wit, 1958). However, the used terminology ‘water use efficiency’ does not follow the classical concept of ‘efficiency’, which uses the same units for input and output. Therefore, International Water Management Institute (IWMI) has proposed a change of the nomenclature from ‘water use efficiency’ to water productivity’. The water productivity per unit of gross inflow (WPG) is the crop production divided by the rain plus irrigation flow.

Factors affecting Water Productivity/ Water Use Efficiency

Genetic factors

Crop growth and yield is a result of interaction between their genetic constitution and environmental conditions in which they grow. Plant species therefore differ widely in their productivity i.e., crop yield and water use i.e., ET. Water use efficiency of C4 plant species such as maize, sorghum, sugarcane, pearl millet, finger miller etc is higher (3.14 to 3.44 mg dry weight/g of water) when compared to C3 species (1.49 to 1.59 mg dry weight/g of water) such as pulses, oilseed crops, wheat, barley, oats etc.

Crop varieties also differ in WUE. High yielding varieties, hybrids, GM crops etc due to their dwarf plant type, responsive to water & fertilizer, pest & disease resistance and high harvest index exhibit higher WUE as compared to traditional varieties characterized by rank vegetative growth, low harvest index, susceptible to lodging, pests & diseases.

Climatic factors

Weather affects both crop yield and crop evapotranspiration. The amount of solar radiation determines the rate of photosynthesis and hence the potential yield. Other components of climate viz., temperature, day length, rainfall etc influence vital physiological processes and thereby determine the actual harvested yield. The lower the relative humidity is, the greater will be the ETc. Therefore, low relative humidity in the atmosphere increases transpiration without any corresponding increase in dry matter production and will reduce WUE. Light and temperature that normally affect both transpiration and dry matter production will either increase or decrease WUE according to which of the two predominates. High wind velocity increase ETc without any concurrent increase in dry matter production hence decrease WUE.

Crop management factors

a) Time of sowing: Timely sowing ensures optimal temperatures, soil moisture availability and other soil physical conditions favouring optimal crop growth and development with greater ability to compete with prevalent weed flora, hence increases WUE.

b) Depth of sowing: Optimal depth of sowing affects seedling emergence, vigour and finally crop yield, hence improves WUE.

c) Direction of sowing: North south row orientation of crop rows influences the interception and utilization of incident solar radiation which in turn influences crop yield and improves WUE as compared to east west direction of row pattern.

d) Plant population: Optimal plant population promotes uniform & rapid development of crop canopy without any competition for growth resources viz., light, nutrients, water, CO_2 etc hence improves WUE.

e) Fertilization: Fertilization of crops suffering from low nutrition under adequate soil water availability increases crop yield considerably, with a relatively small increase in crop evapotranspiration, therefore, markedly improves WUE.

f) Insect pests & diseases: Insect pests and diseases reduce crop yield as well as WUE to varying degrees depending upon the intensity of infestation, because ETc or water requirement of crop will not change to a significant level except in cases where premature death of plants occurs.

g) Irrigation method: Field water use efficiency in general is higher with over head sprinkler, microsprinkler and drip methods of irrigation as compared to surface irrigation methods viz., furrow, border strip, check basin etc owing to higher crop yield and lower seasonal water application.

h) ET control measures: Use of mulches, anti-transpirants, shelterbelts and elimination of weeds etc reduce water losses from cropped field in terms of soil evaporation and transpiration without any reduction in crop yield, hence markedly improve WUE.

Challenges

Availability of water is limited and almost fixed but perpetual increase in its demand coupled with spatial and temporal variation in water resources endowments is resulting in mismatch between utilizable water resources and demand in many regions of the country and the gap is widening. Stiff competition from other sectors especially industrial sector which is able to pay more for water has reduced water availability for agriculture sector but this may have serious repercussions on food availability unless addressed. Though bringing more area under irrigated agriculture is crucial to improve food security, the present increase in yield of irrigated areas is not sufficient to fully meet the projected demand of about 450 million tones food grains by 2050. Challenge is therefore to achieve higher food grain production with reduced availability of water.

At present, WP of India is stubbornly low in comparison with other major food grain producing countries in the world (Molden et al. 1998, Rosegrant et al. 2002, Cai and Rosegrant 2003). In 2000, WP of food grains in India was only 0.48 kg/m3 of consumptive water use (CWU). This was primarily due to low growth in yields. India's food grain yield was 1.7 tons/ha in 2000, which has increased only 1.0 tons/ha during 1960-2000 (FAO 2005). Meanwhile, China with a similar level of yield (and soil-climate conditions) in 1960 (0.9 tons/ha) has increased to about 4.0 tons/ha by 2000. Also, India produces less grain in more cropped area (205 million mt in 124 million ha), while China has much larger production and with less water from a significantly smaller crop area. Indeed India has a significant scope for raising the levels WP by increasing its crop yield alone. Better water management can create additional increase in WP in many regions. Regional estimates show a significant spatial variation in WP across states and districts in India. Variations of water productivity among Indian states: WP varies from 1.01 kg/m3 in Punjab (the highest) to 0.21 kg/m3 in Orissa (the lowest) among states (Table.1).

Low share of irrigation to total CWU in Uttar Pradesh means that effective rainfall contributes to a significant part of CWU. In fact, substantial variation in WP also exists within Uttar Pradesh. For example, water productivity in 53 districts in Uttar Pradesh varies between 0.40 to 1.02 kg/m3. Western region with 20 districts has 34% of the grain area, contributing to 40% of the total food grain production. Average WP in western region is 0.75 kg/m3. Eastern and Bundelkhand regions with 23 districts have 48% of the area under food grains, contributing to 42% of the total food grain production. Average water productivity in these two regions is only 0.54 kg/m3. A key difference between the western and eastern and Bundelkhand region is the irrigated area, where 82% of the area is irrigated in western region compared to 54% in the eastern and Bundelkhand regions.

Table 1: Water productivity of grains across states covering IGB parts of India

Sr. No.	State	Total (Irrigated+Rainfed)						
		CWU	NET	Area	Production	Yield	CWU	WP
	Unit	km^3	km^3	M ha	M Mt	ton/ha	mm	$kg\ m^3$
	India	424	154	123	205.4	1.66	344	0.48
1.	Uttar Pradesh	71.4	34.4	20.3	43.4	2.13	351	0.61
2.	Madhya Pradesh	31.3	14.3	11.2	11.1	0.99	278	0.36
3.	West Bengal	29.5	4.5	6.6	15.2	2.31	447	0.52
4.	Bihar	26.3	8.7	7.1	12.1	1.71	373	0.46
5.	Rajasthan	25.7	13.4	11.7	11.7	1.00	220	0.46
6.	Punjab	25.4	18.9	6.3	25.5	4.07	404	1.01
7.	Haryana	15.6	11.2	4.3	13.4	3.13	363	0.86
8.	Uttaranchal	3.0	0.7	1.0	1.7	1.75	298	0.59
9.	Jammu &Kashmir	2.4	1.0	0.9	1.2	1.38	271	0.51
10.	Himachal Pradesh	2.0	0.2	0.8	1.5	1.78	245	0.73

Bihar, also in the IGB, with 82% of the area under wheat and rice, however has lower WP and share 6.2% of CWU and 5.9% of the food grain production in India. Irrigation contributes to 60% of the area and 33% of the CWU in Bihar. Although a major part of grain area is irrigated, effective rainfall meets much of the CWU in Bihar at present. Irrigated areas contribute to 65% of total CWU in Bihar, but irrigation contributes to only 51% of CWU in irrigated areas.

The mean WP for rice over actual evapo-transpiration is 0.618 kg/m^3, which is at the lower end given by Zwart and Bastiaanssen (2004) from a review of 84 studies. Low WP values are primarily due to low rice yield. The average yield in 2005 is only 1.94 ton/ha whiles the ET over rice growth season remains 335 mm. The four major countries India, Pakistan, Bangladesh and Nepal showed similar levels of rice WP. At the country level, Nepal takes the lead with average of 0.701 kg/m^3 while India has the lowest of 0.603 kg/m^3.

Table 2: Applied water productivity in wheat in three river basin locations in India

Name of the basin	Name of the region	Name of the district	Agronomic Efficiency (Kg/m^3)		Net Economic Efficiency (Rs/m^3)	
			Average	Range	Average	Range
Narmada Basin	Central Narmada Valley	Hoshangabad	0.91	0.43 – 1.60	2.31	0.034 – 7.48
		Jabalpur	0.47	0.23 – 0.88	1.06	0.022 – 4.66
		Narsingpur	0.53	0.26 – 0.75	1.11	0.006 – 3.52
	Jhabua Hills	Jhabua	0.60	0.38 – 0.88	1.20	0.05 – 11.58
	Satpura Plateau	Betul	0.84	0.52 – 2.06	2.61	0.10 – 10.21
	Malwal Plateau	Dhar	1.05	0.64 – 1.80	2.04	0.072 – 6.67
	Nimar Plain	West Nimar	0.83	0.52 – 1.62	1.99	0.012 – 7.60
	Northern Hill Region of Chhattisgarh	Mandla	1.80	0.98 – 2.95	4.09	0.21 – 10.79
	Vindhya Plateau	Raisen	1.01	0.61 – 1.58	2.27	0.25 – 7.67
Indus Basin	South-Western Punjab	Batinda	2.33	1.29 – 4.27	5.93	1.25 – 13.35
Ganges Basin	Eastern Uttar Pradesh	Varanasi	2.61	1.65 – 4.98	10.80	5.02 – 24.51
Sabarmati	North Gujarat, Western India	Sabarkantha (Bayad)	2.75		8.9	
		Sabarkantha (H'nagar)	0.80		2.3	
		Ahmedabad	0.71		1.1	
		Kheda	1.71		4.88	

Table 3: Applied water productivity in paddy in 3 selected river basins in India

Name of the basin	Name of the region	Name of the district	Agronomic Efficiency (Kg/m^3)		Net Economic Efficiency (Rs/m^3)	
			Average	Range	Average	Range
Narmada	Central	Jabalpur	1.62	0.85 –	3.95	0.05 –
	Narmada Valley			2.57		10.28
	Northern Hill Region of Chhattisgarh	Mandla	2.13	1.20 – 4.00	1.43	0.43 – 7.74
Indus	Punjab		3.69	3.17 - 4.36	10.57	4.47 – 24.94
Ganga	UP	Varanasi	2.54	1.21 – 3.96	4.90	0.94 – 11.89
Sabarmati	North Gujarat, Western India	Sabarkantha	0.42		0.91	
		Ahmedabad	1.06		3.34	
		Kheda	0.92		2.98	

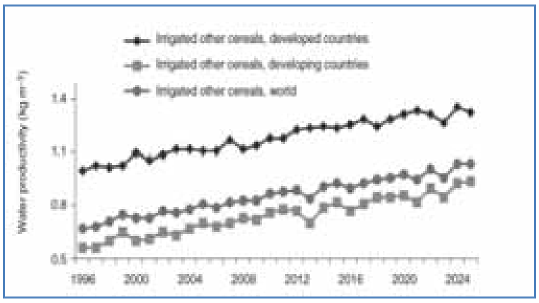

Fig 1: Water productivity of irrigated other cereals.

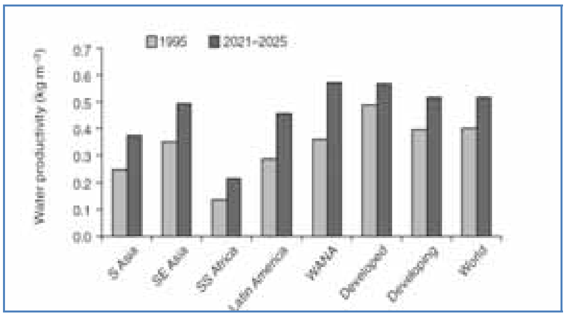

Fig .2 Water productivity of rice in several regions in 1995 and 2021–2025

Possibility of improvement in water productivity

Water productivity may be improved either by reducing the water losses that occur in various ways during water conveyance and irrigation practices or increasing the economic produce of the crop through efficient water management techniques. Principle factors that are influencing water losses and water productivity of a command area are the design and nature of construction of the water conveyance system, management of soil, extent of land preparation and grading, design of the field, choice of irrigation methods and skill of irrigators. Thus factors responsible for enhancing water productivity may be listed as

- Technological innovation
- Better governance and management
- Deficit irrigation strategies
- Decrease soil evaporation
- Irrigation scheduling
- Reduce runoff (and percolation)

- Consider all the inputs (i.e. water table)
- Water reuse
- Cropping system improvement
- Trade and consumer's responsibility

Plant/crop level

Identification of traits and genes using conventional and molecular breeding techniques that have specific characters to improve the water productivity at individual plant level viz. (Bennett, 2003).

Nutritional water productivity

The nutritional productivity of water is calculated/estimated in terms of protein, energy, minerals and vitamins output per unit volume of water (Ali, 2011). Nutritional water productivity (NWP) is expressed in nutritional units/m^3 (protein, energy, minerals, etc.).

$$NWP = Y_a \cdot N_p / ET_a \quad \ldots.(1)$$

where,
Y_a = harvest yield, kg/ha,
N_p = nutritional content of the product, nutrition unit/kg, and
ET_a = evapotranspiration, m^3 of water/ha.
The NWP of some of the common food commodities is presented in Table-4.

Table 4: Nutrient content and nutritional water productivity of some food commodities

Food commodity	Water input for 1 kg of product	Productivity	Nutritional Water Productivity			
			Energy	Protein	Fat	Calcium
Units	**Kg**	**kg/m^3**	**kcal/m^3**	**g/m^3**	**g/m^3**	**Mg/m^3**
Wheat	1159	0.863	2279	74	9	279
Rice	1408	0.710	1989	49	5	132
Maize	710	1.408	3856	77	17	63
Potato	105	9.524	5626	150	9	543
Pulses	2860	0.350	1188	76	4	473
Groundnut	2547	0.393	2382	111	206	296
Soybean	3070	0.325	1400	130	62	780
Tomato	130	7.692	1416	65	11	200
Onion	147	6.802	2259	85	0	1673
Banana	499	2.004	432	11	0	29
Lemon	344	2.907	504	0	0	423
Beef	13500	0.074	102	10	7	3
Pork	4600	0.217	408	21	35	7
Poultry	4100	0.244	330	33	21	14
Egg	2700	0.370	519	41	36	166
Milk	790	1.266	659	40	38	1233
Butter	18000	0.056	404	1	45	11

It is seen from Table-4 that most of the animal products have very low NWP values. Maize, potato, soybean and tomato have the highest NWP values. Therefore, the food habits have to change so that human beings consume more food commodities with high NWP. Accordingly, cropping patterns also should change to make the crops with high NWP values available at low cost.
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Adaptive research trials conducted by MPWSRP at JNKVV Jabalpur on crops and vegetables shown that

- The productivity of soybean was enhanced by adopting improved practices. There was an increase of 51.8% yield over the farmer's practices with ridge & furrow method. (Variety JS 97-52)
- The water productivity of rice which enhance by farmer practices replaced with MR 219 variety and improved technology practices. The WUE was 0.70 Kg/m^3 in farmers practices goes up to 9.47% kg/m^3
- The productivity of wheat was an increase of 38.40 % yield over the farmer's practices with improved proved technology and irrigation technology. (Variety JS 366)
- The productivity of wheat was an increase of 38.40 % yield over the farmer's practices with improved production technology and irrigation technology. (Variety JS 366)
- Yield of tomato is 72.62 % increased by scientific package & practices and hybrid variety over farmer practices.

Carbon sequestration: potential to mitigate climate change

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Preamble

Global climate remained in its pristine purity and congeniality till man stayed in the hunting and food gathering stage. But, as he entered the social and pastoral age and domesticated animals, he gradually passed from the nomadic stage to settled cultivation. When, he cleared the first patch of earth and upturned the first sod and lifted the first bucket of water, the long story of his interference with climate started. Clearing trees for farming, disturbing the moisture regimes and furrowing the land endangered the phenomenon of erosion leading on to the environmental problems such as depletion of biodiversity, global warming, land degradation, shrinking of forest, fuel/fodder shortage, nutritional insecurity and environmental pollution. Today, the significant global environmental challenges are sustainable management and use of natural resources, sustainable production and consumption, a better environment for human health and well-being, biodiversity conservation and global climate change with Particular reference to increase in CO_2 concentration.

As reported by IPCC by the year 2100, CO_2 concentration may be doubled (700 ppm), the temperatures may rise by 4.4 ^{0}C, precipitation increase by 11 % and the sea level rise by 45 cm. Because the change is gradual, the CO_2 concentration would be 426 and 523 ppm and the temperature to 1.2 and 2.4 ^{0}C higher by 2020 and 2050, respectively.

Average temperature will increase 0.4^{o}C per decade, due to increase in green house gases. The increase will be highest (0.6^{0}C) in first half of the winter and lowest (0.3 ^{0}C) during the remaining growing season. The increase in mean temperature will reduce span of the growing season. The increase in temperature of earth's surface will predictably affect ecosystem biodiversity adversely during the 21st century. The structure and function of ecosystem will be affected by this change. The key changes in India will be less being located at lower latitude. 1 to 1.5^{0}C temperature rise will increase transpiration of vegetation approximately by 2.2 to 4% and rainfall will be affected by 5 to 6%. The sea level will rise by about 30-40 cm and may affect the biodiversity of shoreline areas during 21st century. Western Ghats and Coastal Plains, and north- eastern regions are the hot spots of the biodiversity which may suffer threat due to rise in sea level. Crucial management is required due to climate change. Tropical forests including trees outside forest are the treasure of biodiversity and a vehicle for sequestering atmospheric carbon needs conservation. Any activity that affects the amount of biomass in biodiversity has potential to sequester carbon from, or release carbon into, the atmosphere. The continuous emission of green house gases in the atmosphere is due to conversion of natural forest for cultivation and other land use changes. The removal of biomass and destruction of tropical forest have contributed to depletion of natural biodiversity and added to climate change. One of the vital solution of mitigating climate change & reducing the CO_2 concentration is the atmosphere is carbon sequestration in which agroforestry can play a vital role.

Globally agriculture accounts for 54% of anthropogenic methane and 58% of nitrous oxide emissions. Among different sources, agricultural soil is the major contributor to green house effect. In soils, methane is produced during microbial decomposition of organic matter under aneaerobic conditions. Rice fields submerged with water, therefore, are the potential source of methane.

Nitrogenous fertilizers are the source of N2O in fertilized soils, whereas the indigenous N contributes to its release in unfertilized soil.

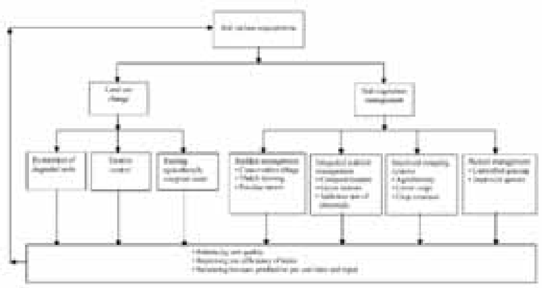
According to Indian Network for Climate Change Assessment (INCCA) Report (2010), the net GHGs emissions were 1727.7 million tons (Mt) of CO2 eq. from India in 2007. the main source was the energy sector, contributing 57.8% of the total GHGs, followed by industrial (21.7%), agricultural (17.6%) and waste (3.0%) sectors. In the agricultural sector with a total emission of 334.4 Mt CO2 eq., the major sources are enteric fermentation (63.4%), rice cultivation (20.9%) agricultural soils (13.0%) manure management (2.4%) and on-field burning of crop residues (2.0%). Thus, the crop production sector (rice cultivation, soils and filed burning of crop residues) contributes 35.9% of the total emissions from agriculture.

Mitigation of climate change is a global responsibility. Agriculture, forestry, fisheries/aquaculture provide, in principle, a significant potential for GHG mitigation. The IPCC estimates that the global technical mitigation potential for agriculture (excluding forestry) will be between 5500 and 6000 Mt. CO2 equivalent per year by 2030, 89 percent of which are assumed to be from carbon sequestration in soils.

Low carbon input and high C sink in agriculture (Pathak and Agarwal, 2012)

1. Minimizing inputs by applying less irrigation, tillage, labor, fertilizers, insecticides and herbicides.
2. Improving efficiency of water and nutrients use, provision of tolerance to stresses of moisture and heat, salt, diseases and pests.
3. Improving soils by resting, retention of resides, control of erosion, pollution and mining of nutrients.
4. Using low cost agro techniques: such as diversified crops & rotation, INM, IPM, SWC, Biofuel, Wind and Solar power.
5. Improving livestock keeping by dietary manipulation and feed and fodder processing.

The overall strategy is to increase SOC density, distribution of SOC in the subsoil, aggregation, and formation of secondary carbonates. The SOC density can be enhanced by increasing C input into the soil and decreasing losses by erosion, mineralization and leaching. The depth distribution of SOC can be achieved by planting deep-rooted species with high below-ground biomass production.



Strategies of soil carbon sequestration.

biosolids and improving earthworm activity can enhance aggregation (Singh and Singh, 1996; Sharma et al., 1995). These strategies can be achieved through a wide range of land use and soil/vegetation management options (Figure 1). Restoration of degraded soils and ecosystems, erosion control and conversion of agriculturally marginal soils to a restorative land use are important options of SOC sequestration

Climate variability and climate change

There is no internationally agreed definition of the term "climate change". Climate

Technological options for soil carbon sequestration

Technology	Cropping system	Region	Reference
1. Green manuring	Sugarcane	Tropical	Yadav (1995)
	Rice-wheat	Northwestern	Aulakh et al. (2001)
	Rice	Tropical	Singh et al. (1991)
	Rice	Tropical	Kumar et al. (1999)
	Rice-wheat	Northern	Joshi et al. (1994)
	Rice-wheat	Punjab	Boparai et al. (1992)
2. Mulch farming/ conservation tillage	Rice-wheat	Punjab	Aulakh et al. (2001)
	Pearl millet	Arid	Aggarwal et al. (1997)
	Soybean-wheat	Central	Kundu et al. (2001)
	Arable land	Northern	Srivastava and Prakash (1982)
	Arable land	Northern	Biswas and Narayanasamy (1998)
	Sugarcane	Tropics	Yadav and Verma (1995)
	Surgarcane	Tropics	Yadav and Prasad (1992)
3. Afforestation/ agroforestry	Silviculture	Northern	Singhal et al. (1975)
	Acacia nilotica	Central	Pandey et al. (2000)
	Agroforestry	Tropical	Chander et al. (1998)
4. Grazing management/ ley farming	Grassland	U.P.	Pandey (1982)
	Grassland	M.P.	Chaubey et al. (1986)
	Mixed farming	Arid	Rao et al. (1997)
5. Integrated nutrient management/ manuring	Arable land	Tamil Nadu	Jayaraman and Perumal (1984)
	Rice-wheat	Northwest	Duxbury (2001)
	Cotton	Central India	Venugopalan et al. (1999)
	Arable land	Northeast	Chakrabarti et al. (2000)
	Rice-rice	Northern	Dinesh et al. (1998)
	Maize-wheat-cowpea	Semi-arid	Kanchikerimath and Singh (2001)
	Rice-wheat	Northern	Yadav et al. (1998, 2000)
	Arable	Northern	Benbi et al. (1998)
	Wetland rice-wheat	Northern	Singh et al. (1996)
	Maize-wheat	Northern	Singh et al. (1995)
6. Cropping systems	Pearl millet	Arid	Kumar et al. (1997)
	Fallowing/ecological approach	Humid/sub-humid	Szott et al. (1999)
	Mint-mustard	U.P.	Patra et al. (2000)

change can refer to: (i) long-term changes in average weather conditions (ii) all changes in theclimate system, including the drivers of change, the changes themselves and their effects or (iii) only human-induced changes in the climate system. There is also no agreement on how to define the term "climate variability". Climate has been in a constant state of change throughout the earth's 4.5 billion-year history, but most of these changes occur on astronomical or geological time scales, and are too slow to be observed on a human scale. Natural climate variation on these scales is sometimes referred to as "climate variability", as distinct from human-induced climate change. UNFCCC has adopted this usage (e.g., UNFCCC, 1992). For meteorologists and climatologists, however, climate variability refers only to the year-to-year variations of atmospheric conditions around a mean state. To assess climate change and food security, FAO prefers to use a comprehensive definition of climate change that encompasses changes in long-term averages for all the essential climate variables. For many of these variables, however, the observational record is too short to clarify whether recent changes represent true shifts in long-term means (climate change), or are simply anomalies around a stable mean (climate variability).

Acclimatization, adaptation and mitigation

Acclimatization is essentially adaptation that occurs spontaneously through self-directed efforts. Adaptation to climate change involves deliberate adjustments in natural or human systems and behaviours to reduce the risks to people's lives and livelihoods. Mitigation of climate change involves actions to reduce greenhouse gas emissions and sequester or store carbon in the short term, and development choices that will lead to low emissions in the long term.

Mitigation of climate change: practices

Reducing emissions of CO2, such as through reduction in the rate of land conversion and deforestation, better control of wildfires, *adoption of alternatives to the burning* of crop residues after harvest, *reduction of emissions from commercial fishing* operations, and more efficient energy use by forest dwellers, commercial agriculture and agro-industries; *reducing emissions of methane and nitrous oxide, such as through improved nutrition* for ruminant livestock, more efficient management of livestock waste and of irrigation water on rice paddies, more efficient applications of nitrogen fertilizer on cultivated fields, and reclamation of treated municipal wastewater for aquifer recharge and irrigation; *sequestering carbon, such as through improved management of soil organic matter,* with conservation agriculture involving permanent organic soil cover, minimum mechanical soil disturbance and crop rotation (which also saves on fossil fuel usage); improved management of pastures and grazing practices on natural grasslands, including by optimizing stock numbers and rotational grazing; introduction of integrated agroforestry systems that combine crops, grazing lands and trees in ecologically sustainable ways: use of degraded, marginal lands for productive planted forests or other cellulose biomass for alternative fuels; and carbon sink tree plantings.

Changes in temperature and precipitation patterns together with occurrence of extreme events are major threat to future food security due to climate change. After collection of long term data for more locations of Madhya Pradesh, climatic characterization was done for longterm trends and occurrence of extreme events for precipitation and temperature in relation to crop growth phases as climate change related occurrence of these extreme events can have serious consequences for agricultural production.

Major Sources of GHGs and their Contributions

Besides CO2, there are some other gases that can contribute the global climate change. However, the contribution to the greenhouse effect by different gases is determined by the characteristics of the gas and its abundance. For instance, CH4 is about 8 fold stronger than CO2 on a molecule-for-molecule basis, however the net contribution of CH4 to the greenhouse effect is much smaller because its lower concentration than that of CO2. From the radiative forcing of the main GHGs, CO2, CH4 and N2O**, it is also evident that CO2 is the predominant** GHG

Increase of dominant greenhouse gases and their radiative forcing [3].

Greenhouse gases	Preindustrial level	Current level	Increase		Radiative forcing (W/m^2)
CO_2	280 ppmv	387 ppmv	107 ppmv	38%	1.46
CH_4	700 ppbv	1745 ppbv	1045 ppbv	149%	0.48
N_2O	270 ppbv	314 ppbv	44 ppbv	16%	0.15
CFC-12*	0	533 pptv	533 pptv	-	0.17

*CFC: chlorofluorocarbon

Cropping Systems for C Sequestration

To improve C sequestration, it is critical to increase the input of plant biomass residues. Biomass accumulation can be enhanced by an increase in cultivation intensity, growing cover crops between main crop growing seasons, reducing fallow period of land, crop rotations, and intercropping systems. Biomass return to the soil can be improved by elimination of summer or winter fallow, and maintaining a dense vegetation cover on the soil surface, which can also prevent soil from erosion for SOC loss.

Cropping Practices

There are a number of reports on C sequestration or SOC accumulation in croplands through integrated cropping systems and cropping practices, such as conservation tillage; cover cropping, crop rotation; land use restoration or shifting cultivation, and fertilization, etc. [4,16,19,37,46-49]. Obviously, soil organic C pool has a great potential to store sequestered C and integrated cropping systems associated with cropping practices has displayed the promising prospects in C sequestration from the atmosphere and shifting the mitigation of climate change.

What is Carbon Sequestration?

Carbon sequestration removes carbon, in the form of CO2, either directly from the atmosphere or at the conclusion of combustion and industrial processes. One type of sequestration is the long-term storage of carbon in trees and plants (the terrestrial biosphere), commonly referred to as terrestrial sequestration. CO2 removed from the atmosphere is either stored in growing plants in the form of biomass or absorbed by oceans. Sequestering carbon helps to reduce or slow the buildup of CO2 concentrations in the atmosphere.

Increases in atmospheric CO2 concentration may be generating increases in average global temperature and other climate change impacts. Although some of the effects of increased CO2 levels on the global climate are uncertain, most scientists agree that doubling atmospheric CO2 concentrations may cause serious environmental consequences. Rising global temperatures could raise sea levels, change precipitation patterns and affect both weather and climate conditions.

This indicates that the horticultural system with more canopy cover, leaf litter and favourable micro- environment enhanced the SOC content.

Accordingly, horticultural land- use appears to be a preferred option for maintaining soil health and for achieving econimic sustainability to the stakeholders of the SAT.

How can agriculture affect climate change?

Agricultural activities serve as both sources and sinks for greenhouse gases, so specific agricultural practices could slow the pace of global warming. Methane dynamics are linked closely to livestock production practices and wetland agriculture, such as rice production. We focus on crop management in Great Plains agriculture in this note and so will ignore methane here. Carbon dioxide dynamics are related to energy use cycles on farms and more importantly, to soil management. Nitrous oxide dynamics are related to soil nitrogen management, including fertilizer nitrogen.

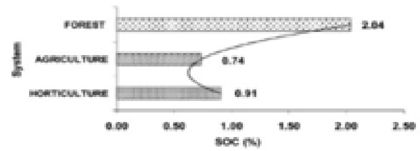
What management practices sequester soil carbon?

Practically, there are three areas of farm management that can affect soil carbon sequestration in the Great Plains: tillage, cropping intensity and fertilization. Tillage and soil carbon are negatively related. The greater the tillage, the less soil carbon. No-till systems build soil organic matter, which is about 58 percent carbon. No reliable data exist in Montana regarding soil carbon accumulation rates due to no-till, but extensive research in nearby southwestern Saskatchewan shows that soils depleted of organic matter typically accumulate soil carbon at a rate of 0.1 tonne/ha/yr (~0.045 tons/ac/yr), but may vary from 0 to 0.2 t/ha/yr depending on soil type, soil management, local weather patterns and specific no-till systems. Different no-till systems result in varying soil disturbance, but any system that reduces tillage substantially can increase soil carbon. Montana field research completed in 2001 showed carbon storage rate from no-till adoption similar to that in southwestern Saskatchewan, but

Quasi-equilibrium of soil organic carbon (SOC) and carbon stock in different land-use system

	QEV of SOC (%)			Soil organic carbon stock (Mg/ha)			
Depth (cm)	0–30	0–50	0–100	0–15	0–30	0–50	0–100
Land-use system							
Agriculture	0.68	0.61	0.52	18.8	33.1	48.5	63.1
Horticulture	0.81	0.71	0.52	22.2	37.5	53	73.1
Forest	1.78	1.55	1.10	44.5	79.6	156.3	169.8

$Mg = 10^6$ g



Quasi-equilibrium of organic carbon (0-15 cm) in different systems.

with considerable farm-tofarm variability. That variability needs to be understood. Cropping intensity and soil carbon are positively related. The more frequent the cropping and greater the biomass inputs, the more soil carbon. Summer fallow reduces cropping intensity. Reducing fallow typically increases soil carbon through greater annualized biomass inputs, but may be economically difficult. No Montana data exist on carbon storage rates due to cropping intensity, but data from southwestern Saskatchewan show average carbon storage rates of about 0.2 tonne/ha/yr (0.09 ton/ac/yr) when converting from 50:50 crop-fallow to continuous cropping. Field research began in 2003 in north central Montana to compare soil carbon accumulation due to no-till adoption and continuous cropping. We expect this research to provide important information about greenhouse gas emissions in the short term, and may serve as long term benchmark sites to support future carbon credit trading. Fertilization affects soil carbon mainly through crop biomass. However the carbon:nitrogen ratio of soil organic matter results in stable organic matter typically within a range of about 8-10:

If insufficient nitrogen is present to permit stable formation of soil organicmatter via soil microbial degradation of crop residues, then little carbon may be sequestered.

Carbon sequestration potential of vegetable crops

Vegetable crops have the ability to capture atmospheric CO2 and through the process of photosynthesis, metabolize it to produce sugars and other compounds that are necessary for the plants normal development. The carbon sequestered by plants is the results of the different between CO2 absorbed from the atmosphere during the process of photosynthesis and the CO2 released to the atmosphere during respiration. This diffrenance is converted into biomass. Therefore, whilst CO2 levels are high, both natural vegetation and agricultural plants including vegetable crops act as a source of sequestered carbon. When this is taken into account, vegetable cultivation also become one of the most effective means in mitigating the increase of atmospheric CO2.

India ranks second in production of cabbage, cauliflower, onion and brinjal at global level and thus, cultivation of vegetable specie3s produce substantial amount of biomass, There is a need to develop simple yet scientific principles and methods for assessing biomass and sequestered carbon and its monetary value in standing vegetable crops.

The major findings are; (a) maximum seasonal carbon storage per plant was observed in eggplant. The fruits contributed most in carbon sequestration; (b) The carbon sequestration rates on hectare basis were similar in cauliflower and eggplant in spite of wide differences in plantation density; (c) On single plant basis, pea gave minimum value of sequestered carbon.

However, the high plantation density in pea brought it at par with tomato having a lower number of plants in a hectare: (d) lower availability of time between sowing of tubers and harvesting affected carbon storage values as was evident from lowest quantity of carbon from potato plants in a hectare; (e) Considering national carbon storage from the cultivated area of 6.08 million hectare in 2010-2011 in India, eight vegetable crops included in this study earned a value of 761.2 million $ from 13.3 million metric tons of sequestered carbon.

Fruit based agroforestry system

The fruits based agroforestry system is a self-sustainable system where solar energy can be harvested at different heights, soil resources can be efficiency used and cropping intensity is increased. The system consists of three main components viz., main crop, filler crop and inter crops which occupy three different tiers in space of the production system.

The main crops: The main crops are the fruit species having a larger canopy size and prolonged juvenile as well as productive phase.

The filler crops: The filler crops are the fruit species which are precocious in nature, prolific bearers having short stature. They utilize the middle layer of the multitier system from which economic productivity is obtained.

Inner crops: The intercrops occupy the lower most layer of the multitier system and are grown in the remaining unused land of the multitier system. Generally the intercrops are the location specific annual crops, selected as per the climatic and socio-economic suitability.

Central India – The land of unique opportunities of Food security

The vegetation diversity of Madhya Pradesh is a typical representative of Indian biota as it harbours largest gene pool. Due to wide range of climate and corresponding diversity in the vegetation, the State of MP is declared as Mega Diversity State in India. Bio-geographically the State is placed in the semi-=arid zone and agro-ecological region-wise, it comes under Central Plateau of growing period. The State is endowed with various forest types ranging from dry thorn forests to tropical dry deciduous, tropical moist deciduous, sub tropical and semi-evergreen types, which are the storehouse of vast flora and fauna (bio- diversity). Some of which are under threat and some are at the verge of extinction. State 77 percent rural population depends on these biodiversty.

The geographical area of Madhya Pradesh 307.44 lac ha. Out of which 49 percent is under cultivation. Large tract of the State has tribal population (24%) with forest (23%) and forest resources. There is an acute shortage of fuel, fodder and small timber. States demand for feed (58 million tones of green fodder annually) and fuel (10 million tones) if not attended to will continue to degrade lands due to overgrazing / over exploitation of natural resources. During last one decade, the total forest area has come down to 21 percent of the total geographical area however the area under Trees outsides forest (TOF) has increased. The majority of cultivated area is under rainfed (600 mm) with enormous unexploited agricultural production potential. Eleven distinct agro climatic zones of the State are endowed with large variations in rainfall (18-1600mm), irrigation potential (3-64%), cropped area (3.5 to 33%), more than 60 percent is non cropped; soil types (alluvial) terrain from plain to high mountain, one third of the net shown area is unutilized culturable wastelands (having less than 50% production). These situations pose threat to crop yields and warrant for an alternate land husbandry and crop diversification for sustainable production. There is a great risk of growing food grains in extremely light textured soils and culturable wastelands of Madhya Pradesh, which occupies 22 percent of the total geographical area of the State. This particular area could be brought under cultivation of tree based farming system. Madhya Pradesh is blessed with climatic variability and diverse soil types. This provides unique opportunities to the farmers to grow multipurpose trees in marginal and culturable wastelands under various agroforestry systems, through which the food security can be achieved.

Agroforestry – A concept of alternate land use

Agroforestry a term coined in 1977 denotes an age-old practice of having trees mixed in the agricultural landcape. It designates a holistic approach to land use in which woody perennials are deliberately grown on the same land management in spatial or temporal sequence. There must be significant ecological and economical interctions between woody and non-woody components. The objective of such combinations is to increase, sustain and diversify the production of land thereby to help in reducing economic and environmental risks.

All agroforestry systems consist of at least two to three major groups of agroforestry components i.e. trees and shrubs (perennial), agricultural crops (annual or biennial) and pasture / livestock. There may be other components also, such as fish, honeybees, silk worms, lac insect etc. Based on Diagnosis and design approach, the need based location specific agroforestry, system with promising species in different agro climatic zones of the State have been recommended (Table 1)

Promising tree species for agroforestry systems under agro-ecological zones of Madhya Pradesh having carbon sequestration potential

S.N.	Agro climatic zones	Systems	Promising tree species
I	Chhattisgarh Plain	Agrisiliviculture	Terminalia spp., Shahtoot bamboo, khamer
		Agrihorticulture	Mango, jackfruit, guava, drumstick, seedless lime, custard apple
II	Northern Hills of Chhattisgarh	Agrisiliviculture/ Agrientomoforestry (Boundary) plantation is also included	Traditional plash based system, eucalyptus, khamer, karanj
		Agrihorticulture	Jamun, bel, Mango, guava, jackfruit, drumstick, lime aonla
III	Kymore Plateau & Satpura Hills	Agrisiliviculture boundary plantation is also included	Traditional acacia-rice palash, eucalyptus, teak, shisham
		Agrihorticulture	Guava, mango, aonla, lime, custard apple, jamun shahtoot
IV	Central Narmada Valley	Agrisiliviculture	Bamboo, khamer, shisham, arjun
		Agrihorticulture	Mango, seedless lime, ber, lime, aonla
V	Vindhya Plateau	Agrisiliviculture	Khamer, neem, babul, eucalyptus, safed shirish
		Agrihorticulture	Mango, guava, lime
VI	Grid Region	Agrisiliviculture	Prosopis spp., Babul, subabul, sissoo, Australian babul
		Agrihorticulture	Lime, ber, custard apple
VII	Bundelkhand Region	Agrisiliviculture boundary plantation is also included	Subabul, neem, karanj, bamboo, palash, mahua

Agroforestry to sequester Carbon

Agricultural producers can help counteract climate change by increasing the storage (or "sequestering") of carbon on agricultural lands. Both soil and vegetation act as carbon sinks and reducing the amount of carbon dioxide the atmosphere. Agroforestry practices can sequester more carbon than is lost to the atmosphere. Carbon accumulates in trees, through the absorption of atmospheric CO_2 and its assimilation into biomass. Carbon is stored in living biomass, including standing timber, branches, foliage and roots; and in dead biomass, including litter, woody debris, and soil organic matter. Any activity that affects the amount of biomass in vegetation and soil has potential to sequester carbon from, or release carbon into, the atmosphere. The carbon stored in the soil and litter of trees also makes up a significant proportion of the total carbon pool. Globally, soil carbon represents more than half of the stock of carbon in trees.

Understanding of the ecological potential of agroforestry systems under different environmental conditions has increased tremendously during the last twenty five years. The greatest ecological potential of agroforestry seems to be in buffering and in maintaining the production capacity of agricultural systems rather than in increasing crop production. The buffering capacities have greatest potential in high potential areas where opportunities for niche differentiation between woody plants and herbs are plentiful. However, an increase in agricultural production can, in most cases, be achieved best by the use of external inputs both organic and inorganic. This does not mean that because trees do not easily contribute to increasing agricultural production, there is no potential for the combination of agricultural cropping and forestry. Properly managed woody plants on crop lands where such external resources are used contribute to prevent resource losses (referring to their buffering functions). A crucial management component in such agroforestry systems is the limitation of resource losses by other means than through crop harvesting. On degraded land the reintroduction of woody plants may assist in restarting the original production potential of the land, but this will normally make many years during which exploitation of the vegetation should be limited. Even if trees exert a negative effect on crops (e.g. through shade or root competition), it may still make economic sense for a farmer to practice agroforestry.

Tree based Carbon Sequestration

The basic premise of carbon sequestration potential of land use systems, including agroforestry systems, is relatively simple: it revolves around the fundamental biological ecological processes of photosynthesis, respiration and decomposition. Essentially, carbon sequestred is the difference between carbon 'gained' by photosynthesis and carbon 'lost' or 'released' by respiration of all component of the ecosystem, and this overall gain or loss of carbon is usually represented bt net ecosystem productivity. Most carbon enters the ecosystem via photosynthesis in the, leaves and carbon accumulation is most obvious when it occurs in aboveground biomass. More than half of the assimilated carbon is eventually transported below ground via root growth and turnover, root exudates (of organic substance) and litter deposition and therefore soils contain the major stock of carbon in the ecosystem. Inevitably, practices that increase net primary productivity (NPP) and or return a greater portion of plant literature on carbon sequestration in agroforestry systems is rather scanty compared with that of tree plantation systems, and considering that carbon sequestration potential of both plantation and agroforestry systems is based mainly on the attributes of the tree component.

Conceptually trees are considered to be a terrestrial carbon sink. Therefore, managed forests can, theoretically, sequester carbon both in situ (biomass and soil) and ex-situ (products). According to FAO estimates, forest plantations cover 187 million ha worldwide, a significant increase from the 1995 estimate of 124 million ha. The reported new annual planting rate is 4.5 million ha globally, with Asia and south America accounting for the main fast growing, short-rotation species are of the genera viz; Eucalyptus and Acacia. Pines and other coniferous species are the main medium rotation utility, species, primarily in the temperate and boreal zones. There is strong variation in the carbon sequestration potential among different plantation species, regions and management. Variations in environmental conditions can affect carbon I sequestration potential such as within a relatively small geographic area. In addition, management practices such as fertilization can easily increase carbon sequestration of f species such aseucalyptus. Various estimates' are available in FAO reports on C sequestration rates of common plantation species of varying rotation ages. Use of native species for reforestation is minimal, and exotic tree species predominate both in industrial and in rural development plantations worldwide. Plantations using indigenous species are restricted for the most part to small and medium sized farms where reforestation is practiced in degraded portions of the land, often using species in response to government incentives.

The relative efficiency of native and exotic species in terms of their carbon accumulation potential has been investigated in a few studies. In experimental plantings in Central America, for example, values of C sequestrations in aboveground biomass for ten native tree species was comparable to exotic species growing under similar conditions. Proper design and management of such agroforestry (or, farm forestry) plantations can increase biomass accumulation rates, making them effective carbon sinks.

Carbon Sequestration Potential of Agroforestry Systems to mitigate climate change

Agroforestry has high potential to simultaneously satisfy three important objectives viz.' i. Protecting and stabilizing the ecosystem. ii. Producing a high level of output of economic goods and iii. Provide stable employment; improve income and basic materials to rural population. Claims of carbon sequestration potential of agroforestry systems are based on the same premise as for tree plantations: the tree components sink of atmospheric carbon production systems, agroforestry can, high productivity. By including trees in agricultural production systems, agroforestry can, arguably increase the amount of carbon stored in lands devoted to agriculture, while still allowing for the growing of food crops. The discussion on planted forests presented in the earlier section has shown that: (1) soil fertility may ,be a limiting factor in realizing carbon sequestration potential of planted forests; (2) mixed stand of plants might be more efficient than sole stands in carbon sequestration; and (3) carbon sequestration estimates should be based on a holistic view of the long term carbon storage potential of all components in the these points: soil detritus soil and forest products. Agroforestry systems score highly in all these points: soil fertility improvement is a distinct possibility in agroforestry systems, especially under low-fertility conditions of the tropics agroforestry systems entail mixed stands of species; and, a holistic rather than compartmental condition of systems is a key concept of agroforestry.

In most agroforestry systems, the tree component is managed often intensively for its products such as pruning of hedgerows in tropical alley cropping and harvest of commercial, mostly non-timber, products. Such harvested materials often are return to the soil (as in alley cropping and improved fallow systems for soil fertility improvement). In addition, the amount of biomass and therefore carbon that is harvested and 'exported' from the system is relatively low in relation to the total tree plantations and other monocultural systems to have a unique advantage in terms of carbon sequestration. Many of these assumptions have, however, been not systematically tested and validated.

Focusing on the tree component of agroforestry, some attempts have been made to estimate the global contribution of agroforestry a sink for carbon. Based on tree growth rates and wood production, and assuming rations of tree stem biomass to carbon content of 1 :2.(i.e. 50 per cent of stem wood is assumed to be carbon), average carbon storage by agroforestry practices has been estimated to be 9,21,50 and 63 Mg C/ha in semiarid sub humid, humid and temperate regions.

The higher levels reported for temperate eco zones reflect the longer cutting cycles in these regions, with a resulting longer term storage. At a global scale, it has been estimated that agroforestry systems could be complemented on 585-1275 x 106 ha of technically suitable land and these systems could store 12 to 288 Mg C ha' under the prevalent climatic and edaphic conditions.

In addition, agroforestry systems can have in indirect effect on C sequestration if they can help to decrease pressure on natural forests, which are the largest sink of terrestrial C. within tropical regions, it as been estimated that one hectare of sustainable agroforestry could potentially offset 5 to 20 hectares of deforestation. Based on this assumption, projects promoting agroforestry in farmland surrounding 'islands' of natural forests have been attempted in Kenya and Madagascar. There are some examples of cases where. promotion and implementation of agroforestry systems has been successful in this regard: in Sumatra, Indonesia, farmers who integrated rice (Oryza sativa) production with tree crops and home gardens exerted much less pressure on adjacent forests, in comparison with. farmers dedicated to rice only. Agroforestry systems can, however, be either sinks or sources of C and other greenhouse gases.

Some agroforestry systems, especially those that include trees and crops agrisilviculture can be C temporarily store C, while others (e.g. ruminant-based agrosilvopastoral systems) are probably sources of C and other greenhouse gases. Especially in tropical regions, agroforestry systems can be significant sources of greenhouse gases: practices such as tillage, burning, manuring, chemical fertilization, and frequent disturbance can lead to emissions of $C0_2$, CH_4 and N_2O from soils and vegetation to the atmosphere. Silvipastoral systems, when practiced in an insustainable manner, can result in soil compaction and erosion with losses of C and from soils. Ruminant-based agrosilvipastoral systems and rice paddy agrisilvicultural systems are well-documented sources of CH_4.

Agroforestry suitable for rainfed areas

It is known that about 70 per cent of our cultivated land is rainfed, naturally, majority of our farmers are directly connected with the progress of rainfed farming. The poor productivity of these lands is attributed broadly to low moisture, erratic rainfall and unpredictable seasonal variations. Incorporation of trees in such areas will certainly bring "Brown Revolution" which is the future of Indian Agriculture. Trees are the important components of this land use system which when combined with crops, yield certain environmental benefits in rainfed areas i.e. (a) conserving the natural forest for precipitation, (b) efficient recycling of nutrients, (c) reduction in nutrient leaching and soil erosion, (d) conserving soil water and checking evaporation from soil surface through mulching, and (e) improving the microclimate. In other words, agroforestry promotes the biomass production as well as rehabilitate the land.

Conclusion

Agricultural producers play an important role in efforts to slow or reverse the release of carbon into the atmosphere. Soil conservation is essential to this effort, as soils are a tremendous organic carbon reservoir. Planting trees and increasing vegetation can aid in conserving soil, while providing other farm benefits and increasing carbon storage. Agroforestry has generated rather high levels of enthusiasm in recent years concern with rainfed land use and sustainable resource management system. It is a resource rich farming system having the productive role with the conservation farming techniques. It is a device of integrating production of trees with the production of agricultural crops in a sustainable manner. It has the most apparent potential in rainfed areas and in resource limiting small holding farming systems where monocultural agriculture may not be the most feasible or desirable, based on the principles of self maintenance.

The National Research Centre for Agroforestry (NRCAF) significantly contribute research on various aspects of agrisilviculture, agrihorticulture silvipastoral including MPTs evaluation suitable for different agroclimatic zones of India. Studies conducted under AICRP on Agroforestry also revealed that incorporation of trees and/or animals in rainfed farming systems improves the overall productivity of the system in a sustainable manner.

On the other hand, agroforestry systems, especially if well managed and if they include soil conservation practices, can contribute to increasing short-term C storage in trees and soils, as will be shown in some example. Finally, whether agroforestry systems can be a sink or a source of C depends on the land-use systems that they replace: if they replace natural primary or secondary forests, they will accumulate comparatively lower biomass and C, but if they are established on degraded or otherwise tree less' lands, their C sequestration value is considerably increased. Which facilities mitigate the climate change.

Enhancing wheat production by genetic improvement for abiotic stress tolerance

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Wheat is the most important staple food crop grown in winter when temperatures are relatively low. Thermal stress due to rising ambient temperatures during grain growth is one of the major constraints in enhancing wheat productivity particularly when the crop is sown late because of delayed harvesting of previous crops. Recently, climate change has increased the risks of exposure to higher temperature by manifold even for timely sown wheat. Each degree rise in temperature causes 3-4% reduction in grain weight as revealed by studies under controlled and natural environments. The total wheat production in the country may get reduced by at least 4 million tons in any given year for each degree rise in ambient temperatures. During 2012-13, abrupt rainfall led to 2.8% loss in total wheat production. Different approaches being followed to achieve this are challenged by complexity of the traits and absence of defined protocols for screening germplasm for stress tolerance.

Wheat production in India had witnessed a quantum jump from 6.5 million tones in 1950-51 to 95.8 million tones in 2013-14. India is a second largest wheat producing country with a share of around 12% in global wheat production. Wheat is a major staple food crop providing around 20 % of calories and proteins in human diet, therefore, play an important role in food security in India. Annual increase of at least 1.6 % in grain yield is required in the coming years in order to fulfill the demand. Moreover, these increasing yield levels must be achieved with the limited available resources and climate change (http://www.fao.org).

Abiotic stresses like heat, drought and salinity are among the major threats to sustainable wheat production in India. Significant part of India comprising north eastern plain zone, central zone and peninsular zone receives terminal heat during wheat growing season. Yield loss of 33.6% was observed in major wheat cultivars due to heat stress in late sown conditions indicating that there is a need to incorporate heat tolerance in wheat cultivars to achieve sustainable production (Joshi *et al.*, 2007; Chatrath*et al.*, 2007). Besides terminal heat, early heat is also posing barrier for stable yield. Farmers in north-western and central India are shifting to earlier sowings to take advantage of residual moisture. This helps to escape terminal heat stress

occurring at the end of March, however, warmer conditions in October cause faster growth and development, resulting in less biomass accumulation, small spike size development and consequently, lower grain yields. Considering the scenario, breeding wheat genotypes for heat tolerance both early and terminal becomes one of the prime objectives in wheat improvement programme.

Therefore several experiments have been conducted to understand the mechanism by which wheat as a crop can adjust to heat, drought, salinity and other abiotic stress conditions. The very basic requirement is to evaluate the germplasm for existing variability for tolerance to heat and drought . In addition, there is a need for better insight into the environments where these stresses are endemic (hot spots) .Physiological and biochemical techniques have potential to increase selection efficiency, securing stress tolerance that may be lost during empirical selection. However, as a prerequisite, it is necessary to understand physiological, genetic and molecular basis of tolerance to high temperature. Physiologically yield is determined by photosynthesis and ability of grains to utilize photosynthates for its growth. High temperature has detrimental effect on both these processes. Earlier efforts in this direction have enabled identification of some of the traits and techniques for screening for thermal tolerance in plants. However, many of them are not efficient in screening early generation material. Hence, there is a need for development of rapid screening techniques. Recent advances in instrumentation such as Chlorophyll Fluorescence and enhanced capacity to identify molecular markers are expected to be useful in developing screening techniques.

Defining heat and drought stress

Heat stress is a function of the magnitude and rate of temperature increase, as well as the duration of exposure to the raised temperature (Wahid *et al.*, 2007). Wheat experiences heat stress to varying degrees at different phenological stages, but heat stress during the reproductive phase is more harmful than during the vegetative phase due to the direct effect on grain number and dry weight (Wollenweber*et al.*, 2003). Heat stress at the end-of-season is also likely to increase for wheat in the near future (Mitra and Bhatia, 2008; Semenov and Halford, 2009). Drought and high temperature occur together in Central and Peninsular India particularly at early stages and terminal stages of growth of wheat. It would be more appropriate to define the combined stress of drought and high temperature in terms of per cent reduction in productivity under given target environment delineated by soil properties such as moisture retention capacity, clay content, organic matter and atmospheric parameters including the rain fall pattern, ambient temperature and evapo-transpiration. Though the day temperatures tend to be high in this region, the night temperatures remain within the favourable limit due to rapid cooling. This may be one of the reasons for reasonably good productivity when water is not a limiting factor.

Data compiled from different zones depicting average daily temperatures of four weeks from heading to maturity, days to maturity along with yield in the irrigated timely sown conditions considered for analyzing their association with productivity of wheat is shown in Fig 1. The results revealed inverse association between temperature and yield mainly due to reduced crop duration.

Figure 1: Mean daily temperature from heading to maturity), days to maturity and yield levels in different wheat producing zones (Based on AICW&BIP reports).

Losses due to droughtand heat

Temperature above 20°C, 10 days after anthesis (DAA) can reduce grain yield by 78% (Gibson and Paulsen, 1999), and the grain number by 11% upon the rise in temperature from 21°C to 30°C (Tashiro and Wardlaw, 1990). In other studies, a yield reduction of 23% was reported in response to high temperature above 32°C for as little as 4 days (Randall and Moss, 1990; Hawker and Jenner, 1993; Stone and Nicolas, 1994).

Among the two monsoon systems operating in India the South-west or summer monsoon accounts for about 80% and the North-east or the winter monsoon accounts for roughly 20% of the rainfall. Due to large variability in the monsoon rainfall on both space and time scales different Indian regions experience drought or flood in some parts of the country almost every year during the monsoon period between June-September. he effect of drought on wheat becomes more conspicuous when the receding south west monsoon fails to leave sufficient soil moisture that is essential for early establishment of wheat grown in winter. The long term analysis reveals that drought occurs once in five years in West Bengal, Bihar, Madhya Pradesh and Maharashtra while the frequency is higher in Gujarat, East Rajasthan and Western Uttar Pradesh(Table 1). This needs to be revised taking into consideration the predicted and recent change in global climate

Table 1: Frequency of occurrence of drought in drought prone states

Probabilities of occurrence	States
Once in 5 years	West Bengal, Madhya Pradesh, Bihar , Western Maharashtra
Once in 4 years	Eastern Uttar Pradesh &Vidarbha
Once in 3 years	Gujarat, East Rajasthan, Western Uttar Pradesh
Once in 2 years	West Rajasthan
Once in 2.5 years	Jammu & Kashmir

It is evident that there was huge reduction ranging from 3.2 to 44 per cent in production of wheat in vulnerable states during drought year 2000-01 as compared to previous year. Much of the fluctuation in the production in drought prone states could be attributed to deficit rainfall. Even the assured irrigated regions can face far reaching implications in terms of surface water supplies, ground water over exploitation, excessive power consumption and overall production strategies. Such situations may severely affect substantial area of wheat in the states of Madhya Pradesh, Rajasthan, Gujarat, Maharashtra and Bundelkhand region of Uttar Pradesh where wheat is grown on limited supply of water. In all these states, timely sowing of wheat is suggested to harness the potential of residual moisture due to extended withdrawal of rainfall. This enhances the possibilities of wheat getting exposed to supra optimal temperatures at early stages.

Table. 2: Fluctuation as per cent of previous years in wheat production in drought prone areas

	1999-00	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**
Bihar	4.1	-3.2	1.4	-10.2	-8.7	-11.5	-13.6
Gujarat	-40.1	-36.4	76.4	-25.2	137.7	-11.3	28.5
Madhya Pradesh	4.3	-44.0	23.3	-18.0	49.7	-0.5	-15.4
Maharashtra	9.0	-33.5	13.7	-8.7	-20.9	30.6	28.0
Rajasthan	-2.1	-17.6	15.2	-23.7	20.5	-2.9	2.8

Effects of high temperature on wheat

Heat stress is a complex function of heat intensity (rise in temperature above the environmental temperature), duration of exposure, rate of rise in temperature and plant response at each development stage. Heat stress implies alteration in diverse metabolic processes, with qualitative and quantitative losses in the produce, in extreme cases can result in plant death. Effect of heat stress on wheat can be categorized as follows.

Effects on yield and quality of wheat

Effect of heat stress begins right from the early stage of emergence in wheat. Wheat seedlings subjected to short term heat stress showed significant reduction in dry mass and length of shoot as well as root, chlorophyll content and membrane stability index (Gupta *et al*., 2013), suggesting that breeding for early heat tolerance is necessary to ensure better crop stand. High temperature is often accompanied with drought and the combination show detrimental effect on reproductive development such as flower initiation, ovary and pollen development, below average fertilization and subsequently yield loss due to reduced sink potential (Barnabas *et al*, 2008).

Heat stress along with drought also showed pronounced effect on grain yield, biomass, days to maturity and grain weight in wheat (Balla*et al*., 2014; Kaur and Behl, 2010; Tahir *et al*., 2006). A recombinant inbred line population derived from the cross of Kauz and MTRWA116 showed significant decrease in grain yield (46.7%), thousand grains weight (20.6%), grain filling duration (20.4%), kernel per spike (23.6%) and spikelet per spike (11.7%) due to heat stress (Modarresi*et al*., 2010). Garg*et al.* (2013) reported reduction in thousand grain weight due to reduction in grain filling duration and grain growth rate with increase in temperature.

Heat stress is also identified as a major factor for end-use quality of wheat. It was observed that increase in temperature resulted in increased sedimentation values, soluble and insoluble proteins, and mixograph peak height. In contrast, flour yield, mixing time and mixing tolerance of the dough were significantly decreased, may be due to rapid desiccation during ripening (Gibson *et al*., 1998; Tahir *et al*., 2006). It is widely reported that the grain protein content increased significantly due to post-anthesis exposure to heat stress, whereas, a reduction in the glutenin/gliadin ratio takes place which has a negative effect on flour quality (Ashraf, 2014).

Effect of heat stress on photosynthesis

Photosynthesis is a fundamental physiological process in plants involving various enzymatic reactions for carbon fixation, ATP generating electron transport system and oxygen evolving photosystems. Damage due to environment stress to any of these components can severely affect entire photosynthesis process in plant (Allakhverdiev*et al*., 2008). Physiological parameters like chlorophyll content, efficiency of PSII, net assimilation rate, transpiration, stomatal conductance and intercellular CO_2 concentration were greatly reduced due to heat stress and its interaction with drought. Therefore, physiological and yield parameters should be jointly considered in determination of heat tolerance in wheat (Balla*et al*., 2014). In a meta-analysis to assess the effect of elevated temperature and CO_2, it was observed that heat stress along with elevated CO_2 showed negative effect on photosynthesis efficiency in herbaceous crop species. The study also highlighted importance of interactive effect among various abiotic factors including heat and drought stress in determination of thermo-tolerance in plants (Wang *et al*., 2012). Wheat cultivars grown under heat stress showed damage to thylakoid membrane and progressive loss in chlorophyll content over time (Ristic, 2007). This may be due to increase in activity of proteolytic enzymes that leads to protein degradation and chlorophyll loss (Harding *et al*., 1990). Deactivation of *rubisco*, a key enzyme in photosynthesis, is one of the deleterious effects of heat stress in plants which occurs due to lower concentration of CO_2 caused by stomatal closing under various stresses. Decreased activity of *rubisco* under heat stress has been reported in wheat, maize, cotton and tomato (Ashraf and Harris, 2013).

Oxidative stress

Generation of reactive oxygen species in excess is one of the major consequences of heat stress in plant. These reactive oxygen species are partially reduced forms of oxygen like super oxide radical (O_2^-), hydrogen peroxide (H_2O_2) and hydroxyl radical (HO^-) which leads to oxidative stress by destruction of cellular components like membranes and macromolecules. Production rate of reactive oxygen species is low under normal conditions; however, environmental stresses such as high temperature, drought, salinity and cold disrupt cellular homeostasis by enhancing the production of reactive oxygen species. The sources of production of these reactive oxygen species include photorespiration and mitochondrial respiration in plants. Plant cell maintains cellular homeostasis by scavenging reactive oxygen species using enzymes such as superoxide dismutase, catalase, peroxidase, ascorbate peroxidase and glutathione reductase and non-enzymatic antioxidants such as tocopherols, ascorbic acid, glutathione and carotenoids. In wheat seedling exposed to heat stress, diminished activity of catalase and increased activity of superoxide dismutase, peroxidase, ascorbate peroxidase and proteases were observed during heat induced programmed cell death (Hameed *et al*., 2012). Over-expression of a wheat mitochondrial Mn superoxide dismutase (Mn SOD3.1) enhanced heat, drought and cold tolerance in transgenic canola (Gusta, 2009), demonstrating importance of superoxide dismutase in stress tolerance.

Defense mechanism against heat stress in wheat

Plant can survive in hot and dry conditions by combinations of adaptations including avoidance/ escape mechanism through morphological adaptations and tolerance mechanism which involve biochemical adaptations (Hasanuzzaman et al. 2013). Early maturity is an effective way to minimize yield loss during terminal heat stress. Leaf rolling reduces exposure to solar radiations. Intensive transpiration also keeps plant canopy temperature cooler than ambient temperature under well watered condition. Stay-green habit allows plant to retain their stems and leaves in active photosynthesis stage for longer grain filling period under terminal heat stress. This helps in maintaining stable yield levels even under heat stress. These morphological adaptations are often associated with biochemical adaptations responsible for tolerance to environmental stress. Sarieva*et al*. (2010) concluded that leaf rolling helps to stabilize the structural and functional organization of PSI and PSII under short-term temperature stress. The degree of leaf rolling determines the maintenance of optimal photosynthetic activity in leaves. Leaf rolling provides high adaptation potential and facilitates increase the efficiency of water metabolism in wheat flag leaves. They also stated that active accumulation of carotenoids is also a major factor for adaptation heat stress. At the onset of inhibition of photosynthesis as a consequence of heat stress, stem reserve provides a powerful resource for grain filling (Blum, 1998). Either stable photosynthesis or useful stem reserve ensures stable grain filling under heat stress (Yang *et al*., 2002a) provided that enzymes essential for photosynthesis and incorporation of carbohydrates into starch during grain filling are stable under heat stress (Wardlaw and Wrigley, 1994).

Tolerance mechanism comprised of molecular chaperones which contribute to cellular homeostasis by protein folding, translocation and degradation. They also stabilize protein by refolding or re-solubilizing under stress conditions. Wang *et al*. (2004) reported that Hsp/chaperone sHsp and Hsp70 maintain the non-native protein in a competent state by stabilizing protein conformation and preventing aggregation. This competent protein is subsequently refolded by Hsp60, Hsp70 and Hsp90. Denatured or misfolded proteins can be re-solubilized by Hsp100/Clp followed by refolding, or degraded by protease. This network of HSP/chaperones helps maintaining cellular homeostasis under environmental stress. In a recombinant inbred lines population, a unique plastid-localized Hsp was reported to be linked with thermo-tolerance in wheat (Joshi *et al*., 1997). A positive correlation was observed between low molecular weight Hsp and genetic difference in thermo-tolerance in wheat. Reports have shown that different kinds of HSP are synthesized in various tissues in wheat in response to duration and kind of heat stress. In transgenic Arabidopsis, chaperonin-60β helps in acclimation of photosynthesis after heat stress, possibly by protecting Rubiscoactivase (Salvucci, 2008).

Breeding for heat tolerance in wheat

Breeding for abiotic stress tolerance involve identification of genetic stocks from available gene pool, its utilization in hybridization programme and selection of breeding lines for stress tolerance using associated surrogate traits. Since abiotic stresses impart by several physiological and biochemical changes, many genes are involved in tolerance to stresses. Elucidation of molecular and genetic basis of stress tolerance will help to identify functional marker and subsequently enhance efficiency of selection for improved abiotic stress tolerance.

Evaluating genetic diversity for heat tolerance

Wheat genetic resources must be screened for identification of donor genotypes for heat tolerance traits. Evaluating wheat genotype for yield stability under heat stress across different location is a classic approach towards identification of superior genetic stock for improvement in heat tolerance. In a study consisting of advance breeding lines and wheat cultivars from different wheat breeding centers in India, genotypes Raj 3765 and Raj 4037 were identified as stable genetic stocks for grain yield. A common research strategy with emphasis on stable grain yield was also proposed to develop wheat genotype tolerant to heat stress (Rane et al., 2007).

Sareen*et al*. (2012) screened synthetic wheat hexaploids for terminal heat tolerance under field and temperature controlled conditions and identified four heat tolerant lines ALTAR 84/ *Ae.squarrosa*(192); 68.111/RGB-U//WARD/3/FGO/4/RABI/5/*Ae.squarrosa(629);*68 .111/RGB-U//WARD/3/ GO/4/RABI/5/ *Ae. squarrosa(878) and* LC,K59. 6'1/*Ae.squarrosa*(313), which performed well under both stress as well as non stress conditions. Using ISSR markers, Sharma *et al*. (2014) reported that three of these lines had different genetic basis of tolerance. Hexaploid and tetraploid Indian wheat cultivars and their diploid relatives were screened by Khanna-Chopra and Viswanathan (1999) for stability of yield and yield components under heat stress. Hexaploid wheat cultivars C306 & HI1136, *T. dicoccoides*, *T. monococcum*acc. BSP1 and *Ae. speltoides*ssp. *liqustica*were found to be highly heat tolerant with respect to their grain yield. In another study, 129 accessions of *Aegilopstauschii*Coss., the

D genome donor of wheat, were evaluated for cell membrane stability as an indicator of heat tolerance at cellular level. Accessions of *Aegilopstauschii*excelling over heat tolerant bread wheat were identified as donor for thermo-tolerance in wheat (Gupta *et al*., 2010). Cultivated emmer wheat also serves as useful gene pool for improvement of heat and drought tolerance in wheat. In another study, results confirmed the potential value of *Aegilopsgeniculata* for improvement of high temperature and drought stress tolerance in wheat and could contribute to the choice of traits to be introgressed and the accessions to be used in wide hybridization programs.

Wheat-alien chromosome introgression lines are also one of the useful genetic resources for improvement of thermo-tolerance in wheat. Mohammed *et al*. (2014) evaluated the responses of wheat - *Leymusracemosus*chromosome introgression lines of Chinese Spring towards heat stress. Certain *Leymus* chromosomes were found to be associated with heat tolerance, hence, can be used as bridge to transfer heat tolerance traits to wheat cultivars.

Traits for improvement of heat tolerance in wheat

Breeding for heat tolerance was relied earlier on classical selection methods, however with the advances in understanding biochemical, physiological and molecular basis of heat tolerance, surrogate traits have been identified and are being used in addition to classical methods for selection of heat tolerant genotype. Use of these surrogates in breeding programme depends mainly on their correlation with yield under stressed conditions, genetic variability in the available germplasm, heritability and genotype × environment interaction as source of variance for these traits. A conceptual model of genetically determined physiological traits to improve heat tolerance in wheat was proposed by Cossani and Reynolds (2012) based on light interception, radiation use efficiency and partitioning of total assimilates. Early vigour or ground cover is an indicator of efficiency of genotype to produce biomass and canopy area. It can be quantified in field using digital imaging (Mullan and Reynolds, 2010) and canopy reflectance indices. Stay-green habit allows plant to retain its photosynthetic potential under heat stress, enhances grain filling period and ensures stable yield.

Under heat stress conditions, significant correlation was observed between loss of chlorophyll and damage to thylakoid membranes. Since chlorophyll content is associated with heat stress, measurements of chlorophyll content using a chlorophyll meter will be useful as a method for high throughput screening for heat tolerance in wheat. Moreover, this is cost effective and does not required dark adaptation of plants before measurement (Ristic*et al*., 2007).

Under hot irrigated conditions, canopy temperature depression showed more reliable association with grain yield and yield components. Moreover, it is extremely rapid as it takes 10 to 20 seconds to evaluate a plot, therefore it is suitable for screening large number of breeding lines in field conditions. Canopy temperature at vegetative growth stage and at grain filling stage showed association with yield and biomass under hot irrigated conditions as well as under drought conditions (Reynolds *et al.,* 2007). Since deeper root system have better access to soil moisture, it helps crop canopies to meet high evaporative demand associated to under drought enables heat-stress (Cossani and Reynolds, 2012).

The source of carbon fixation diminishes during grain filling as a result of natural senescence of green biomass of plant. At the same time demand of carbohydrates increases for optimum grain filling. In these conditions, water soluble carbohydrates in stem provide a useful resource for grain filling.

Adaptive mechanisms for mitigating these stresses by wheat plants

Various drought-adaptive traits have been investigated in wheat. However, association of these traits with genetic gains for yield under drought has been poorly tested and documented. Major difficulties encountered in the identification of common set of drought tolerance traits are mainly due to a wide range of climatic conditions featured by different drought scenarios worldwide. Hence, it is necessary to focus on those traits which are specific to target environment.

Table 4: Traits associated with tolerance to drought in wheat

Traits for early drought tolerance (adopted from Monneveux, et al., 2012)		
Trait	**Association**	**Reference**
Large seed size	Emergence, early ground cover, and initial biomass	Mian and Nafziger, 1994
Long coleoptiles	Emergence from deep sowing and through crop residues	Radford, 1987; Rebetzke*et al*., 2005
Early ground cover (visual)	Decrease of evaporation and increase of radiation-use efficiency (RUE)	Hafid*et al*., 1998; Richards, 1996
Specific leaf dry weight	Thinner, wider leaves, early ground cover	Merah*et al*., 2001a
Traits for mid season and terminal drought tolerance (Monneveux et al., 2012)		
Growth habit (visual)	Lower soil evaporation and higher RUE	Richards *et al.*, 2002
Tiller survival	Survival and recovery	Loss and Siddique, 1994
Long and thick stem internodes	Storage of carbon products	Loss and Siddique, 1994

Vegetation indices (normalized difference vegetation index; NDVI)	Green biomass	Royo*et al*., 2003
Earliness	Drought escape	Blum, 1988; Monneveux*et al*., 2005
Number of grain per spike	Spike sterility	Hafsi*et al*., 2006
Stomatal conductance	Extraction of water from soil	Farquhar and Sharkey, 1982
Canopy temperature depression	Stomatal conductance, extraction of water from soil	Reynolds*et al*., 2000
Carbon isotope discrimination	Stomatal conductance, extraction of water from soil	Araus*et al*., 2003; 1998; Monneveux*et al*., 2005
Ash content	Stomatal conductance, extraction of water from soil	Misra*et al*., 2006
Spike photosynthetic capacity	Grain filling	Evans*et al*., 1972
Leaf color (visual, SPAD)	Delayed senescence, maintenance of photosynthesis	Araus*et al*., 1997
Leaf waxiness	Lower transpiration rate and reduced photo-inhibition	Richards, 1996
Leaf pubescence	Lower transpiration rate and reduced photo-inhibition	Richards, 1996
Leaf thickness and posture	Lower transpiration rate and reduced photo-inhibition	Reynolds *et al*., 2000
Leaf rolling	Lower transpiration rate and reduced photo-inhibition	Reynolds *et al*., 2001b
Glume pubescence	Lower transpiration rate and reduced photo-inhibition	Trethowan*et al*., 1998
Delayed senescence	Higher RUE	Hafsi*et al*., 2006
Fructans in stem	Storage of carbon products	Rawson and Evans, 1971
Stem reserve mobilization	Grain filling in the absence of current leaf photosynthesis	Rawson and Evans, 1971; Blum, 1998a
Solute concentration in cells	Osmotic adjustment (OA)	Morgan and Condon, 1986
Accumulation of ABA	Reduced stomatal conductance and cell division	Innes *et al*, 1984

Phenotyping methods

Since wheat is grown in different drought scenarios worldwide; the physiological traits that confer drought resistance in specific environments may be very distinct. The combination of yield data with data relating to secondary traits from field experiments at different sites ranging from well-watered to high stress levels has to be used in understanding GEI of traits related to drought tolerance. It is always assumed that the secondary traits having heritability higher than that of yield as well as the high genetic correlation of these traits with yield in the target environment has to be considered. However, it is possible that if a trait which is contributing biomass or root system architecture but not highly correlated with yield can bring desirable change in production under drought condition.

The molecular marker approaches can help in selectively introgressing such traits. While tools and technologies for deciphering the technologies are getting more robust, the limitation to understand their functions useful for crop improvement is limited by our capacity to characterize the plant responses to stresses. In this context the phenotyping traits associated stress tolerance in controlled and natural environment is gaining immense significance. It is increasingly being realized that the success of molecular marker depends on the phenotyping methods used to characterize the plant responses. The method should involve either perfect simulation of targeted drought stress environment or thorough characterization of field environment in addition to precise and reproducible assessment of plant response to the stress relative to non stress environment. This can be achieved by repeated experiments and increasing replications within the experiments particularly when the genotypes are evaluated under field condition. This may often appear as impossible task when a large number of genotypes have to be characterized with conventional methods.

International efforts on conventional phenotyping aimed at a quantification of quality, photosynthesis, development, architecture, growth or biomass productivity of single plants or plant stands using a broad variety of analysis procedures. Some of these procedures are well-known analysis tools of classical plant physiology based on visual observations, measurements or biochemical analyses. However, these were recorded by means of remote sensing or scanners which did not allow very high-throughput acquisition and processing of data. Many of these procedures were based on visual observations, often biased by the examiners' perception and thereby not sufficiently accurate and reproducible. Over the past few decades, rapid development has taken place towards phenotyping for abiotic stresses. This is mainly for the traits that contribute to plant survival in stress conditions. e.g. root architecture, transpiration efficiency/carbon isotope discrimination, stomatal conductance, canopy temperature, osmotic adjustment, nitrogen fixation, stay green etc.

Facilities like phytotron were created for raising the plants in controlled environment, but it can allow crop plants to be grown in a limited number and at an exorbitant cost. Novel phenotyping approaches involve automatic and remote sensing based devices for non destructive screening against temperature stress/drought conditions in bigger plots with sufficient replications for better prediction of association between plant phenotype and genotype. In India, establishment of large and unique facilities for phenotyping has been recent phenomena where intellectual and scientific inputs are considered highly critical right from conceptualization of designs of structures to its successful demonstration to simulate environmental stresses. One of such phenotyping facilities recently created at DWR could successfully maintain temperatures 1^0 to 10^0C higher than than ambient temperatures under natural field conditions. This type of controlled facility would help in evaluation of germplasm and identification of suitable genotypes for utilization in crossing blocks or for direct release as a cultivar. This can be further supported by the emerging phenomics techniques including image based monitoring of plant growth and development combined with automations. These techniques can make it possible to monitor many of the changes in morphological traits by employing visible images while non destructive measurements of physiological traits such as high temperature, at whole plant or canopy level is possible through cameras that are designed to trap and differentiate infrared, near infrared and chlorophyll fluorescence radiation emerging from the objects. Further, emerging non destructive measures to understand the root system architecture can also break the hurdles in improving root traits that can play significant role in stress tolerance.

Molecular markers for drought and heat tolerance

Breeding for this trait is difficult and new molecular methods such as molecular markers, quantitative trait loci (QTL) mapping strategies, and expression patterns of genes should be applied to produce drought and heat tolerant genotypes. QTL analysis is so important to target genes and for doing this some steps are required. Firstly, phenotypic evaluation of relatively large population for markers which are polymorphic is needed. Secondly, genotyping of the population is important. Thirdly, there is a need for statistical analysis to detect the loci that are influencing the target trait. On the other hand, QTL for drought tolerance has some drawbacks like genetic and environmental interactions, numerous numbers of genes, and using of mapping populations which are inappropriate. These have limited plans for mapping of QTL for high yield under drought condition (Gupta *et al*., 1999). Few studies have identified QTLs associated with specific components of drought response (Table 5).

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References

- Ashraf M (2014). Stress-Induced Changes in Wheat Grain Composition and Quality. Critical Reviews in Food Science and Nutrition, 54:12, 1576-1583
- Ashraf M, Harris PJC (2013). Photosynthesis under stressful environments: An overview. Photosynthetica 51: 163-190
- Balla K, Bencze S, Bónis P, Árendás T, Veisz O (2014). Changes in the photosynthetic efficiency of winter wheat in response to abiotic stress. Cent. Eur. J. Biol., 9: 519-530.
- Barnabas B, Jager K, Feher A (2008). The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ 31:11–38
- Chatrath R, Mishra B, Ortiz Ferrara G, Singh SK, Joshi AK (2007). Challenges to wheat production in South Asia. Euphytica 157: 447–456
- CossaniCM,Reynolds MP (2012). Physiological traits for improving heat tolerance in wheat.Plant Physiol.160:1710-1718
- Gibson LR, McCluskey PJ, Tilley KA, Paulsen GM (1998). Quality of hard red winter wheat grown under high temperature conditions during maturation and ripening. Cereal Chem 75:421–427
- Gupta S, Kaur S, Sehgal S, Sharma A, Chhuneja P, Bains NS (2010). Genotypic variation for cellular thermotolerance in *Aegilopstauschii*Coss., the D genome progenitor of wheat. Euphytica 175: 373–381
- Gupta NK, Agarwal S, Agarwal VP, Nathawat NS, Gupta S, Singh G (2013). Effect of short-term heat stress on growth, physiology and antioxidativedefence system in wheat seedlings. ActaPhysiol Plant 35:1837–1842
- Gusta LV, Benning NT, Wu G, Luo X, Liu X, Gusta ML, McHughen A (2009). Superoxide dismutase: an all-purpose gene for agri-biotechnology. Mol Breeding 24: 103–115
- Hasanuzzaman M, Nahar K, AlamMd M, Roychowdhury R, Fujita M (2013). Physiological, Biochemical, and Molecular Mechanisms of Heat Stress Tolerance in Plants. Int. J. Mol. Sci. 14: 9643-9684
- Hawker JS and Jenner CF (1993) High temperature affects the activity of enzymes in the committed pathway of starch synthesis in

developing wheat endosperm. Aust. J. Plant Physiol. 20: 197-209.

- Joshi AK, Mishra B, Chatrath R, Ortiz Ferrara G and Singh RP (2007) Wheat improvement in India: present status, emerging challenges and future prospects. Euphytica. 157: 431-446
- Mitra R and Bhatia CR (2008) Bioenergetic cost of heat tolerance in wheat crop. Current Sci. 94: 8.
- Kaur V, Behl RK, (2010). Grain yield in wheat as affected by short periods of high temperature, drought and their interaction during pre- and postanthesis stages. Cer. Res. Commun., 38: 514-520.
- Mitra R and Bhatia CR (2008) Bioenergetic cost of heat tolerance in wheat crop. Current Sci. 94: 8.
- Mohammed YSA, Tahir ISA, Kamal NM, Eltayeb AE, Ali AM, Tsujimoto H (2014). Impact of wheat-*Leymusracemosus*added chromosomes on wheat adaptation and tolerance to heat stress. Breeding Science 63: 450–460
- Mullan DJ, Reynolds MP (2010). Quantifying genetic effects of ground cover on soil water evaporation using digital imaging. Funct Plant Biol 37: 703–712
- Rane J, Pannu RK, Sohu VS, Saini RS, Mishra B, Shoran J, Crossa J, Vargas M, Joshi AK (2007). Performance of Yield and Stability of Advanced Wheat Genotypes under Heat Stress Environments of the Indo-Gangetic Plains. Crop Sci. 47:1561–1573
- Randall PJ, Moss HJ (1990) Some effects of temperature regime during grain filling on wheat quality. Australian Journal of AgriculturalResearch. 41: 603-617.
- Reynolds MP, Saint Pierre C, Saad ASI, Vargas M, Condon AG (2007) Evaluating potential genetic gains in wheat associated with stress-adaptive trait expression in elite genetic resources under drought and heat stress. Crop Sci 47:172–189
- Ristic Z, Bukovnik U, Vara Prasad PV (2007). Correlation between Heat Stability of Thylakoid Membranes and Loss of Chlorophyll in Winter Wheat under Heat Stress. Crop Sci. 47:2067–2073
- Salvucci ME (2008). Association of Rubiscoactivase with chaperonin-60β: a possible mechanism for protecting photosynthesis during heat stress. Journal of Experimental Botany, 59: 1923–1933
- Sareen S, Tyagi BS, Tiwari V, Sharma I (2012).Response Estimation of Wheat Synthetic Lines to Terminal Heat Stress Using Stress Indices. Journal of Agricultural Science 4: 97 – 104
- Sarieva GE, Kenzhebaeva SS, LichtenthalerHK (2010). Adaptation Potential of Photosynthesis in Wheat Cultivars with a Capability of Leaf Rolling under High Temperature Conditions. Russian Journal of Plant Physiology, 57: 28–36
- Semenov MA and Halford NG (2009) Identifying target traits and molecular mechanisms for wheat breeding under a changing climate. J. Exper. Bot. 60: 2791–2804.
- Stone PJ and Nicolas ME (1994) Wheat cultivars vary widely in responses of grain yield and quality to short period of post-anthesis heat stress. Aust. J. Plant Physiol. 21: 887-900.
- Tashiro T, Wardlaw, IF (1990) The response to high temperature shock and humidity changes prior to and during the early stages of grain development in wheat. Aust. J. Plant Physiol. 17: 551–561.
- Wahid A, Gelani S, Ashraf M.andFoolad MR (2007) Heat tolerance in plants: An overview. Environment and Experimental Bot. 61: 199–223
- Wang W, Vinocur B, Shoseyov O, Altman A (2004). Role of plant heat-shock proteins and molecular chaperones in the abiotic stress response. Trends in Plant Science, 9: 244-252
- Wardlaw, I.F. & C.W. Wrigley, 1994. Heat tolerance in temperate cereals: An overview. Aust J Plant Physiol 21: 695–703.
- Wollenweber B, Porter JR and Schellberg J (2003). Lack of interaction between extreme high temperature events at vegetative and reproductive growth stages in wheat. Journal of Agronomy and Crop Science. 189: 142–150.
- Yang J, Sears RG, Gill BS, Paulsen GM (2002a). Genotypic differences in utilization of assimilate sources during maturation of wheat under chronic heat and heat shock stresses-utilization of assimilate sources by wheat under heat stresses. Euphytica125: 179–188

Climate change adaptation and mitigation strategies for improving soil health

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Climate change is a statistical variation in properties of the climate system that includes changes in global temperature, precipitation, etc due to natural or human drivers over a long period of time. It may affect distribution and quality of natural resources thereby influencing livelihood security of the people (Status of Indian Agriculture, 2013). Recent climate change activities is the increase in earth's temperature by 0.74 ^{o}C between 1906 to 2005 (IPCC 2007) due to increase in anthropogenic emissions of green house gases such as carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and chlorofluorocarbon (CFCs). Increase in concentration of green house gases influence future climate as well as agriculture (IPCC, 2001; Aggarwal, 2003).

With the current climate change scenario, there is a need to reduce the intensity and slow down the growth of greenhouse gas emissions. Additionally, increase resilience of production systems to climate-change-driven extreme events and maintain sustainability of these systems in the face of long-term climate changes (FAO, 2014). Soils are the basis of food production. Ninety five percent of our food is directly or indirectly produced on our soil. A healthy soil maintain a diverse community of organisms that helps in controlling pests (insects, weeds, and fungus) but also form beneficial symbiotic association with plant roots, recycle essential plant nutrients and improve soil structure. A healthy soil can also be a strategic ally in mitigating and adapting to climate change, as soil sequesters CO_2 and prevent to escape into the atmosphere. Beside this, it contributes to mitigate climate change by maintaining or increasing its carbon content. This can be said that the proportion of organic carbon is available more in the soil than combining both atmosphere and ground vegetation. Most of the soil organic carbon (SOC) stored in the first metre of the soil in the form of organic matter. However, organic matter degrades due to deforestation, deplete soil biodiversity, loss of nutrients as consumed by crop plants, soil compaction due to excessive use of agricultural machineries, soil erosion, waterlogging conditions, and urbanization , which release greenhouse gases like CO_2, CH_4, and N_2O into the atmosphere causing global warming and climate change. One third of all CO_2 emissions comes from changes in land use

(deforestation, shifting cultivation, and intensification of agriculture) whereas two-thirds of CH_4 and majority of N_2O emitted through agricultural practices (Kotschi and Müller-Sämann, 2004).

Challenges due to climate change on Indian agriculture

The challenge is to enhance productivity in agriculture as it is declining due to loss in soil fertility, increase cost of production, and rainfed nature of agriculture in the state. Current observations of data sets of various weather parameters indicate a gradual increase in temperature across all the seasons with erratic and uneven spatial and temporal distribution of south-west monsoon (SWM), which poses a major constraint for achieving target levels of production particularly in rainfed area. In the current situation, the season is observing aberrations that include delay in onset, long dry spells, and early withdrawl of SWM that may affect crop and reduce productivity levels with majority of area under rainfed agroecosystem, and soils have low organic carbon content having multi-nutrient deficiencies. These rainfall aberrations may likely to increase in future with more skewed distribution and reduction in the number of rainy days. Climate projections also indicate a future increase in temperature by 2050s with uneven distribution of rainfall across the state, with perceptible decrease in rainfall during winter period, and almost no change in rainfall during monsoon with respect to current climate. These predicted changes could lead to spatial and temporal shift of cropping centres and decline in the productivity of crops. It is likely that the onset of south-west monsoon may shift from June to the first fortnight of July that could affect cropping sequence and sowing time. Also, increase in rate of evapotranspiration also increase with temperature, which will lead to depletion in moisture retention capacity of different soil types and may pose a threat to agriculture. On the other side, increase in rainfall leads to faster runoff causing higher soil erosion, which will deteriorate soil health and its fertility. The rise in temperature cause stored carbon to be released from the soil. Beside this, night temperature may increase in the future particularly in peninsular India , which is a cause of concern for agriculture as increased night temperature accelerate respiration, hasten crop maturity, and reduce yield along with increase in the crop water requirement. The risk of crop failure and poor yields always influence farmers' decision on investing on new technologies and level of input use (Pandey et al., 2000). Numerous technological (e.g. cropping patterns, crop diversification, soil health management, rainwater harvesting, shifts to drought/salt tolerant varieties etc) and socio-economic (e.g. ownership of assets, access to services, infrastructural support etc) factors will come into play in enhancing or constraining the current capacity of rainfed farmers to cope with climate change (Srinivasarao etal., 2014).

Certain areas have soils with low underlying storage capacity and low water availability for irrigation. Due to less irrigation, farmers used to plant one crop in a year. Under utilization of large tract of fallow land, or use for one season contribute to under realization of the potential productivity of crops. Beside this, monocropping also makes the crop susceptible to failure if there is a change in climatic conditions for optimal production. On the other hand, use of fertilizers coupled with chemicals for longer period affects soil fertility and productivity in high cropping intensity regions.

In the present agricultural scenario, without taking further risks, there is a need to look for solutions that are based on ecological and biological principles and have fewer environment costs. Therefore, the quest for climate-proof food systems is of interest to all (Scialabba and Müller-Lindenlauf, 2010).

Climatic Variability of Madhya Pradesh

Annual Rainfall pattern of Madhya Pradesh was depicted in the Fig.1 with data from 1971-2001 with weather dataset obtained from National Initiative on Climate Resilient Agriculture (NICRA) project from Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. It was compared with yearly rainfall pattern that occurred in the last decade from 2002 to 2011 in Madhya Pradesh (Fig. 2). Analysis of 30 years data (1971-2001) of annual rainfall of different districts of Madhya Pradesh suggest that annual rainfall trend started increasing from normal in certain districts like Sidhi, Shahdol, Bhind, Gwalior, Datia, Burhanpur, Seoni, Mandla, Balaghat, Guna, Vidisha, Bhopal, and Raisen of Madhya Pradesh. Annual rainfall trend of the 2002-2011 decade observed 30 out of 51 districts of Madhya Pradesh suggest increase in rainfall with an increase in the number of districts observing increasing trend of annual rainfall however Balaghat, Sidhi, and Shahdol districts observed decreasing trend in the previous decade as compared from 1971-2001 decades. This suggests that these districts are more vulnerable to rainfall in the coming years as climate change or rainfall decrease in these districts as compared to the other districts of Madhya Pradesh.

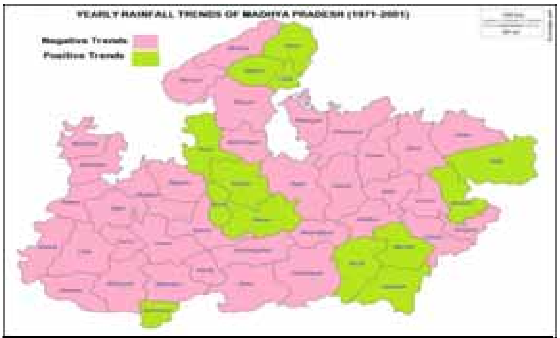

Fig. 1 Annual rainfall trend of Madhya Pradesh (1971-2001)

Fig. 2. Annual rainfall trend of Madhya Pradesh in the last decade (2002-2011)

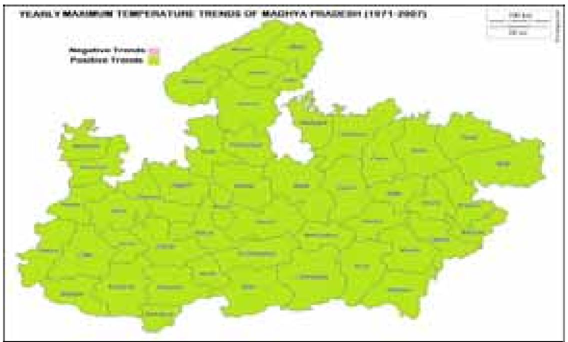

Fig. 3. Long-term annual trend of maximum temperature of M.P. (1971-2007)

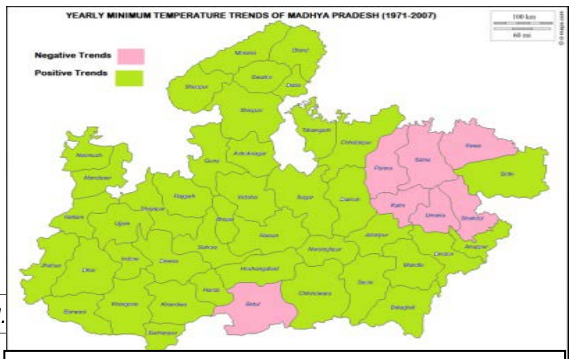

Fig. 4. Long-term annual trend of minimum temperature of M.P. (1971-2007)

Similarly, maximum and minimum temperatures long-term pattern suggest an increase in annual temperature from normal in all the districts of Madhya Pradesh on annual and season basis except Barwani district that observed a decrease in temperature during kharif season (Fig. 3).Likewise, minimum temperature analysis suggest increase in minimum temperature in almost all the districts except in north-east region covering Panna, Satna, Rewa, Katni, Umariya, and Shahdol districts (Fig. 4). Similarly, Betul district in the southern region also observed a decrease in minimum temperature from normal. From crop growth , minimum temperature is more important than the maximum temperature as increasing maximum temperature leads to more evapotranspiration while minimum temperature affects reproductive performance particularly grain filling of the crop(Venkateswarlu and Rao, 2014). With the increase in maximum temperature, the soil temperature will be affected with influence on soil flora and fauna with losses in evaporation and release of carbon from the soil.

Strategies for sustainable soil management: Globally, 25 percent of planet land is highly degraded. There is a need for action to increase area under sustainable soil management practices to enhance the restoration of degraded soils, and promote sustainable crop production intensification. A sustainable soil management could produce upto 58 % more food than intensive management systems. It required diverse farming strategies with inclusion of agroecology, organic farming, conservation agriculture, agroforestry and zero tillage that need to be included in a system with a holistic system approach. Overall aim is to address the food demand caused by growing population. Certain strategies /methods to be adopted to sustain soil health and ultimately combat climate change include: analyze soil condition; raise awareness about greenhouse gases; increase organic content of soil; cultural practices like crop rotation, minimum tillage and land-use planning with an aim to reduce soil erosion and degradation. Application of recommended dose of nutrients to be added into the soil as it will prevent nutrient imbalance in the soil. Similarly, reduce water and wind erosion by improving soil vegetation and tree cover that also prevent soil degradation while maintaining water and nutrient cycling of crop plants. Crop rotation improves soil health by reducing soil nutrient depletion, which takes place more in monocultural intensive agricultural systems. Further, planting diversified crops will protect soil from erosion and also improves soil structure either through rooting, enriching soil nutrients by providing organic matter, and establishing symbiotic relationships with soil bacteria.

On the other side, livestock sector provide food and income for one billion people mostly poorer people of this world. This sector follow the practices of grazing, removing soil cover, making soil vulnerable to soil erosion thereby reducing important soil functions such as climate regulation. Grass type and pasture rotation helps to keep the soil system functional. With the rise in demand of products obtained from this sector, soil protection and conservation on pasturelands become even more critical. Similarly, forest provide livelihood for more than one billion people worldwide, and vital for conservation of biodiversity, energy supply, and soil and water protection. Nearly, 1/3rd of the total carbon in terrestrial ecosystem is captured in forest thus act as a ‘carbon sink’. In the current scenario, increase use of solid biofuels with expansion of agricultural lands thereby reducing forest land or decreasing the capacity of forest soils to act as carbon sink by 20 -40 percent in the future.

The key lies in building healthy and dynamic ecosystems more resilient to stresses, and better able to cope with – and respond to – climate change, extreme weather events, emerging diseases, shift in population patterns and economic disruption and shocks (FAO, 2014).

Adaptation and mitigation strategies for improving soil health

The major aim of these strategies is to attempt a gradual reversal of effects caused by climate change and sustain development under the inescapable effect of climate change. Mitigation and adaptation are related to temporal and spatial scales on which they are effective. The benefits of mitigation activities carried out today will be evidenced in several decades because of the long residence time of greenhouse gases in the atmosphere, whereas the effects of adaptation measures should be apparent immediately or in the near future (Kumar and Parikh, 2001). Besides, mitigation has global in addition to local benefits, whereas adaptation typically takes place on a local or regional scale (Srinivasarao et al., 2014).

Technically, adaptation measures are related with change in production systems like adjusting planting or fishing dates, rotations, multiple cropping/species diversification, crop-livestock pisciculture systems, agroforestry, soil, water and biodiversity conservation and development by building soil biomass, restoring degraded lands, rehabilitating rangelands, harvesting and recycling water, planting trees, developing adapted cultivars and breeds, protecting aquatic ecosystems to maintain long-term productivity Adaptation measures also include disaster risk management plans and risk transfer mechanisms, such as crop insurance and diversified livelihood systems. Mitigation options include carbon sequestration in agriculture and forestry. Mitigation of climate change is a global responsibility. Agriculture, forestry, fisheries/aquaculture provide in principle, a significant potential for greenhouse gases mitigation (Venkateswarlu and Shanker, 2009; Srinivasarao et al., 2014).

Agroecology: It is a system approach based on a variety of diverse technologies, practices and innovations including local and traditional knowledge and modern science.

Organic Farming: Organic agriculture is a holistic production management system, which promotes sustainable agriculture and enhances agro-ecosystem health. It ensures qualitative development of soil, water and environment on sustainable basis. The experimental evidences could prove that a holistic soil and crop management had similar productivity as compared to conventional agriculture and often higher yields in the regions of the world where the production environment is much fragile and tough (rainfed and hilly areas) (Scialabba and Müller-Lindenlauf, 2010). On this note, organic agriculture may prove to be an alternating strategy to avert climate change with basic principles as mentioned by Kotschi and Müller-Sämann (2004) in organic agriculture with regard to mitigation of climate change, and it include to:

- Encourage and enhance biological cycles within the farming system
- Maintain and increase long-term fertility in soils
- Use as far as possible , renewable resources in locally organized production systems
- Minimize all forms of pollution

Beside this, organic agriculture give priority to the optimal (recycled and reuse) use of inputs with an aim to achieve maximum output.

Resource Conservation Based Technologies: The key resource conservation-based technologies are *in situ* moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in crop production and irrigation and use of poor quality water. Other strategies include characterization of bio-physical and socio-economic resources utilizing GIS and remote sensing; integrated watershed development; developing strategies for improving rainwater use efficiency through rainwater harvesting, storage, and reuse; contingency crop planning to minimize loss of production during drought/flood years (Kapoor, 2006).

Beside this, use of zero tillage reduced the demand for water, and save fuel beside enriching soil organic matter. Also bed planting increased water use efficiency, reduced water logging, better access for inter-row cultivation, weed control and banding of fertilizers, better stand establishment, less crop lodging and reduced seed rates.

System for Rice Intensification (SRI) technology consists of keeping rice fields moist rather than continuously saturated, thereby minimizing anaerobic conditions, and improving root growth. Rice plants are also spaced optimally in SRI method that permit more growth of roots and canopy and to keep all leaves photosynthetically active. To minimize transplant shock, rice seedlings are transplanted at two-leaf stage to avoid trauma to roots (Venkateswarlu and Shanker, 2009).

Integrated Nutrient Management (INM) and Site-Specific Nutrient Management (SSNM) techniques have the potential to mitigate effects of climate change by reducing carbon dioxide emissions and improving crop yield. One of the key emerging technologies to reduce GHG emissions from paddy fields is the use of zymogenic bacteria, acetic acid and hydrogen-producers, methanogens, methane oxidizers, and nitrifiers and denitrifiers in rice paddies which help in maintain the soil redox potential in a range where both nitrous oxide and methane emissions are low (Venkateswarlu and Shanker, 2009). The application of urease inhibitor, hydroquinone (HQ), and a nitrification inhibitor, dicyandiamide (DCD) together with urea also is an effective technology for reducing nitrous oxide and methane from paddy fields. Use of neem-coated urea is another simple and cost effective technology.

Conservation agriculture: In the climate change scenario and facing nine billion mouths to feed by 2050, conservation agriculture is a key to future food security by

(a). Conservation agriculture observes three major principles/pillars as

- Direct seeding of growing crops without mechanical field preparation and with minimal soil disturbance since the harvest of previous crop.
- A permanent coil cover to protect soil against deleterious effect of exposure to rain and sun; addition of micro and macro organisms in the soil with a constant supply of 'food'; and alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots.

- Crop rotation provide different root depths exploring different soil layers for nutrients, and also provide diverse 'diet' to the soil microorganisms.

(b). With the increasing organic matter under conservation agriculture, soil can retain carbon from carbon dioxide and act as a carbon repository for longer time period fighting climate change problem.

(c). Conservation agriculture provides small-scale farmers with diversification opportunities : Reduced labor requirements for tillage, land preparation and weeding. More time availability offers real opportunities for diversification options such as for example poultry farming or on-farm sales of produce, or other off-farm small enterprise developments.

(d). Conservation agriculture lowers farm power: Reduced requirements for farm power and energy for field production by up to 60 % compared to conventional farming. Additionally equipment investment, particularly the number and size of tractors, is significantly reduced. Zero tillage reduces soil compaction causing more carbon to retain in the soil, thereby improving soil health.

Agroforestry: It include both traditional and modern land-use system where trees are managed together with crops and/or animal production systems in agricultural setting. Agroforestry systems buffer farmers against climate variability, and reduce atmospheric loads of greenhouse gases. Agroforestry can both sequester carbon and produce a range of economic, environmental, and socio-economic benefits. For example, trees in agroforestry systems improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased nitrogen aeration, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling. In India, reducing emissions from deforestation and forest degradation is a major event that need to evaluate to rectify it.

Biomass recycling: Indian agriculture produce around 500 550 million tonnes (Mt) of crop residues annually, which can be used as animal feed, soil mulch, manure, thatching for rural homes and fuel for domestic and industrial purposes. However, large portion of around 90-140 Mt residues burnt on-farm annually to clear the field for the next succeeding crop (NAAS, 2012). Burning causes release of smoke, deleterious particles, emission of green house gases , and loss of plant nutrients like N,P,K,S, and carbon from the soil, which are beneficial for soil health.

A large amount of energy is used in cultivation and processing of crops like sugarcane, food grains, vegetables and fruits, which can be recovered by utilizing residues for energy production (Srinivasarao et al., 2014). This can be a major strategy of climate change mitigation by avoiding burning of fossil fuels and recycling crop residues (Venkateswarlu, 2010). Lack of availability equipment that helps to incorporate soil is one of the major reasons for biomass wastage in India. Other issues include high labour and transport costs that causes lack of interest in utilizing the biomass. Many technologies like briquetting, anaerobic digestion, vermicomposting and biochar etc exist, but they have not been commercially exploited among farmers and growers (Srinivasarao et al., 2014). CRIDA (2014) suggest biochar application to soil improves soil properties and crop yield .

Tank silt application: Community tanks and *taals* commonly found in Madhya Pradesh used to collect rain water along with nutrient-rich top soil eroded from catchment areas. This tanks silt can supplied organic carbon and several nutrients beside improving soil physical, chemical and biological properties, if applied in the field.

Mulching-cum-manuring: In permanent cropping system, soil organic carbon improves by use of organic manures added through plant residues, mixed cropping, legume based crop rotations, or agroforestry (Drinkwater et al., 1998). On the opposite side, sole use of synthetic nitrogen fertilizer application increases oxidation of organic matter, thereby reducing organic carbon from the soil. It improves soil surface conditions to increase infiltration, and water holding capacity, and reduce evaporation losses from the field. Beside this, it also add additional nitrogen into the soil thereby improving soil health.It reduces temperature fluctuation in the soil and lowered down the canopy temperature at grain filling stage in wheat giving higher yield and test weight levels. It can be done through the use of crop residues, green manure crops, green leaf manure crops, brown manuring etc.

Mitigating N_2O emission from soils: N_2O emission contributes 38 % of agricultural GHGs emissions (Smith et al., 2007) of which 1 % as direct N_2O emission from applied nitrogenous fertilizers. These emissions can be reduced by adding catch or cover crops that have the capacity to extract stored nitrogen from the soil that was not used by the previous crops. However, study suggests higher N_2O emission after manure application compared to mineral fertilizer application due to higher oxygen consumption for decomposition of organic matter (Flessa and Beese, 2000). These can be reduced by improving soil aeration either by lowering bulk density, rescue incorporation of legumes, and increase tillage practices (as no-tillage cause low aeration with more release of N_2O gas.

Carbon sequestration for mitigating Climate Change: Lal (2004) implies soil carbon sequestration is the transfer of atmospheric CO_2 into long-lived soil pools and storing it securely so that it may not be reemitted back instantly. It means increasing soil organic and inorganic carbon stocks through judicious land use with best recommended management practices. The global soil carbon pool of 2500 gigatons (Gt) include 1550 Gt of soil organic carbon and 950 Gt of soil inorganic carbon (Lal, 2004). Depletion of soil organic carbon (SOC) degrade soil quality, reduces biomass productivity, and adversely impact water quality, and this depletion increase the cause of global warming (Lal, 2004). Cultural practices like no-tillage improves carbon sequestration however it also increases N_2O emissions. Beside this, carbon stored through no-tillage is released by single ploughing due to its labile quality (Stockfisch et al., 1999) that showed that removal of GHGs from the atmosphere through carbon sequestration is limited.

Improving and sustaining SOC particularly in rainfed agroecosystem is a major agronomic challenge. Their concentration improves or maintain more in the soil with INM practices with the application of organics in conjunction with the fertilizers (Srinivasarao et al., 2013). The SOC stock in the soil profile varies with soil order with more SOC accumulate in vertisol > Inceptisol>Alfisol > Aridisol. Their rate of depletion ranges from 0.15 Mg C/ ha/yr under rice system to 0.92 Mg C/ ha/yr in groundnut-finger millet system (Srinivasarao e al., 2014). To arrest this depletion, carbon input of 1.10 – 3.47 Mg C/ ha/yr is required as a maintainence dose. Further, potential of tropical soils to sequester more carbon can be harnessed by identifying appropriate production systems and management practices for sustainable development and improved livelihood in the tropics (Srinivasarao et al., 2014).

References

- Aggarwal, P. K. 2003. Impact of climate change on Indian agriculture. J. Plant Biology 30(2), 189–198.
- CRIDA. 2014. Annual Report 2013-14, Central Research Institute for Dryland Agriculture, Hyderabad, India. pp 37-38.
- Drinkwater, L.E., Wagoner, P. and M. Sarrantonio, M. 1998. "Legume-Based Cropping Systems Have Reduced Carbon and Nitrogen Losses," Nature 396: 262–65.
- FAO. 2014. Target and indicators for the post 2015 development agenda and the sustainable development goals. Available at www. Fao.org/file admin/user_upload/post2015/Target_and_indicator_RBA_joint_proposal.pdf
- Flessa, H. and Beese, F. 2000. Laboratory estimates of trace gas emissions following surface application and injection of cattle slurry. Journal of Environmental Quality 29:262– 268.
- IPCC .2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assess-ment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.
- IPCC. 2007. Contribution of Working Group 1 to the Fourth Assesment Report of the Inter Governmenttal Panel on Climate Change. pp 996. Solomom S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M and Miller HC (Eds).Cambridge University Press, Cambridge, UK and Newyork, USA.
- Kapoor, A. 2006. Mitigating natural disasters through preparedness measures. Proc. International Conference on Adaptation to Climate Variability and Change, 5-7 January 2006, New Delhi, organized by Institute for Social and Environmental Transition and Winrock International India. 184 p.
- Kotschi, J., and Müller-Sämann, K. 2004. The Role of Organic Agriculture in Mitigating Climate Change: A Scoping Study. IFOAM, Bonn, Germany. Available at http://www.ifoam.org/press/positions/Climate_study_green_house-gasses.html. Accessed February 12, 2009.
- Kumar, K.S.K. and Parikh, J. 2001. Indian agriculture and climate sensitivity. *Glob. Environ. Chang.* 11(2): 147-154.
- Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623–1627.
- NAAS, 2012. Management of crop residues in the context of conservation agriculture. Policy Paper No. 58, National Academy of Agricultural Sciences, New Delhi. pp. 12.
- Pandey, S, Behura, D.D, Villano, R. and Naik, D. 2000. Economic costs of drought and farmers' coping mechanisms: A study of rainfed rice systems in eastern India. Discussion Paper Series 39, IRRI, Phillipines. 35 p.

- Scialabba, N.E. and Müller-Lindenlauf, M. 2010.Organic agriculture and climate change. Renewable Agriculture and Food Systems: 25(2); 158–169.
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H.,Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., and Sirotenko, O. 2007. Agriculture. In B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- Srinivasarao, Ch, Venkateswarlu, B, Rattan Lal, Singh, A.K. and Kundu, S. 2013. Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. In: 'Advances in Agronomy' (Ed. Donald L. Sparks). Vol. 121, pp. 253-329. (Academic Press, Burlington).
- Srinivasrao,Ch, Gopinath, K.A., Venkatesh, G., and Jain, M.P. 2014. Climate change adaptation and mitigation strategies in rainfed agriculture. In Souvenir: National Seminar on 'Technologies for sustainable production through climate resilient agriculture' , JNKVV, Jabalpur, August8-9, 2014.L-13.
- Status of Indian Agriculture. 2013. Directorate of Economics and Statistics. Department of Agriculture and Cooperation. Ministry of Agriculture, Government of India, New Delhi.
- Stockfisch, N., Forstreuter, T., and Ehlers, W. 1999.Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. Soil and Tillage Research 52:91–101.
- Venkateswarlu, B. 2010. Climate change: Adaptation and mitigation strategies in rainfed agriculture. The 21st Dr. S.P. Raychaudhuri Memorial Lecture, delivered on 25th September, 2010 at BAU, Ranchi.
- Venkateswarlu, B. and Shanker, A.K. 2009. Climate change and agriculture: Adaptation and mitigation strategies. *Indian J. Agron.* 54(2): 226-230.
- Venkateswarlu, B. and Rao, V.U.M. 2014. Agriculture in Madhya Pradesh:Impacts of climate change and adaptation strategies. Available at www.skmccc.net.

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Impact of climate change on insect pests and future challenges

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The most general definition of *climate change* is a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause. According to Intergovernmental Panel on Climate Change (IPCC), it is defined as "Change in climate over time, either due to nature variability or as a result of human activity".

The global mean surface temperature is predicted to increase by 1.4 to 5.8^0 C from 1990 to 2100. The atmospheric concentration of carbon dioxide in 2005 was 379 ppm[3] compared to the pre industrial levels of 280 ppm[3].The carbon dioxide levels have increased to 380 ppm[3] by the end of the century.

Climate change can be positive, negative or neutral impact on individual pest systems because of the specific nature of interactions of host, the pest and the environment. Global climate change affects species distribution, life histories, community composition and ecosystem function. In ecosystem, the tritrophic interaction between plants, herbivorous insects and natural enemies (predators, parasitoids and pathogens) result from a long co-evolution process and effects are likely to be more pronounced at higher trophic levels.

Insects and the environment

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Predictions of insect life stage are most often calculated using accumulated degree days from a base temperature and biofix point. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors. It has been estimated that with an increase of 2^{o}C in temperature, insects might experience one to five additional life cycles per season. Other researchers have found that effects of moisture and CO_2 on insects can be potentially important considerations in a global climate change setting.

Impact of rising temperatures on insects

Climate change resulting in increased temperature could impact crop pest insect populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, but most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects. Increased temperature could increase insect pest populations. Researchers have shown that increased temperatures can potentially affect insect survival, development, geographic range, and population size. Temperature can influence insect physiology and development directly or indirectly through the physiology or existence of hosts. Depending on the development "strategy" of an insect species, temperature can exert different effects.

Some insects take several years to complete one life cycle – these insects (cicadas, arctic moths) will tend to moderate temperature variability over the course of their life history. Some crop pests are "stop and go" developers in relation to temperature – they develop more rapidly during periods of time with suitable temperatures. Increased temperatures will accelerate the development of these types of insects – possibly resulting in more generations (and crop damage) per year. "Migratory" insects may arrive earlier in the area in which they are able to overwinter, may be expanded.

Natural enemy and host insect populations may respond differently to changes in temperature. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before parasites emerge. Hosts may pass though vulnerable life stages more quickly at higher temperatures, reducing the window of opportunity for parasitism.Temperature may change gender ratios of some pest species such as thrips and potentially affecting reproduction rates.

Insects that spend important parts of their life in the soil may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air.

Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations. Higher average temperature might result in some crops being able to be grown in other regions and it is likely that at least some of the insect pests of those crops will follow the expanded crop areas. Insect species diversity per area tends to decrease with higher latitude and altitude, meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates. Based on evidence developed by studying the fossil record some researchers concluded that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature. Increased temperature could decrease pest insect populations:

Some insects are closely tied to a specific set of host crops. Temperature increases will compel farmers not to grow the host crop any longer, would decrease the populations of insect pests which are specific to those crops. The same environmental factors that impact insect pests can impact their insect predators and parasites as well as the disease organisms that infect the pests, resulting in increased attack on insect populations.

At higher temperatures, aphids have been shown to be less responsive to the aphid alarm pheromone they release when under attack by insect predators and parasitoids – resulting in the potential for greater predation.

Impact of rainfall / precipitation on insects

There are fewer scientific studies on the effect of precipitation on insects than temperature. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. This consideration is important when choosing management options for onion thrips. For some insects that overwinter in soil, flooding the soil has been used as a control measure. It is expected that more frequent and intense precipitation events forecasted with climate change would have negative impact on these insects. Other insects such as pea aphids are not tolerant of drought. As with temperature, precipitation changes can also impact insect pest predators, parasites, and diseases resulting in a complex dynamic.

Fungal pathogens of insects are favored by high humidity and their incidence would be increased by climate changes that lengthen periods of high humidity and reduced by those that result in drier conditions.

Impact of rising Carbon dioxide levels on insects

Generally carbon dioxide impacts on insects are thought to have indirect impact on insect damage results from changes in the host crop. Some researchers have found that rising carbon dioxide can potentially have important effects on insect pest problems.

Recently, free air gas concentration enrichment (FACE) technology was used to create an atmosphere with carbon dioxide and oxygen concentrations similar to what climate change models predict for the middle of the 21st century.

FACE allows for field testing of crop situations with fewer limitations than those conducted in enclosed spaces. During the early season, soybeans grown in elevated carbon dioxide atmosphere had 57% more damage from insects than those grown in today's atmosphere, and required more insecticide treatment in order to protect the crop. It is thought that increase in the levels of simple sugars in the soybean leaves may have stimulated the additional insect feeding.

Some researchers have observed that insects sometimes feed more on leaves that have low nitrogen content, in order to obtain sufficient nitrogen for their metabolism. Increased carbon to nitrogen ratios in plant tissue resulting from increased carbon dioxide levels may slow insect development and increase the length of life stages vulnerable to attack by parasitoids.

Examples on impact of extreme climate / weather on pests

- Invasion of sugarcane wooly aphid, *Ceratovacuna lanigera* in Maharashtra in 2002.
- *Helicoverpa armigera* was a major pest of chickpea and pigeonpea, but after the introduction of *Bt* cotton in 2002, its infestation in these crops has significantly declined in the cotton based cropping system. There is no significant movement of this pest from cotton- to – pigeon pea- to- chickpea.
- During 2006, mealy bug, *Phenacoccus solenopsis* which was never reported as a serious pest of cotton in India gained pest status on *Bt* cotton in Gujarat and during 2007 in Punjab, and Rajasthan and Maharashtra causing heavy reduction in yield.
- During 2008, occurrence of *Spodoptera litura* epidemic on soybean in Vidarbha region of Maharashtra and brown plant hopper in Haryana / Western Uttar Pradesh belt of Basmati rice were mainly due to favourable prevailing weather conditions.
- Declined survival rate of brown plant hopper *Nilaparvata lugens* (Stal) and rice leaf folder, *Cnaphalocrocis medinalis* (Guen) at higher temperature indicated the impacts of rising temperature could do the changes in the pest population dynamics of rice ecosystem.

Impact of extreme climate / weather on farmers

It is likely that farmers will experience extensive impacts on insect management strategies with changes in climate. Entomologists expect that insects will expand their geographic ranges, and increase reproduction rates and overwintering success. This means that it is likely that farmers will have more types and higher numbers of insects to manage. Based on current comparisons of insecticide usage in different areas, it likely means more insecticide use and expense in some areas. It is apparent that for some crop pests, warmer temperatures will require increased insecticide applications to produce a marketable crop. Insecticides and their applications have significant economic costs for growers and environmental costs for society. Additionally, some classes of pesticides (pyrethroids and spinosad) have been shown to be less effective in controlling insects at higher temperatures.

Entomologists predict additional generations of important insect pests in temperate climates as a result of increased temperatures, probably necessitating more insecticide applications to maintain populations below economic damage thresholds. A basic thumb rule for avoiding the development of insecticide resistance is to apply insecticides with a particular mode of action less frequently than with more insecticide applications required, the probability of applying a given mode of action insecticide more times in a season will increase, thus increasing the probability of insects developing resistance to insecticides.

A number of cultural practices that can be used by farmers could be affected by changes in climate – although it is not clear whether these practices would be helped, hindered, or not affected by the anticipated changes. Using crop rotation as an insect management strategy could be less effective with earlier insect arrival or increased overwintering of insects. However, this could be balanced by changes in the earliness of crop planting times, development, and harvest.

Adaptation strategies by the farmers to mitigate climate change

Farmers should keep in mind that climate change is likely to be a gradual process that will give them some opportunity to adapt. It is likely that new pests will become established and attack plants in new regions. It is likely that plants in some regions will be attacked more frequently by certain pests. A few pests may be less likely to attack crops as change occurs.

Clearly, it will be important for farmers to be aware of crop pest trends in their region and flexible in choosing both their management methods and in the crops they grow. Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency, and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest management technique. If more insecticide applications are required in order to successfully grow a particular crop, farmers will need to carefully evaluate whether growing that crop remains economical.

Those farmers who make the best use of the basics of integrated pest management (IPM) such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change.

Summary

- The precise impacts of climate change on insects are somewhat uncertain because some climate changes may favor insects while others may inhibit a few insects.
- The preponderance of evidence indicates that there will be an overall increase in the number of outbreaks of a wider variety of insects
- It can cause a shift in geographical spread, diversity.
- The possible increased use of insecticides resulting from an increase in pest outbreaks will likely have negative environmental and economic impacts for agriculture in areas.
- The best economic strategy for farmers to follow is to use integrated pest management practices to closely monitor insect and disease occurrence.
- Keeping pest and crop management records over time will allow farmers to evaluate the economics and environmental impact of pest control and determine the feasibility of using certain pest management strategies or growing particular crops.

References

- Aerts, M., P. Cockrell, G. Nuessly, R. Raid, T. Schueneman, and D. Seal. 1999. Crop Profile for Corn (Sweet) in Florida. http://www.ipmcenters.org/CropProfiles/docs/FLcorn- sweet.html
- Ammann, B. (2000): Biotic responses to rapid climatic changes; Introduction to a multidisciplinary study of the Younger Dryas and minor oscillations on an altitudinal transect in the Swiss Alps. – Palaeogeography, Palaeoclimatology, Palaeoecology 159 (3-4): 191-201.
- Andrew, N.R. and L. Hughes. 2005. Diversity and assemblage structure of phytophagousHemiptera along a latitudinal gradient: predicting the potential impacts of climate change. Global Ecol Biogeogr. 14:249-262.
- Andrew, N.R and Hughes, L. (2007): Potential host colonization by insect herbivores in a warmer climate: a transplant experiment. – Global Change Biol. 13: 1539-1549.
- Awmack, C.S., C.M. Woodcock and R. Harrington. 1997. Climate change may increase vulnerability of aphids to natural enemies. Ecological Entomology. 22:366-368.

- Ayres, M.P and Lombardero, M.J. (2000): Assessing the consequences of global change for forest disturbance from herbivores and pathogens. – The Science of the Total Environment 262(3): 263-286.
- Bale, J.S. G.J. Masters, I.D. Hodkinson, C. Awmack, T.M. Bezemer, V.K. Brown, J.Butterfield,
- Buse, J.C. Coulson, J. Farrar, J.E.G. Good, R. Harrington, S. Hartley, T.H. Jones. R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt, and J.B. Whittaker. 2002. Herbivory in global climate change research: direct effects of rising temperatures on insect herbivores. Global Change Biology 8:1-16.
- Baniecki, J. and M. Dabaan. 2000. Crop Profile for Corn (sweet) in West Virginia.http://www.ipmcenters.org/CropProfiles/docs/wvcorn-sweet.html
- Buxton, P.A. (2004): The effect of climatic conditions upon populations of insects. –
- Transactions of the Royal Society of Tropical Medicine and Hygiene 26: 325-356.
- Cannon, R.J. 1998. The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. 4:785-796.
- Chander S (1998) Infestation of root and foliage/earhead aphids on wheat in relation to predators. *Indian J. Agric. Sci.* 68(11): 754-755.
- Chander S (2012) .Impact of Climate Change on insects. In " Climate Change Impact,
- Adaptation and Mitigation in Agriculture: Methodology for Assessment and Application". Ed: H.Pathak, P.K. Aggarwal and S.D.Singh, Division of Environmental Sciences , IARI, ICAR, New Delhi, pp. 111-130.
- Chander S, Reji G and Aggarwal PK (2009) Assessing impact of climate change on rice gundhi bug using a population dynamics simulation model. In: *Global Climate Change and Indian Agriculture: Case Studies from the ICAR Network Project*. Ed: P.K. Aggarwal. ICAR, New Delhi, pp. 60-65.
- Chander S, Singh VS and Kalra N (2003) Aphid infestation on barley in relation to climatic variability. *Proc. National Symposium on Frontier Areas of Entomological Research*, 5-7 Nov. Entomology Division, Indian Agricultural Research Institute, New Delhi, pp. 37-38.
- Chen, W., Chen, J and Cihlar, J. (2000): An integrated terrestrial ecosystem carbon-budgetmodel based on changes in disturbance, climate, and atmospheric chemistry. – Ecological Modelling 135(1): 55-79.
- Conrad, K.F., Woiwod, I.P and Perry, J.N. (2002): Long-term decline in abundance and distribution of the garden tiger moth (*Arctia caja*) in Great Britain. – Biological Conservation 106(3): 329-337.
- Coops, N.C., Waring, R.H and Law, B.E. (2005): Assessing the past and future distribution and productivity of ponderosa pine in the Pacific Northwest using a process model, 3-PG. – Ecological Modelling 183(1): 107-124.
- Coviella, C. and J. Trumble. 1999. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. Conserv. Biol. 13:700-712.
- Coviella C and Trumble JT. 2000. Effect of elevated atmospheric CO2 on use of foliar application of *Bacillus thuringiensis*. *Biocontrol* 45**:**325-36.
- Crookston, N.L and Dixon, G.E. (2005): The forest vegetation simulator: A review of its structure, content, and applications. – Computers and Electronics in Agriculture 49(1): 60-80.
- Das DK, Singh J and Vennila S. 2011. Emerging Crop Pest Scenario under the Impact of Climate Change. *J Agril Phy.* 11(1&2):13-20
- Dhaliwal GS, Jindal V and Dhawan AK. 2010. Insect Pest Problems and Crop Losses: Changing Trends. *Indian J Ecol*. 37(1):1-7
- Dhawan, A.K., Singh, K., Saini, S., Mohindru, B., kaur, A., Singh, G. and Singh, S.(2007)
- Incidence and damage potential of mealybug, *Phenacoccus solenopsis* Tinsley, on cotton in Punjab. *Indian J. Ecol.*, 34, 110-116 .
- Dhillon , M.K. and Sharma, H.C. (2007). Effect of storage temperature and duration on viability of eggs of *Helicoverpa armigera* (Lepidoptera: Noctuidae) . Bull. Entomol. Res. 97:55- 59
- Dyck, M. van (1999): Keyword Reference Guide for the Forest Vegetation Simulator. – WO-TM Service Center, USDA Forest Service. Fort Collins, CO. September 1, 1996. pp. 134.
- Elias, S.A and Devender, T.R. van (1990): Fossil insect evidence for late Quaternary climatic change in the Big Bend region, Chihuahuan Desert, Texas. – Quaternary Research 34(2): 249-261.
- Estay, S.A., Lima, M and Labra, F.A. (2009): Predicting insect pest status under climate change scenarios: combining experimental data and population dynamics modelling. – J. Appl. Entomol. 133(7): 491-499.
- Feehan, J., Harley, M and van Minnen, J. (2009): Climate change in Europe: impact on terrestrial ecosystems and biodiversity. – Agron Sust. Dev. 29: 409-421.

- Firake, D.M. ; Behere, G.T.; Azad Thakur , N.S.; Burange , P.S. and Bharambe V.Y. 2013
- Climate change and insect pests: Potential Impacts and future strategies. Popular Kheti 1 (2): 67-70
- Fleming, R.A., Barclay, H.J and Candau, J.N. (2002): Scaling-up an autoregressive timeseries model (of spruce budworm population dynamics) changes its qualitative behaviour. – Ecological Modelling 149(1-2): 127-142.
- Fournier, A. 1999. Crop Profile for Corn (sweet) in Maryland. http://www.ipmcenters.org / CropProfiles /docs / MDcorn-sweet.html
- Fuhrer, J. (2003): Agro ecosystem responses to combinations of elevated CO2, ozone, and global climate change. – Agriculture, Ecosystems & Environment 97(1-3): 1-20.
- Gaston,K.J. and P.H. Williams. 1996. Spatial patterns in taxonomic diversity. In: Biodiversity 202-229. Blackwell Science, Oxford.
- Georghiou, G.P. and Taylor, C.E. 1986. Factors influencing the evolution of resistance. In: Pesticide Resistance: Strategies and tactics for management. National Research Council, National Academy Press. Pages 143-157.
- Gillman, M. (2009): An introduction to mathematical models in ecology and evolution. – Oxford, Wiley-Blackwell, pp. 158.
- Gordo, O., Sanz, J. (2006): Temporal trends in phenology of the honey bee *Apis mellifera* (L.) and the small white *Pieris rapae* (L.) in the Iberian Peninsula (1952-2004). – Ecol. Entomol. 31: 261-268.
- Hamilton, J.G., O. Dermody, M. Aldea, A.R. Zangerl, A. Rogers, M.R. Berenbaum, and E. Delucia. 2005. Anthropogenic Changes in Tropospheric Composition Increase Susceptibility of Soybean to Insect Herbivory. Envirn. Entomol. 34:2 479-485.
- Hanson, P.J and Weltzin, J.F. (2000): Drought disturbance from climate change: response of United States forests. – The Science of the Total Environment 262(3): 205-220.
- Harrington, R., R, Fleming, I. P. Woiwood. 2001. Climate change impacts on insect management and conservation in temperate regions: can they be predicted? Agricultural and Forest Entomology 3:233-240.
- Hilker, F.M and Westerhoff, F.H. (2007): Preventing extinction and outbreaks in chaotic populations. – Am Nat. 170: 232-241.
- Hoffman, B. 1999. Crop Profile for Potatoes in Pennsylvania. http://www.ipmcenters.org/CropProfiles/docs/papotatoes.html
- Hunter, M.D. 2001. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. Ag. Forest. Entomol. 3:153-159.
- IPCC (2001). Climate Change 2001: The scientific basis . Contribution of working group I to the third assessment report of the intergovernmental panel on climate change (IPCC) . Cambridge University Press, Cambridge. htpp://www.grida.no/climate /ipcc_tar/
- Joshi, S. and Viraktamath, C.A.(2004) The sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner (Hemiptera: Aphididae): its biology, pest status and control. *Curr. Sci.*, , 87, 307-316.
- Karuppaiah, V and Sujayanand, G.K. (2012). Impact of climate change on population dynamics of insects. World journal of Agricultural Sciences 8(3): 240-246
- Kearney, M., Porter, W.P., Williams, C., Ritchie, S and Hoffmann, A.A. (2009): Integrating biophysical models and evolutionary theory to predict climatic impacts on species' ranges: the dengue mosquito *Aedes aegypti* in Australia. Func Ecol. 23: 528-538.
- Kiritani, K. (2006): Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. Popul. Ecol. 48: 5-12.
- Klok, C.J and Chown, S.L. (2001): Critical thermal limits, temperature tolerance and water balance of a sub-Antarctic kelp fly, *Paractora dreuxi* (Diptera: Helcomyzidae). Journal of Insect Physiology 47(1): 95-109.
- Kogan, M and Jepson, P. (2007): Perspective in ecological theory and integrated pest
- management. – Cambridge, Cambridge University Press, pp. 570.
- Ladányi, M and Horváth, L (2010) : A review of the potential climate change impact on insect populations – general and agricultural aspects - 151 - Applied Ecology And Environmental Research 8(2): 143-152.http://www.ecology.uni-corvinus.hu _ ISSN 1589 1623 (Print) _ ISSN 1785 0037 (Online) _ 2010, ALÖKI Kft., Budapest, Hungary
- Lee, J.H., Stahl, M., Sawlis, S and Suzuki, S. (2009): A potential risk assessment of a dengue outbreak in North Central Texas, USA (Part 2 of 2): development of a practical prevention strategy. – J. Env. Health 71: 36-39.
- Lee, J.H., Stahl, M., Sawlis, S., Suzuki, S Lee, J.H., Stahl, M., Sawlis, S., Suzuki, S and Lee,
- J.H. (2009): A potential risk assessment of a dengue outbreak in North Central Texas, USA (Part 1 of 2): abundance and temporal variation of dengue vectors. – J. Env. Health 71: 24-29.

- Lee, J.H. (2009): A potential risk assessment of a dengue outbreak in North Central Texas, USA (Part 1 of 2): abundance and temporal variation of dengue vectors. – J. Env. Health 71: 24-29.
- Lemdahl, G. (1991): A rapid climatic change at the end of the Younger Dry as in south Sweden –palaeoclimatic and palaeoenvironmental reconstructions based on fossil insect assemblages. – Palaeogeography, Palaeoclimatology, Palaeoecology 83(4): 313-331.
- Lemdahl, G. (2000): Lateglacial and Early Holocene insect assemblages from sites at different altitudes in the Swiss Alps — implications on climate and environment. – Palaeogeography, Palaeoclimatology and Palaeoecology 159(3-4): 293-312.
- Lenteren, J.C. van (2000): A greenhouse without pesticides: fact or fantasy? Crop Protection 19(6): 375-384.
- Lewis, T. 1997. Thrips as crop pests. CAB International, Cambridge: University Press. 740 pp.
- Lima, M and Berryman, A., (2006): Predicting nonlinear and non-additive effects of climate: the *Alpine ibex* revisited. Clim. Res. 32: 129-135.
- Lima, M., Harrington, R., Saldana, S and Estay, S., (2008): Nonlinear feedback processes and a
- latitudinal gradient in the climatic effects determine green spruce aphid outbreaks in the UK. Oikos 117: 951-959.
- Lima, E.A.B.F., Ferreira, C.P and Godoy, W.A.C. (2009): Ecological Modeling and Pest
- Population Management: a Possible and Necessary Connection in a Changing World. Neotropical Entomology 38(6): 699-707.
- McKibben, G.H., Willers, J.L., Smith, J.W and Wagner, T.L. (1991): Stochastic model for studying boll weevil dispersal. Environ. Ent. 20(5): 1327-1332.
- Mcvean, R. and A. F. G. Dixon. 2001. The effect of plant drought-stress on populations of the pea aphid *Acyrthosiphon pisum*. Ecol. Entomol. 26: 440-443.
- Memmott, J., Craze, P.G., Waser, N.M and Price, M.V. (2007): Global warming and the disruption of plant–pollinator interactions. Eco Let. 10: 710-717.
- Merrill, R., Gutie´rrez, D., Lewis, O., Gutie´rrez, J., Diez, S and Wilson, R., (2008): Combined effects of climate and biotic interactions on the elevational range of a phytophagous insect. J. Anim. Ecol. 77: 145-155.
- Mols, P.J.M. (1990): Forecasting orchard pests for adequate timing of control measures. Proc. Exp. & Appl. Entomol., NEV. Amsterdam 1: 75-81.
- Mols, P.J.M. (1992): Forecasting an indispensable port of IPM in apple orchards. Acta Phytop. Entom. H. 27(1-4): 449-460.
- Musolin, D. (2007): Insects in a warmer world: ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. Glob. Chang. Biol. 13: 1565- 1585.
- Musser, F. P and A. M. Shelton. 2005. The influence of post-exposure temperature on the toxicity of insecticides to *Ostrinia nubilalis* (Lepidoptera:Crambidae). Pest Manag Sci. 61:508 -510.
- Norango, S.E., Sawyer, A.J. (1989): A simulation model of northern corn rootworm. *Diabrotica barberi*, population dynamics, oviposition: significance of host-plant phenology. Can. Ent. 121: 169-191.
- Olfert, O and Weiss, R. (2006): Impact of climate change on potential distributions and relative abundances of *Oulema melanopus*, *Meligethes viridescens* and *Ceutorhynchus obstrictus* in Canada. Agric. Ecosyst. Environ. 113: 295-301.
- Osbrink WLA, Trumple JT and Wagner RE. 1987. Host suitability of *Phaseolus lunata* for
- *Trichoplusia ni* (Lepidoptora:Noctuidae) in controlled carbon dioxide atmosphere. *Envi. Entomol*. **16**: 639-44.
- Paegle, McLawhorn (1983): Correlation of nocturnal thunderstorms and boundary-layer convergence. – Monthly Weather Review 101: 877-933.
- Parmesan, C. (2007): Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Glob. Chang. Biol. 13: 1860-1872.
- Porter, J.H., Parry, M.L and Carter, T.R. (1991): The potential effects of climatic change on agricultural insect pests. Agricultural and Forest Meteorology 57(1-3): 221-240.
- Powell, J.A and Logan, J.A. (2005): Insect seasonality: circle map analysis of temperature driven life cycles. Theoretical Population Biology 67(3): 161-179.
- Rao MS, Srinivas K, Vanaja M, Rao GGSN, Venkateswarlu B and Ramakrishna, YS (2009) Host plant (*Ricinus communis* Linn.) mediated effects of elevated CO2 on growth performance of two insect folivores. *Curr. Sci.* 97(7): 1047-1054.
- Regi G and Chander,S. (2008). A degree-day simulation model for the population dynamics of the rice bug , *Leptocorisa acuta* (Thumb.).J.Appld. Entomolo. 132:646-653
- Reiners, S and C. Petzoldt (eds). 2005. Integrated Crop and Pest Management

Guidelines for Commercial Vegetable Production. Cornell Cooperative Extension publication #124VG
http://www.nysaes.cornell.edu/recommends/

- Roth SK and Lindroth RL. 1995. Elevated atmospheric CO2: Effect on photochemistry, insect performance and insect parasitoid interactions. *Global Change Biol. 1*: 173-82.
- Schwert, D.P., Anderson, T.W., Morgan, A., Morgan, A.V and Karrow, P.F. (1985): Changes in late Quaternary vegetation and insect communities in southwestern Ontario. Quaternary Research 23(2): 205-226.
- Seppelt, R. (1999): Applications of optimum control theory to agro-ecological modelling. In: Ecological Modelling 121(2-3): 161-183.
- Seppelt, R. (2000): Regionalised optimum control problems for agro-ecosystem management. In: Ecological Modelling 131(2-3): 121-132.
- Seppelt, R. (2001): Agro-ecosystem Management. In: J. Pinter (ed.): Global Optimization & Selected Case Studies, Kluver, Dordrecht, New York.
- Sharon, R., Degani, G and Warburg, M. (2001): Comparing the soil macro-fauna in two oakwood forests: does community structure differ under similar ambient conditions? Pedobiologia 45(4): 355-366.
- Shelton, A.M., W.R. Wilsey, and D.M. Soderlund. 2001. Classification of insecticides and acaricides for resistance management. Dept. of Entomology, NYSAES, Geneva,NY14456.315-787-2352. http://www.nysaes.cornell.edu/ent/faculty/shelton/pdf/res_mgmt.pdf
- Spencer, J.L., Hibbard, B.E., Moeser, M., Onstad, D. (2009): Behaviour and ecology of the western corn rootworm *Diabrotica virgifera virgifera* LeConte. Agric For Entomol. 11: 9-27.
- Srikanth, J.(2007). World and Indian scenario of sugarcane woolly aphid. In Woolly Aphid Management in Sugarcane (eds. Mukunthan, N., Srikanth, J., Singaravelu, B., Rajula Shanthy, T., Thiagarajan, R. and Puthira Prathap, D.), Extension Publication, Sugarcane Breeding Institute, Coimbatore, 154, 1-12 .
- Srivastava, C.P. ; Joshi,N and Trivedi,T.P.2010. Forecasting of Helicoverpa armigera population and impact of climate change. Ind. J.Agri.Sci. 80(1):3-10
- Stivers, L. 1999. Crop Profile for Corn (sweet) in New York. http://pestdata.ncsu.edu/cropprofiles/docs/nycorn-sweet.html.
- Strand, J.F. (2000): Some agro meteorological aspects of pest and disease management for the
- 21st century. Agricultural and Forest Meteorology 103(1-2): 73-82.
- Takken, W and Knolsm G.J. (2007): Emerging pests and vector-borne diseases in Europe:
- ecology and control of vector-borne diseases. Netherlands, Wageningen Academic Publishers, 500p.
- Tang, S and Cheke, R.A. (2008): Models for integrated pest control and their biological implications. Math. Biosc. 215: 115-125.
- Tanwar, R.K., Jeyakumar P. and Vennila, S.(2010). *Papaya mealybug and its management strategies.* Technical Bulletin 22, National Centre for Integrated Pest Management, New Delhi.
- Uniyal, S.K., Uniyal, A. (2009): Climate change and large-scale degradation of spruce: common pattern across the globe. – Clim. Res. 38: 261-263.
- Vincent, C., G. Hallman, B. Panneton, and F. Fleurat-Lessardú. 2003. Management of agricultural insects with physical control methods. Ann Rev Entomol 48: 261-281.
- Volney, W.J.A and Fleming, R.A. (2000): Climate change and impacts of boreal forest insects. Agriculture, Ecosystems & Environment 82(1-3): 283-294.
- Ward, N and Masters, G. (2007): Linking climate change and species invasion: an illustration using insect herbivores. Glob. Chang. Biol. 13: 1605-1615.
- Whinam, J., Chilcott, N and Bergstrom, D.M. (2005): Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms. Biological Conservation 121(2): 207-219.
- Whitney, S, J. Whalen, M. VanGessel, B. Mulrooney. 2000. Crop Profile for Corn (sweet) in Delaware. http://www.ipmcenters.org/CropProfiles/docs/DEcorn-sweet.html
- Yamamura, K. and K. Kiritani. 1998. A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. Appl. Ent. and Zool. 33:289 -298.

Microirrigation: Prospects and problems

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Agriculture sector is the largest consumer of water. We have spend more than Rs. 80,000 crores and claim to have an irrigation potential of over 90 m ha (an increase of 65 m ha since independence). Further increase in irrigation potential may be increasing more difficult and expensive. The demand of water has been consistently increasing from various sectors like municipal use; industry etc. and such uses can often be at the cost of agriculture. The dominant method of irrigation practiced in large parts of the country is surface irrigation under which crops utilize only less than one half of the water released and remaining half get lost in conveyance, application, runoff and evaporation (Rajput and Patel, 2012). Micro-irrigation methods like drip and sprinklers need to be employed for efficient distribution and application of water for crop production. Many studies across the country confirmed the superiority of micro-irrigation methods in different aspects of water management including water saving, water use efficiency, saving in labour, reduction in weed, use of saline water, disease and pest reduction, fertilizer use efficiency, soil erosion control and increase in crop yield (Singh, 2001). The potential for coverage under drip and sprinkler irrigation is estimated to be about 27 and 42.5 million ha respectively in India (National Task Force on Micro-irrigation, GOI 2004). Hence by adopting micro-irrigation methods larger area can be brought under irrigation along with increasing the land and water productivities.

Investment in micro-irrigation also appears to be economically viable even without availing state subsidy. Despite this as of today, the coverage of drip (2.13 percent) and sprinkler (3.30 percent) method of irrigation is very meagre to its total potential. It is identified that slow spread of micro- irrigation is not mainly due to economic reasons, but due to less awareness among the farmers about the real economic and revenue related benefits of it (Narayanmoorthy, 2004). Therefore, apart from promotional schemes, various technical and policy interventions are suggestive of the fact for increasing the adoption of these two water saving technologies.

Global water resources

The 70% of the earths' surface is covered with water but in reality 97.3% of total water on the earth is saline and only 2.7 % is available as fresh water. About 77% of this fresh water is locked up in glaciers and permanent snow and 11% is considered to occur at depths exceeding 800 m below the ground, which cannot be extracted with the technology available today (CGWB, 2007). About 11% of the resources are available as extractable groundwater within 800 m depth and about 1% is available as surface water in lakes, reservoir and river systems. The global renewable water supply is about 7000 m^3 per person per year. For adequate living standards as in the western and industrialized countries, a renewable water supply of at least 2000 m^3 per person per year is necessary. As per the international norms, if per capita water is less than 1700 m^3 per year then the country is classified as "water stressed" and if it is less than 1000 m^3 per year than the country is classified as "water scarce".

So, globally the renewable water supply is enough to meet the requirement for at least three times the present world population, but water shortages occur due to imbalances between population and precipitation distribution. The world has "water have" areas like Africa and USA, which constitutes one third of land mass, while remaining two third areas are semi arid and arid.

Water resources scenario of India

India has total geographical area of 329 million hectares which is about 2% of the world's area but has 16% of its population. The country receives average annual rainfall of 1194 mm with a spatial variation of about 100 mm/year at Jaisalmeer, Rajasthan in western regions to 11,690 mm/year in Mousinram, Cherapunji of North-eastern region of India. With 4000 billion cubic meter (BCM) of annual rainfall, average runoff generated is only 1869 BCM. Due to various constraints about 1122 BCM of water can be put to beneficial use of which 690 BCM is through surface water and 432 BCM by groundwater (Table-1). Out of 690 BCM of surface water, so far about 213 BCM of storage are built through major irrigation projects. Another 184 BCM of storage are under construction. Similarly out of 432 BCM of groundwater resource, about 360 BCM of groundwater is expected to be available for irrigation out of which present usage is about 135 BCM.

Table 1: Water resources of India

Sr. No.	Parameters	Quantity (BCM)	% of precipitation
1	Annual precipitation (including snowfall)	4000	100
2	Evaporation + groundwater flow	2131	53.3
3	Average runoff generated in rivers	1869	46.7
4	Estimated utilizable water resources a. Estimated utilizable surface water b. Replenishable groundwater	1122 690 432	28.1 17.3 10.8

Declining trend of per capita water availability

Per capita per year water resources of the country has been continuously declining from 5176 m^3 in 1951 to 4732 m^3 in 1955, 2200 m^3 in 1991, 1869 m^3 in 2001 and 1703.6 m^3 in 2007. The population of India is expected to stabilize around 1640 million by the year 2050 as a result of which the per capita water availability will further decline to 1140 m^3/year (Table 2) and most parts of the country would be under water stress.

Table 2: Per capita water availability in India (past, present and future)

Year	Population (in million)	Per capita water availability (in cubic metre)
1951	361	5177
1955	395	4732
1991	846	2200
2001	1027	1869
2025	1394 (projected)	1341
2050	1640 (projected)	1140

Source: Manual on Artificial Recharge of Ground Water (CGWB, 2007)

Gap between irrigation potential created and utilized

Irrigation is one of the key drivers of modern intensive agriculture. Ultimate potential of irrigation of the country has been estimates as 139.9 M ha, out of which 58.9 M ha through major and medium projects (surface) and 81.0 M ha using minor irrigation (surface and ground). Still there is wide gap between irrigation potential created and utilized. By 2005-06, the irrigation potential created for 120.86 M ha with the utilization of 89.55 M ha (Table-3).

Table 3: Irrigation potential of the country (up to 2005-06)

A. Major and medium (surface water)	
Ultimate	58.90 M ha
Created	40.85 M ha
Utilized	33.45 M ha
B. Total Minor (surface and ground)	
Ultimate	81.0 M ha
Created	66.22 M ha
Utilized	56.10 M ha
C. Total (major and medium + minor)	
Ultimate	139.9 M ha
Created	120.86 M ha
Utilized	89.55 M ha

Source: National Commission on Integrated Water Resources Development Planning; GOI

Growing water demand in agriculture and other sectors

Agriculture sector is the largest consumer of water (82.8%) but with growing population, urbanization and industrialization in the country, the requirements of water from competing sectors like domestic and industrial needs, are increasing (Table 4). Ministry of Water Resources (MoWR), Government of India has projected that by the year 2025 total demand of water will be 1093 billion cubic meter (BCM), the bulk of which (910 BCM) will be consumed by irrigation and the country will face the stiff competition for water from different sectors. On the other hand, National Commission on Integrated Water Resources (NCIWRD) projected much lower water demand of 784-843 BCM under different scenarios.

Out of the 140.86 M ha of net sown area in the country, 63.19 M ha is under irrigation (44.5%). Out of this 26% is under canal irrigation and more than 60% is through tube wells and other wells. Tank irrigation is only less than 5% and confined mainly to the peninsular region of the country.

Table 4: Sector wise utilization of water resources

Sr. No.	Sector	Present utilization of water, BCM	% of total water utilized
1	Irrigation	501	82.8
2	Domestic	30	5.0
3	Industrial	20	3.3
4	Energy	20	3.3
5.	Other	34	5.6
	Total	605	100

Source: National commission on Integrated Water Resources Development Planning (NCIWRD); GOI

In spite of having the largest irrigated area in the world, India too has started facing sever water scarcity in different regions. Owing to various reasons the demand for water for different purposes has been continuously increasing in India, but the potential water available for future use has been declining at a faster rate (Saleth, 1996; CWC, 2005). The agricultural sector (irrigation), which currently consumes over 80 percent of the available water in India, continues to be the major water-consuming sector due to the intensification of agriculture (Saleth, 1996; MOWR, 1999, Iyer, 2003). Though India has the largest irrigated area in the world, the coverage of irrigation is only about 40 percent of the gross cropped area as of today. One of the main reasons for the low coverage of irrigation is the predominant use of flood (conventional) method of irrigation, where water use efficiency is very low due to various reasons. Available estimates indicate that water use efficiency under flood method of irrigation is only about 35 to 40 percent because of huge conveyance and distribution losses (Rosegrant, 1997; INCID, 1994).

State-wise area (ha) under Drip & micro-sprinkler irrigation (2004-05)

State	Drip	Micro-sprinkler *
Maharashtra	36957	110000
Andhra Pradesh	24905	55000
Tamil Nadu	9988	10000
Karnataka	6408	125000
Rajasthan	1134	425000
Bihar	392.2	500
Gujarat	304.0	11000
Kerala	297.0	8000
Madhya Pradesh	288.8	85000
Punjab	279.0	10000
India	81357.34	1634997*
Sources: AFC (1998), INCID (1998), GOI (2004) and NCPAH (2005)		

Micro irrigation methods

Considering the water availability for future use and the increasing demand for water from different sectors, a number of demand management strategies and programmes (water pricing, *warabandhi*, waters users' association, etc) have been introduced since late seventies in India to increase the water use efficiency, especially in the use of surface irrigation water. While the various strategies introduced to improve the water use efficiency have been continuing, the net impact of these strategies in increasing the water use efficiency is not very impressive as of today. One of the demand management strategies introduced relatively recently to control water consumption in Indian agriculture is micro irrigation (MI), which includes mainly drip and sprinkler irrigation method. Under micro-irrigation, unlike flood method of irrigation (FMI), water is supplied at a required interval and quantity using pipe network, emitters and nozzles. Therefore, the conveyance and distribution losses are reduced completely which result in higher water use efficiency under MI.

Though both drip and sprinkler irrigation methods of irrigation are treated as MI, there are distinct characteristics differences between the two in terms of flow rate, pressure requirement, wetted area and mobility (Kulkarni, 2005). While drip method supplies water directly to the root zone of the crop through a network of pipes with the help of emitters, sprinkler irrigation method (SIM) sprinkles water similar to rainfall into the air through nozzles which subsequently break into small water drops and fall on the field surface. Unlike flood irrigation method, DIM supplies water directly to the root zone of the crop, instead of land, and therefore, the water losses occurring through evaporation and distribution are completely absent (INCID, 1994, Narayanamoorthy, 1996; 1997; Dhawan, 2002). The on-farm irrigation efficiency of properly designed and managed drip irrigation system is estimated to be about 90 percent, while the same is only about 35 to 40 percent for surface method of irrigation (INCID, 1994). In sprinkler irrigation method, water saving is relatively low (up to 70 percent) as compared to drip irrigation since SIM supplies water over the entire field of the crop (INCID, 1998; Kulkarni, 2005).

Micro-irrigation is introduced primarily to save water and increase the water use efficiency in agriculture. However, it also delivers many other economic and social benefits to the society. Reduction in water consumption due to drip method of irrigation over the surface method of irrigation varies from 30 to 70 percent for different crops (INCID, 1994, Narayanamoorthy, 1997; Postal, 2001). According to data available from research stations, productivity gain due to use of micro-irrigation is estimated to be in the range of 20 to 90 percent for different crops (INCID, 1994; 1998). While increasing the productivity of crops significantly, it also reduces weed problems, soil erosion and cost of cultivation substantially, especially in labour-intensive operations. The reduction in water consumption in micro-irrigation also reduces the energy use (electricity) that is required to lift water from irrigation wells (Narayanamoorthy, 1995 and 2001).

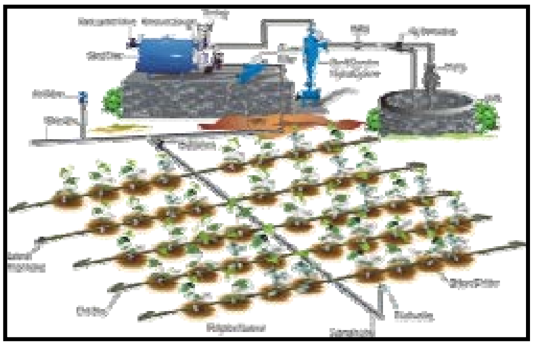
India has enormous potential for both DIM and for SIM. Two of the INCID (1994 and 1998) reports, which present an overview about the development of drip irrigation and sprinkler irrigation in India, indicate that about 80 crops, both narrow and widely spaced crops, can be grown under micro-irrigation. Although DIM is considered to be highly suitable for wide spaced and high value commercial crops, it is also being used for cultivating oilseeds, pulses, cotton and even for wheat crop (INCID, 1994). Closely grown crops such as millets, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices and condiments have been found to be suitable to cultivate under sprinkler irrigation. Importantly, an experimental study suggests that sprinkler irrigation can also be used successfully even for cultivating paddy crop (Kundu, *et al.*, 1998).

Micro-irrigation can also be adopted in all kind of lands, which is not generally possible through flood irrigation method. Research suggests that DIM is not only suitable for those areas that are presently under cultivation, but it can also be operated efficiently in undulating terrain, rolling topography, hilly areas, barren land and areas which have shallow soils (Sivanappan, 1994). Given the population growth and increasing requirement of agricultural commodities, there is a need to increase the area under cultivation. Micro-irrigation can be one of the viable options for expanding area under cultivation.

In spite of having many economic and other advantages over the method of flood irrigation, the coverage of area under micro-irrigation is not appreciable in India, except for a few states as of today. While DIM has been in practice since early seventies in India, SIM has been in use over since mid-seventies. However, an appreciable improvement in the adoption of DMI has taken place only from the eighties, mainly because of various promotional programmes introduced by the Central and State governments. The area under DMI has increased from a mere 1500 ha in 1985 to 70,859 ha in 1991-92 and further to 5,00,000 ha as of March 2003 (INCID, 1994; GOI, 2004). Similarly, the area under SIM has increased from 0.23 m ha in 1985-86 to 0.67 m ha in 1997-98 and further to 1.63 m ha in 2004-05. Though remarkable growth has been achieved over the last 15 years in adopting micro-irrigation, its share to the gross irrigated area of the country is only negligible percent as of today. Among the various reasons for the slow progress of adoption of this new technology, its capital-intensive nature seems to be one of the main deterrent factors. Micro-irrigation technology requires fixed investment that varies from Rs.20,000 to Rs.55,000 per hectare depending upon the nature of crops (wide or narrow spaced) and the material to be used for the system. Since the Indian farmers have been getting water for low cost from the public irrigation system and also from well irrigation (because of free and flat-rate electricity tariff), there is less incentive to them to adopt this capital-intensive technology unless it is necessary. Moreover, since it involves fixed investment, farmers often ask questions like what will be the water saving and productivity gains? Is investment on drip irrigation economically viable? What will be the payback period of the drip investment? These issues are raised because of the following two reasons. First, the awareness of the farmers about this technology is very low due to poor extension service. Second, most of the studies available on micro-irrigation in India is based on experimental data collected from different regions, which generally do not present the field level position (Verma and Rao, 1998; INCID, 1994; Dhawan, 2002). Some of the studies have shown that the results derived from research station data are substantially different from that of survey data (Narayanamoorthy, 1997; 2001; 2005). In the absence of reliable field studies, it is difficult to judge the actual economic viability of drip method of irrigation.

Components of Drip Irrigation System (Listed in order from water source)

a) Pump or pressurised water source.
b) Water Filter(s) - Filtration systems: Sand separator, cyclone, screen filter, media filters.
c) Fertigation systems (Venturi injector).
d) Backwash controller.
e) Main line (larger diameter pipe and pipe fittings).
f) Hand-operated, electronic, or hydraulic control valves and safety valves.
g) Smaller diameter polytube (often referred to as "laterals").
h) Poly fittings and accessories (to make connections).
i) Emitting devices at plants (Example: Emitter or Drippers, micro spray heads, inline drippers, trickle rings).



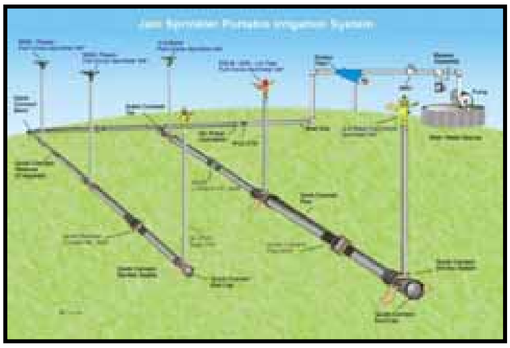
Components of sprinkler irrigation system

A typical sprinkler irrigation system usually consists of the following parts/ components.

- Pipe network - mains, sub mains and laterals,
- QRC Couplers,

- Sprinkler head, and
- Other accessories such as valves, bends, plugs, risers and fittings.

A pumping unit is also required for pumping



the water through the system. In a typical sprinkler system, the breakup of costing is: pipe network 70%, couplers 15%, sprinkler heads 7% and other accessories 8%. In addition, the pumping and control unit costs about 40% of this total cost.

Research on water saving technologies

Considering the limited potential of water resources as well as growing demand for water from different purposes, it has become essential to adopt Water Saving Technologies (WSTs) so as to avoid the water stress in the future. It has been proved by studies that drip and sprinkler method of irrigation helps to save water and improves water use efficiency (INCID, 1994 and 1998). While reducing water consumption, it also reduces substantial amount of electricity required for irrigation purpose, by reducing working hours of irrigation pumpsets (Narayanamoorthy, 1996; 2004).

The water saving capacity of DIM is expected to be different for various crops as the consumption and the requirement of water varies from crop to crop. As expected, the water saving for vegetable crops varies from 12 percent to 84 percent per hectare over the conventional method of irrigation. Similarly, water saving varies from 45 percent to 81 percent per hectare in fruit crops. In crops like cotton, coconut and groundnut, water saving varies from 40 percent to 60 percent per hectare. Importantly, water saving in sugarcane, which is one of the water-intensive crops, is over 65 percent per hectare when compared to conventional method of irrigation.

The experimental studies carried out by the Precision Farming Development Centre (PDCs) clearly demonstrate that water saving due to DIM is substantial over the method of surface irrigation in different crops (GOI, 2004). There are three main reasons for enormous water saving under drip method of irrigation. First, since water is supplied through a network of pipes, the evaporation and distribution losses of water are very minimum or completely absent under DIM. Second, unlike FIM, water is supplied under DIM at a required time and required level and thus, over-irrigation is totally avoided. Third, under the conventional method of irrigation, water is supplied for the whole cropland, whereas DIM irrigates only the plants. Though the results of the experimental data discussed above clearly suggest that water saving due to DIM is substantial, one cannot completely rely on these results because the conditions that are prevailing under experimental stations are totally different from that of the farmers' field.

Apart from reducing water consumption, drip method of irrigation also helps reducing cost of cultivation and improving productivity of crops as compared to the same crops cultivated under flood method of irrigation. Quite a few studies have attempted to study the impact of drip method of irrigation on productivity of crops, mainly using experimental data. INCID (1994) report presents the results of various crops carried out at different locations in the country (Table 5). It shows that the productivity of different crops is significantly higher under DIM when compared to FIM. Productivity increase due to drip method of irrigation is noticed over 40 percent in vegetable crops such as bottle gourd, potato, onion, tomato and chillies, whereas the same is noticed over 70 percent in many fruit crops. Productivity difference is also found to be over 33 percent in sugarcane cultivated under DIM over the same crop cultivated under FIM. Specific experiments carried out at Punjabrao Krishi Vidyapeeth (Akola, Maharashtra State) on vegetable crops such as cauliflower, tomato and brinjal also suggest that productivity enhancement due to DIM is substantial. Similar kinds of results have also been noted at different experimental stations located in different states.

Table 5: Water saving and productivity gains under drip method of irrigation: India

Crop's Name	Water Consumption (mm/ha)		Yield (tone/ha)		Water Saving over FIM (%)	Yield Increase over FIM (%)	Water Use Efficiency (yield/ha)/(mm/ha)	
	FIM	DIM	FIM	DIM			FIM	DIM
Vegetables:								
Ash gourd	840	740	10.84	12.03	12	12	0.013	0.016
Bottle gourd	840	740	38.01	55.79	12	47	0.045	0.075
Brinjal	900	420	28.00	32.00	53	14	0.031	0.076
Beet root	857	177	4.57	4.89	79	7	0.005	0.028
Sweet potato	631	252	4.24	5.89	61	40	0.007	0.023
Potato	200	200	23.57	34.42	Nil	46	0.118	0.172
Lady's finger	535	86	10.00	11.31	84	13	0.019	0.132
Onion	602	451	9.30	12.20	25	31	0.015	0.027
Radish	464	108	1.05	1.19	77	13	0.002	0.011
Tomato	498	107	6.18	8.87	79	43	0.012	0.083
Chillies	1097	417	4.23	6.09	62	44	0.004	0.015
Ridge gourd	420	172	17.13	20.00	59	17	0.041	0.116
Cabbage	660	267	19.58	20.00	60	2	0.030	0.075
Cauliflower	389	255	8.33	11.59	34	39	0.021	0.045
Fruit Crops:								
Papaya	2285	734	13.00	23.00	68	77	0.006	0.031
Banana	1760	970	57.50	87.50	45	52	0.033	0.090
Grapes	532	278	26.40	32.50	48	23	0.050	0.117
Lemon	42	8	1.88	2.52	81	35	0.045	0.315
Watermelon	800	800	29.47	88.23	Nil	179	0.037	0.110
Mosambi*	1660	640	100.0	150.0	61	50	0.060	0.234
Pomegranate*	1440	785	55.00	109.0	45	98	0.038	0.139
Other Crops:								
Sugarcane	2150	940	128.0	170.0	65	33	0.060	0.181

Cotton	856	302	2.60	3.26	60	25	0.003	0.011
Coconut	--	--	--	--	60	12	--	--
Groundnut	500	300	1.71	2.84	40	66	0.003	0.009

Notes: * - yield in 1000 numbers
Sources: INCID (1994) and NCPA (1990).

A number of studies have also been carried out in the context of sugarcane using experimental data, which have found a substantial water saving and productivity gains due to drip method of irrigation in sugarcane cultivation (Venugopal and Rajkumar, 1998; Dash, 1998; Sankpal, *et al.*, 1998; Dhonde and Banger, 1998; Deshmukh, *et al.*, 1998; Hapase, *et al.*, 1992; Batta and Singh, 1998; Parikh *et al.*, 1993). Single cane weight, cane girth, cane length, number of inter-nodes, leaf length and leaf breadth were also found to be higher with sugarcane cultivated under drip method of irrigation when compared to that cultivated under flood method of irrigation (Venugopal and Rajkumar, 1998). Because of less moisture stress under DMI, the recovery rate of sugarcane cultivated under DMI was found to be higher when compared to the crop cultivated using FIM (Sankpal, *et al.*, 1998; Dhonde and Banger, 1998; Banger, 1998). Importantly, a study carried out on heavy soils and sub-humid climatic conditions of South Gujarat region suggests that a large scale adoption of drip method of irrigation in sugarcane in South Gujarat area can help to solve the problem of water logging and secondary salinization which are increasing in this region (Parikh, *et al.*, 1993).

It is clear from the above that the adoption of drip method of irrigation in crop cultivation not only increases water saving and productivity of crops but also reduces the cost of cultivation and weed problems. Importantly, DIM also helps to increase the germination of seed (cane) and the recovery rate of sugarcane. Though drip method of irrigation is proved to be an effective technology for increasing crop productivity, one can always question the credibility of the results of research station based studies as the conditions prevailing at farmers' field are totally different from research station where trails are carried out.

However, studies available based on filed level data also suggest that drip irrigation is economically suitable for different crops. A few studies carried out using farm level data in high value crops like banana, grapes and sugarcane also suggest that DIM increases water use efficiency, productivity and reduces cost of cultivation for different operations (Table 6) Significant amount of saving in electricity use due DIM has also been observed using field data. Importantly, these field based studies found that the investment in drip irrigation technologies is economically viable for farmers even at 15 percent discount rate, without availing subsidy from government (Narayanamoorthy, 1996, 1997, 2001).

Table 6: Field survey results of drip irrigation: banana, grapes and sugarcane

Particulars	Crop's Name	Method of Irrigation		Benefit over FIM	
		DIM	FIM	In percent	In value
Water consumption (hp $hr^{-1}ha^{-1}$)	Banana	7884.70	11130.30	29.20	3245.60
	Grapes	3310.40	5278.40	37.30	1968.00
	Sugarcane	1767.00	3179.98	44.43	1412.98
Productivity (q ha^{-1})	Banana	679.50	526.35	29.10	153.20
	Grapes	243.25	204.29	19.10	38.96
	Sugarcane	1383.60	1124.40	23.05	259.20
Electricity consumption (k wh ha^{-1})	Banana	5913.33	8347.75	29.16	2434.42
	Grapes	2482.77	3958.78	37.28	1476.01
	Sugarcane	1325.25	2384.99	44.43	1059.74
Water use efficiency (hp hrs q^{-1})	Banana	11.60	21.10	45.10	9.50
	Grapes	13.60	25.80	47.30	12.20
	Sugarcane	1.28	2.83	5.48	1.55
Cost of cultivation (Rs. ha^{-1})	Banana	51437	52740	2.50	1303
	Grapes	134506	147915	9.10	13409
	Sugarcane	41993	48540	13.49	6547
Gross income (Rs. ha^{-1})	Banana	134044	102935	30.22	31109
	Grapes	247817	211038	17.40	36779
	Sugarcane	106366	85488	24.00	20878
Capital cost of drip-set (Rs. ha^{-1}) without subsidy	Banana	33595	--	--	--
	Grapes	32721	--	--	--
	Sugarcane	52811	--	--	--
Net present worth (Rs. ha^{-1}) without subsidy	Banana	241753	--	--	--
	Grapes	540240	--	--	--
	Sugarcane	169896	--	--	--
Benefit-Cost ratio without subsidy	Banana	2.288	--	--	--
	Sugarcane	1.909	--	--	--
	Grapes	1.767	--	--	--

Notes: Banana and grapes data relate to the year 1993-94 and sugarcane data relate to the year 1998-99; * - 15 percent of discount rate is considered for computing benefit cost ratio. Source: Computed using Narayanamoorthy (1996; 1997 and 2001).

Research on sprinkler irrigation

Among the two micro-irrigation technologies, the research on sprinkler irrigation appears to have not much developed as compared to drip irrigation (Dhawan, 2002). In fact, unlike drip irrigation method, studies using field level data (published in standard journals for Indian context) are seldom available. Most of the studies are mainly used experimental data for its analysis, which of course may not completely reflect the farm level condition.

The available results suggests that yield improvement and water saving in sprinkler irrigation is less striking, though the picture does vary considerably across crops and across space (Dhawan, 2002). This can be seen from the results of experimental data presented in INCID (1998) report pertaining to 15 crops carried out in different locations in India. The crops are grouped into three categories namely food grains, oilseeds and other crops for the purpose of comparison. Except for a few crops reported in Table 7, considerable amount of water saving and yield improvement has been noted in all other crops. Not surprisingly, water saving due to SIM is found to be relatively higher among food grain crops, whereas relatively higher yield gain is observed in oilseed crops. Sugarcane, a water-intensive crop, does not show any impressive result in terms of water saving and yield gain due to the adoption of SIM, implying that the sugarcane is not very much suitable for cultivation under SIM. Similarly, cotton crop also shows not substantial gain due to the adoption of SIM.

Table 7: Farm research data on sprinkler irrigation in comparison to conventional surface irrigation

Crops	Location	Yield (q/ha)		Irrigation water (cm)		Water Use efficiency (q ha^{-1} cm)		Benefits over FIM (%)	
		FIM	SIM	FIM	SIM	FIM	SIM	water	Yield
1. Wheat	Rahuri	32.41	36.39	35.00	20.25	0.93	1.79	42.14	12.28
	Udaipur	26.61	33.02	33.02	14.52	0.81	2.27	56.03	24.09
	Hissar	44.80	48.70	33.94	32.68	1.32	1.49	3.89	8.70
2. Bajra	Rahuri	6.97	8.33	17.78	7.82	0.39	1.07	56.02	19.51
3. Jowar	Rahuri	4.92	6.62	25.40	11.27	0.19	0.59	55.63	34.55
4. Sorghum (k)	Rahuri	44.12	54.97	18.00	12.00	2.45	4.58	33.33	24.59
5. Maize (k)	Udaipur	15.62	18.10	12.80	9.00	1.22	2.01	33.00	15.88
6. Barley	Bikaner	24.09	28.15	17.78	7.82	1.35	3.59	56.01	16.85
	Hissar	35.10	34.80	23.87	21.88	1.47	1.59	8.34	-0.85
7. Gram	Hissar	6.55	9.91	17.78	7.82	0.37	1.27	56.02	51.29
Food grains (Avg)		24.12	27.90	23.54	14.51	1.05	2.03	40.04	20.69
8. Oilseeds	Delhi	8.33	9.34	60.00	30.00	0.14	0.31	50.00	12.12
9. Groundnut(s)	Rahuri	23.24	28.98	90.00	62.00	0.26	0.47	31.11	24.69
	Junagarh	13.00	16.00	91.00	65.00	0.14	0.25	28.57	23.08
	Dharwad	33.96	39.86	76.30	63.60	0.45	0.63	16.64	17.37
	Punjab	5.50	11.90	68.60	50.20	0.08	0.24	26.82	116.38
	Navsari	31.00	30.00	56.00	44.00	0.55	0.68	21.43	-3.22
	Rahuri (k)	18.31	22.15	21.00	14.00	0.87	1.58	33.33	20.97
10. Sunflower (r)	Rahuri	16.02	19.19	30.00	20.00	0.53	0.96	33.33	19.79
Oilseeds (Avg)		18.67	22.18	61.61	43.60	0.38	0.64	30.15	28.90
11. Chillies (k)	Pune	17.41	21.52	36.00	24.00	0.48	0.89	33.33	23.61
	Rahuri	17.15	20.91	39.00	26.00	0.44	0.80	33.33	21.92
12. Garlic	Rahuri	69.99	73.99	84.00	60.00	0.83	1.23	28.57	5.71
13. Onion (s)	Rahuri	334.90	412.70	78.00	52.00	4.29	7.94	29.69	23.23
14. Cotton	Navsari	6.99	7.04	40.64	29.65	0.17	0.24	27.04	0.71
	Punjab	10.00	15.00	91.10	58.60	0.12	0.26	35.68	50.00
15. Sugarcane	Rahur	792.10	866.30	245.00	188.00	3.23	4.61	23.26	9.37
	Dharwad	55.70	48.00	51.40	43.50	1.08	1.10	33.33	-13.82
Others (Avg)		163.03	183.18	83.14	60.22	1.33	2.13	30.53	15.09

Source: INCID (1998).

A large number of individual evaluation studies on sprinkler irrigation have also been carried out in different crops. Let us briefly understand the impact of SIM in each crop. Using three years experimental data, a study was carried out in Udaipur district of Rajasthan on Maize and Wheat crops to know the economic feasibility of SIM. The result of the study shows the average incremental yield in maize and wheat was 4.45 and 6.95 percent respectively over flood irrigation method (FIM). Water saving due to SIM was 14.48 and 16.89 percent respectively for maize and wheat (Acharyna *et al.*, 1993).Similarly, another experimental result of three year trail conducted in Gujarat with winter maize indicates the superiority of sprinkler irrigation over flood irrigation method. The trail shows about 40 percent of water saving and 30 percent of productivity gain over the conventional method of irrigation (Patel, *et al.*, 1993).

In order to find out the relative economics of SIM over FIM in Fenugreek crop, a three year trail was conducted in North Gujarat. The study shows that under the conditions of normal water availability, the use of SIM can result in 29 percent water saving along with 35 percent yield increase. Importantly for farmers, the net income per mm of water used rose from Rs. 2.80 with surface method to Rs. 9.57 with sprinkler method of irrigation (Mehta, *et al.*, 1993).

An exploratory experiment carried out to study the comparative performance of micro-tube, sprinkler and furrow method of irrigation in Sugarcane at Vasantdada Sugar Institute as well as in Co-operative sugar factories in Maharashtra shows that water saving due to use of micro-tube irrigation is almost two fold as compared to sprinkler irrigation. This relatively more water saving in micro-tube was attributed to less water evaporation and required water quantity applied at the root zone of the crop with maximum frequency. The increase in yield with micro-tube irrigation was also found to be higher (172.12 mt/ha) as compared to SIM (142.30 mt/ha) and FIM (135.50 mt/ha). The water use efficiency of micro-tube was observed nearly 2.5 times more than FIM irrigated sugarcane (Hapase, *et al.*, 1993).

A field experiment conducted in south Gujarat during 1989 to 1991 to explore the feasibility of adoption of mini sprinkler irrigation system for onion crop during *rabi* season shows a considerable increase of yield and water saving over the method of flood irrigation (Desai, *et al.*, 1993). Similar to onion, another experimental study carried out in south Gujarat to study the feasibility of mini sprinkler in Safflower also shows that its gain in increasing yield (about 13 percent), water saving (20.31 percent) and water use efficiency (47.61 percent) as compared to conventional method of irrigation (Patel, *et al.*, 1993). Similar results were also reported by Abrol and Sharma (1990) in Sunflower crop.

On groundnut, Gujarat Agricultural University, Sardar Krushinagar conducted an experimental study during three summer seasons of 1990, 1991 and 1992, which shows that sprinkler irrigation is highly suitable for groundnut cultivation. Water use efficiency was found to be higher in all schedules of sprinkler and save 9.6 to 53.9 percent of irrigation when compared to surface irrigation method. The net income per mm water used was found to be more under all the sprinkler irrigation schedules over surface method of irrigation (Patel *et al.*, 1993). Dhawan (2002) mentions, using the experimental data on summer GROUNDNUT from farm research station of the Dharward campus of the University of Agricultural Sciences, about 17 percent improvement in groundnut yield and a like amount of water saving owing to use of sprinkler instead of surface irrigation, but a 40 percent improvement in water use efficiency. Similarly, a field experiment conducted at Anand, Gujarat (Mehta, *et al.*, 1993) in groundnut crop also shows considerable increase in yield and water use efficiency of groundnut over the flood method of irrigation, which are presented in Table 8.

Table 8: Yield of groundnut under different treatments of sprinkler and surface

Treatment	Pod yield (Kg/ha)				Net realisation (Rs/ha)	BCR
Sprinkler irrigation at 0.45 IW/CPE	1285	1182	1299	1255	2275	1.22
Sprinkler Irrigation at 0.60 IW/CPE	1462	1990	1563	1671	5667	1.54
Sprinkler Irrigation at 0.75 IW/CPE	1875	2493	1854	2074	9562	1.87
Surface Irrigation	1181	1448	1347	1459	6626	1.77

Source: Mehta *et al.*, (1993).

Though a large number of studies showed that SIM is suitable even for foodgrain crops such as wheat, maize, pulses and groundnut, etc, these studies have mainly dealt with the impact of sprinkler irrigation on water saving and yield gain. Seldom studies have dealt with the economic viability of sprinkler investment in foodgrain and oilseed crops, especially using field level data. Given the vast potential of sprinkler irrigation, properly designed field based studies need to be carried out particularly on food grain crops so as to understand the real impact of it. What is the impact of MI on the over-exploitation of groundwater is an another issue, which also needs to be probed using filed level data.

Efficiency of drip and sprinkler irrigation

One of the main reasons for adopting micro-irrigation in crop cultivation is to save water and increase the efficiency of water use. Over centuries all over the world, irrigation water has been predominantly applied for crops using flood/gravity method. Generally, under conventional (flood/gravity) method of irrigation, water is supplied through unlined canal and field channels for crops where controllability of water is not easily possible and therefore, conveyance and distribution losses are substantial. Unlike conventional method of irrigation, both sprinkler and drip irrigation supply water to crop using pipe network along with drippers, emitters and nozzles. As a result of supplying water directly to the crop or to the field, the conveyance and distribution losses are found to be completely absent under micro-irrigation method.

Table 9: Irrigation efficiencies under different methods of irrigation

Irrigation Efficiencies	Methods of Irrigation		
		Sprinkler	Drip
Conveyance efficiency	40-50 (canal) 60-70 (well)	100	100
Application efficiency	60-70	70-80	90
Surface water moisture evaporation	30-40	30-40	20-25
Overall efficiency	30-35	50-60	80-90

Source: Sivanappan (1998).

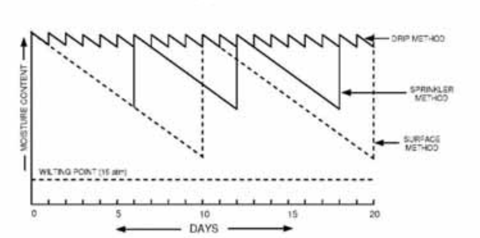
It is difficult to measure the water use efficiency under different methods of irrigation at the farmers' field as each farmer uses different types of pumpsets (where efficiency varies considerably) and pipe network. Estimates carried out at different research stations under different methods of irrigation reveal the comparative efficiency of irrigation under different methods (Table 10). While the conveyance efficiency under surface method of irrigation is estimated to be only in the range of 40-50 percent in canal and 60-70 percent in well, the same is estimated to be 100 percent in both sprinkler and drip method of irrigation. As mentioned earlier, the higher level of conveyance efficiency under micro-irrigation is mainly because of application of water by pipe network, where seepage and other leakages are also completely absent. A less than 50 percent of conveyance efficiency in surface irrigation method suggests that by converting all the surface method of irrigation into micro-irrigation, we would be able to double the irrigated area without constructing any new irrigation projects.

Application efficiency refers to water use at the farm level. Estimates suggests that there are wide variation here too in the level of efficiency. Water can be applied at a required quantity and time under micro-irrigation and therefore, the application efficiency is always higher under micro-irrigation as compared to conventional surface irrigation method. The overall application efficiency is estimated to be 60-70 percent in surface irrigation, whereas the same comes to 70-80 percent for sprinkler and 90 percent for drip irrigation method. Because of flooding of water under surface irrigation method, large quantity of water is wasted in the form of evaporation and seepage losses and thus, the application efficiency is always lower while applying water by surface method. Since water is applied directly to the root zone of the crop at a required quantity by drip method of irrigation, the application efficiency is always nearing 100 percent. The application efficiency is estimated to be relatively lower under sprinkler irrigation as compared to drip method because of two reasons. First, sprinkler irrigation is often affected by wind interference which ultimately reduces the efficiency. Second, unlike drip method, sprinkler supplies water to whole of cropped area and therefore, water losses would obviously be higher.

Table 10: Water use efficiency (q/ha/cm) in surface, sprinkler and drip irrigated crop

Sprinkler Vs. Flood Method			Drip Vs. Flood Method		
Crops	Water Use efficiency		Crops	Water Use efficiency	
	FMI	SMI		FMI	DIM
1. Wheat	0.93	1.79	Papaya	0.57	3.13
2. Bajra	0.39	1.07	Ashgourd	1.29	1.63
3. Jowar	0.19	0.59	tomato	1.24	8.29
4. Sorghum (kharif)	2.45	4.58	ladys finger	1.87	13.15
5. Maize (kharif)	1.22	2.01	Brinjal	3.11	6.67
6. Barley	1.35	3.59	Sweet potato	0.67	2.34
7. Gram	0.37	1.27	Radish	0.23	1.10
8. Oilseeds	0.14	0.31	Beet	0.07	0.50
9. Groundnut(summer)	0.26	0.47	Potato	11.79	17.21
10. Sunflower (rabi)	0.53	0.96	Watermelon	3.68	11.03
11. Chillies (kharif)	0.48	0.89	Chillies	0.39	1.46
12. Garlic	0.83	1.23	Bottlegourd	4.53	7.54
13. Onion (summer)	4.29	7.94	Onion	1.54	2.03
14. Cotton	0.17	0.24	cotton	0.25	0.61
15. Sugarcane	3.23	4.61	Sugarcane	8.10	21.27

Figure 2: Moisture Availability for Crops in Different Irrigation Methods



Unlike application efficiency, there are no variations between surface method and sprinkler method of irrigation in the case of surface water moisture evaporation. In both surface and sprinkler method, it is estimated to be the same, varying from 30 to 40 percent. In the case of drip, the surface water moisture evaporation is only 20-25 percent. Drip method of irrigation does not allow water to spread beyond the root zone of the crop and therefore, the water moisture evaporation is very less in drip irrigation.

Because of very high level of conveyance and application efficiency and low water moisture evaporation, the overall water use efficiency is very high (80-90 percent) under drip method of irrigation as compared to sprinkler (50-60 percent) and surface method of irrigation (30-35 percent). Therefore, drip irrigation appears to be the most efficient method of irrigation in terms of absolute use of water for crop cultivation. Drip irrigation method also appears to be efficient method in terms of moisture availability of crops. (Fig. 2). Apart from increasing water use efficiency in absolute term; there is also a need to increase water use efficiency in terms of productivity (water productivity) because of fast decline of irrigation water potential and growing demand for water from different sectors. In order to satisfy the growing demand for various agricultural commodities, it is essential to increase the water productivity from the existing level. Available studies based on experimental data suggest that the crops being cultivated under micro-irrigation require relatively less amount of water to produce one unit of output. Data presented in Table 10 on various crops clearly confirms that the water productivity is much higher under both sprinkler and drip irrigation as compared to flood irrigation method. Among sprinkler and drip method of irrigation, drip method appears to be more efficient in terms of producing output per unit of water. Since the application efficiency of water is much higher in drip irrigation method, the water use efficiency in terms of productivity is also substantially higher in drip method. Net gain in terms of money value from each unit of water is also estimated to be higher under micro-irrigation method as compared to surface and other improved methods (Table 11).

Table 11: Water use efficiency as net benefit in Rs. per mm of water use

Crop	Surface	Sprinkler	Drip	Improved Surface Irrigation	
				With PVC network	With field channel
Cotton	18.40	28.11	--	33.70	25.50
Pigeon pea	21.36	18.49	--	33.62	28.71
Wheat	7.28	9.16	--	11.56	8.50
Sorghum (R)	9.90	15.45	--	18.19	13.20
Gram	13.77	22.21	--	25.47	18.38
Sunflower (R)	7.83	12.08	--	14.32	10.41
Maize	7.79	11.66	--	14.12	10.30
Groundnut (HW)	14.71	27.11	--	28.61	20.28
Sugarcane	12.52	21.91	18.03	23.70	17.21
Sweet Orange	61.82	119.98	116.02	122.76	86.88

Source: Holsambre, *et al.*, (1998).

On the whole, the estimates presented above suggest that the efficiency of water use is substantially higher under SIM and DIM in comparison to the efficiency of flood irrigation method, mainly because of reduction in conveyance and distribution losses. It also clearly suggests that the present level of water use efficiency under surface irrigation method is very low, which can be increased substantially by focusing more on demand management strategies such as drip and sprinkler. This would also help increasing the irrigated area without exploiting the limited irrigation potential.

Potential of micro irrigation:

Adoption of micro irrigation methods could bring a large area under irrigation along with increasing the land and water productivities. The potential for coverage under drip and sprinkler irrigation is estimated to be about 27 and 42.5 million ha respectively as per the following break up given in Table 12 (National Task Force on Micro irrigation, Government of India). The area under tea, coffee and recreational facilities including golf etc. also offer a suitable location for the adoption of micro irrigation systems which have not been considered in the estimates presented in (Table 12)

Table 12: Theoretical potential area (m ha) for drip and sprinkler in India

Crop	Area		
	Drip	Sprinkler	Total
Cereals	-	27.6	27.6
Pulses	-	7.6	7.6
Oil seeds	3.8	1.1	4.9
Cotton	7.0	1.8	8.8
Vegetables	3.6	2.4	6.0
Spices and condiments	1.4	1.0	2.4
Flowers, medical and aromatic plants	--	1.0	1.0
Sugarcane	4.3	--	4.3
Fruits	3.9	--	3.9
Coconuts, plantation crops and oil palm	3.0	--	3.0
Total	27.0	42.5	69.5

Advantages of micro irrigation

- Crop Yield Enhancement, 30-200%
- Saving of Irrigation Water, 30-70%
- Saving in Energy for pumping
- Savings in Fertilizers, 30-40%
- Uniformity of Water Application
- Improvement in Quality of Produce
- Improved Pest and Disease Control
- Improves Soil Health
- Reduced Weed Growth
- Reduced Labour Costs
- Ideal for Difficult Land Terrain (hilly, undulating) and Marginal lands
- Suitable for inferior quality water
- Highest water use efficiency, 90-95%

Limitations of micro irrigation:

- High initial cost.
- Restricted area of root growth.
- Requirement of higher level of design, management and maintenance.
- Salt accumulation near plant.
- Clogging of emitters.

Reasons of slow growth of area under drip and sprinkler irrigation:

- ✓ High capital cost required for the system
- ✓ Subsidy is not easily available for farmers
- ✓ Poor awareness about the importance of water saving technologies
- ✓ Not suitable for marginal and small farmers following subsistence farming
- ✓ After sale service is not satisfactory
- ✓ Free electricity and low price of canal water
- ✓ Fear about system clogging among the farmers
- ✓ Promotional schemes are not available in many states
- ✓ Poor extension and training facilities to farmers
- ✓ Benefit cost of water saving technologies has not been adequately demonstrated to farmers
- ✓ State machinery (officials) is not keen to promote micro irrigation without subsidy

Conclusion

From the various aspects mentioned above it is concluded that to achieve higher water use efficiency and water saving, precise water management micro irrigation techniques like drip and micro sprinkler are the present need for sustaining agriculture production.

References

- Abrol IP and Sharma BR. 1990. Efficient water management in crucial for achieving self-sufficiency in food. Indian Farming 40 (7): 25-27.
- Acharyna MS, Singh J, Gupta AP and Singh AK. 1993. Economic analysis of sprinkler irrigation in Southern Rajasthan. In CBIP.1993. Sprinkler and Drip Irrigation Systems, Central Board of Irrigation and Power, New Delhi. pp 74-76.
- AFC.1998. Evaluation of drip irrigation system, Agricultural Finance Corporation (AFC) Limited, Mumbai, October.
- Batta RK and Singh SR. 1998. Adoption of drip irrigation in Sugarcane in India. In Varma and Rao (Eds.). pp. VII 27 - VII 45.
- Central Ground Water Board. 2007. Manual on Artificial Recharge to Groundwater, CGWB, MoWR, New Delhi, pp 181.
- CWC (1996; 1998; 2002 and 2004), Water and Related Statistics, Ministry of Water Resources, Central Water Commission (CWC), Government of India, New Delhi.
- Dash NK.1998. Drip irrigation and micro-Irrigation potential and prosperity for Sugarcane cultivation with reference to Orissa. In VSI pp. III 7 - III 12.
- Desai ND.1993. Feasibility of mini sprinkler in Onion. In CBIP. 1993. pp 121-123.
- Deshmukh AS, Shinde PP and Katake SS. 1998. Role of drip irrigation in increasing water use efficiency for Sugarcane crop. In VSI pp. III 34 - III 46.
- Dhawan BD. 2002. Technological change in Indian irrigated agriculture: A study of water saving methods, Commonwealth Publishers, New Delhi.
- Dhonde RM and Banger AR.1998. Peoples participation in drip irrigation system for Suru Sugarcane in Kukadi and Krishna Commands of Maharashtra: An Overview. In VSI pp III 25 - III 33.
- GOI. 1994. Report of Task Force on Microirrigation, (Chairman: N. Chandrababu Naidu), Ministry of Agriculture, Government of India, January.
- Hapase DG, Deshmukh AS and. Shinde PP.1993. Micro-Irrigation in Sugarcane Agriculture. In CBIP pp 86-89.
- Holsambre DG, Sahni BM and Bhalage PS.1998. Developing interface of pressurized irrigation in canal command in Maharashtra. In Varma, CVJ. and Rao ARG (Eds.). pp VII 46 - VII 64.
- INCID.1994. Drip irrigation in India, Indian National Committee on Irrigation and Drainage, New Delhi.
- INCID.1998. Sprinkler Irrigation in India, Indian National Committee on Irrigation and Drainage, New Delhi.
- Iyer, Ramasamy R.2003. Water: Perspectives, Issues, Concerns, Sage Publications, New Delhi.
- Kulkarni SA. 2005. Looking beyond eight sprinklers", Paper presented at the National Conference on Micro-Irrigation, G. B. Pant University of Agriculture and Technology, Patnagar, India, June 3-5, 2005.
- Kundu DK, Neue HU and Singh R.1998. Comparative effects of flooding and sprinkler irrigation on growth and mineral composition of rice in an Alfisol. Proceedings of the National Seminar on Micro-Irrigation Research in India: Status and Perspective for the 21st Century, Bhubaneswar, July 27-28, 1998.

- Mehta H M.1993. Comparative study of sprinkler versus flood irrigation in summer groundnut. In CBIP.1993. pp 167-168.
- Microirrigation, Central Board of Irrigation and Power, New Delhi.
- MOWR.1999. Report of the working group on water availability for use. National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, Government of India, New Delhi.
- Narayanamoorthy A. 1997. Economic viability of drip irrigation: An empirical analysis from Maharashtra. Indian Journal of Agricultural Economics 52 (4) : 728-739.
- Narayanamoorthy A. 2001. Impact of drip irrigation on Sugarcane cultivation in Maharashtra, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune.
- Narayanamoorthy A.1996. Evaluation of drip irrigation system in Maharashtra. Mimeograph Series No. 42, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, Maharashtra.
- Narayanamoorthy A.2005. Efficiency of Irrigation: A case of drip irrigation. Occasional Paper: 45, Department of Economic Analysis and Research, National Bank for Agriculture and Rural Development, Mumbai, India.
- Narayanmoorthy A. 2004. Drip irrigation in India: Can it solve water scarcity? Water Policy 6 (2) :117-130.
- National Commission on Integrated Water Resources Development Planning, Government of India
- National Task Force on Micro-irrigation. 2004. Ministry of Agriculture, GOI Report. p
- 330.
- NCPA. 1990. Status, potential and approach for adoption of drip and sprinkler irrigation systems. National committee on the use of plastics in Agriculture, Pune, India.
- Parikh MM, Shrivastava PJ, Savani NG and Raman S. 1993. Feasibility study of drip in Sugarcane. In CBIP pp 124-127.
- Patel IS. 1993. Studies on sprinkler vs surface method of irrigation in summer groundunt cv.GG-2. In CBIP.1993. pp 150-152.
- Postal S, Polak P, Gonzales F and Keller J. 2001. Drip irrigation for small farmers: A new initiative to alleviate hunger and poverty. Water International, Vol. 26, No. 1.
- Rajput TBS and Patel Neelam. 2012. Micro-irrigation in India-Present status and future scope. India Water Week 2012- Water, Energy and Food Security: Call for Solutions, 10-14 April 2012, New Delhi.
- Rosegrant WM.1997. Water resources in the twenty-first century: Challenges and implications for action, food and agriculture, and the environment discussion paper 20. International Food Policy Research Institute, Washington D.C., U.S.A.
- Saleth, RM.1996. Water institutions in India: Economics, Law and Policy, Commonwealth Publishers, New Delhi.
- Sankpal VY, Danawale NJ, Khade KK and Bhoite DS. 1998. Response of sugarcane varieties to drip irrigation during Suru Season. In VSI , pp III 13-III 24.
- Singh HP. 2001. Emerging scenario of micro-irrigation in India. Proceedings of international conference on micro and sprinkler irrigation systems, 8-10 Feb.2000. CBIP publication, 282, pp 18-30.
- Sivanappan RK. 1994. Prospects of micro irrigation in India. Irrigation and Drainage System 8 (1) : 49-58.
- Sivanappan RK. 1998. Irrigation water management for Sugarcane. In VSI, pp II.
- Varma CVJ and Rao ARG. (Eds.). 1998. Micro-irrigation and sprinkler irrigation systems. Central Board of Irrigation and Power, New Delhi.
- Venugopal R and Rajkumar M.1998. Drip irrigation system - New concept in Sugarcane culture at Baramba of Orissa state. In VSI, pp III 7 - III 12. Water Policy 6(2): 117-130.

Nutrient management and carbon sequestration potential of soybean-Wheat and sorghum-wheat cropping systems in Vertisols

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To study the impact of nutrient management on carbon sequestration in soil, soil samples from the plot supplied with differential amount of nutrients at two long term sites viz., Jabalpur and Akola were collected and analyzed for soil carbon. The amount of carbon added through residual biomass (roots, leaf, rhizodeposition, stubble etc) was estimated and the relationship between carbon added to soil and the change in soil carbon was worked out using first order kinetic equation. By using this relationship threshold value of carbon to maintain initial level of carbon was worked out. The results revealed that integrated application of nutrient resulted increase in carbon addition and sequestration as well in soil. This concomitantly increased with increase in productivity. For instance at Jabalpur amount of carbon sequestered in control plot after 40 years was 2.06 Mgha^{-1} which increased to 3.14, 4.5 and 7.38 Mg ha^{-1} on application of N, NP and NPK, respectively. Similarly at Akola, the net amount of carbon sequestered in soil after 26 years of experimentation was -3.74 Mg ha^{-1} (depleted) in control, however, increased to 0.4 Mg ha^{-1}, 1.5, 2.4 and 7.8 on application of N, NP, NPK and NPK+FYM and the corresponding amount of carbon added annually by sorghum- wheat crop sequence through residue biomass was 220, 2003, 3385, 5057 and 6576 kg ha^{-1}, respectively. The minimum amount carbon (threshold carbon) required to be added to maintain initial amount of carbon was 2434 at Jabalpur whereas under the climatic condition of Akola the threshold value of carbon worked out was 2217 kg ha^{-1}. Decline in SOC in control plot at Akola is due to addition of carbon (220 kg ha^{-1}) in quantity less than the amount of loss of carbon from soil (2217 kg) due to poor productivity. Whereas amount of carbon added in control plot at Jabalpur was almost equal to threshold carbon value and there is not much change in SOC. So from the results it is evident that application of nutrient not only played a positive role in enhancing productivity but also carbon sequestration in soil.

Introduction

Carbon dynamics and global warming are interrelated phenomenon and go hand in hand.

Carbon dynamics in agriculture system is an important phenomenon which acts as sink and source as well for carbon and at the same time plays important role in improvement of soil fertility. Increase in agronomic productivity of crop not only ensures the food security but also taking care of climate by absorbing more CO_2 from atmosphere (2, 5). Carbon sequestration in soil from atmospheric carbon is dependent on productivity, climate, management, and silt + clay content of soil (2). Capacity of crops to assimilate carbon from atmosphere may also have impact on carbon sequestration in soil. Since carbon sources in plant parts are derived from atmosphere and drawl of CO_2 from it helps in mitigating climate change. Crop residue incorporation also encourages carbon sequestration (4, 5). Studies revealed that most of soil carbon particularly in Indian soil is contributed through residual biomass of plants which is added to soil through leaf fall, crop stubble, root and rhizodeposition as straw is not recycled back due to other competitive uses like fodder and fuel (8). The studies indicated that quantity of residual biomass is proportional on above ground productivity (3). So to enhance carbon sequestration we should follow the practices which increase productivity, may be through supplying the nutrient in balanced way. Reasons like disproportionate nutrient supply and mining of nutrient by crops in quantity larger than to be replenished to the soil are the key constraints in achieving the potential productivity of crop (12). Under such implications of nutrient application balanced use of nutrient is one of the ways to obtain potential yield of crop. In this paper attempt has been made to evaluate the impact of nutrient management on productivity and carbon sequestration by soybean-wheat and sorghum-wheat system grown on Vertisols under long term fertilizer experiment.

Materials and methods

To evaluate soil health soil carbon is most important constituent of soil. So, our attempt should be to enhance soil carbon for improving soil health and sustaining the system. To study the impact of nutrient management on soil health, AICRP long term fertilizer experiment was initiated during 1972. The present study was undertaken in long term fertilizer experiments which are in progress with soybean-wheat at JNKVV, Jabalpur and sorghum-wheat at PDKVV, Akola. The experiment was laid out with following treatments and details of nutrient supplied in each treatment are given in Table 1.

Table 1 - Total (kharif + rabi) amount of nutrients (kg ha^{-1}) applied each year at Jabalpur and Akola

Treatment	Jabalpur				Akola			
	N	P	K	FYM*	N	P	K	FYM
Control	0	0	0	0	0	0	0	-
100% N	140	-	-	-	200	-	-	-
100% NP	140	68	-	-	200	33	-	-
100% NPK	140	68	33	-	200	33	66	-
150% NPK	210	104	50	-	300	50	99	-
100% NPK +FYM	140	68	33	15	200	33	66	10
100% NPK -S	140	68	33	-	-	-	-	-

*FYM was applied during Kharif every year. In NPK-S treatment P was applied through DAP and other treatments through SSP.

Experiments were conducted in randomized block design (RBD) and the treatments were randomized within block. Treatments were replicated four times. Soil of experimental site at Jabalpur was calcareous in nature with carbon content 0.57 percent. Available N, P and K contents at time of start of experiment were 193 kg N ha^{-1}, 7.6 kg P_2O_5 ha^{-1} and 370 kg K_2O ha^{-1}, respectively. Similarly the soils of experimental site at Akola were also alkaline in nature and developed from basaltic material having organic carbon content 0.46 percent. The available N, P and K contents were 120 kg ha^{-1}, 8.4 kg P_2O_5 ha^{-1}, 358 kg K_2O ha^{-1}, respectively. Soybean-wheat and sorghum-wheat were test cropping systems and were initiated during 1972 and 1986 at Jabalpur and Akola, respectively. Soil and plant samples were drawn at the completion of 40 years at Jabalpur and 26 years at Akola.

Soil organic carbon was estimated by Walkley and Black method whereas carbon content in plant, seed, root etc was estimated through gravimetric method using dry combustion in replicated samples. Carbon content assimilated in different plant parts were calculated taking into account carbon content of plant parts and the productivity. However, for calculating amount of carbon added through rhizodepostion a factor 1.4 was taken from the study carried out by Regmi (1994) in 20 plant species (6).

Amount of carbon added to soil and the change in carbon has got relationship. So, rate constant of the carbon incorporation into SOM through annual C inputs (h) in the soil and decay rate constant (K) of native SOC were calculated from the following equations (Jenkinson 1988) assuming a single pool first order kinetic relationship between C-addition and storage in a given soil (1):

$$\delta Cs/\delta t = h.\ A - K\ .\ Cs$$

where, *Cs* is the soil organic C, *t* is the time and *A* is the annual C input to the soil. For computing *A* Value, we assumed that entire amount of biomass through stubbles, leaf fall is distributed in soil and we assumed that 70% of the biomass contributed by roots, nodules and exudates remained in 0-15 cm soil depth. Quantification of leaf fall, root and nodule etc in soybean and stubble and root biomass in wheat and sorghum were estimated by survey sampling in field.

Results and discussion

Data recorded on yield of soybean seed, trash, root biomass, nodule, leaf fall and rhizo-deposition and grain and straw yield and root biomass of wheat is presented in table 2. Perusal of data revealed that integration of nitrogen with phosphorus and K with NP resulted increase in seed and trash yield of soybean. Data further revealed that the amount of leaf fall from soybean, root biomass and nodule weight increased with increase in productivity. Increase in productivity on application of N is expected because N applied acted as starter dose to boost the growth of soybean till 20 days of growth as nodules start functioning only after 15-20 days after sowing. Singh *et al* (1996) recorded increase in productivity on application of 25 kg N ha^{-1} as booster dose at the time of sowing (10). Application of P and K also increased the productivity of all the components. Continuous absence of P and K in fertilizer schedule has resulted decline in available P_2O_5 from 7.6 kg ha^{-1} to 4.2 kg ha^{-1} and K_2O from 370 to 231 kg ha^{-1}, below the level at which crop started showing response to applied P and K. Singh and Wanjari (2014) observed response of soybean, wheat, sorghum in Vertisols of Central India after few years of growing of crop (11). Consistently good yield (1188 kg) of wheat even after 40 years without fertilizer is due to leaving of 35-56 kg biologically fixed nitrogen in soil by soybean each year which is utilized by wheat (7).

Table 2 - Effect of nutrient management on productivity (kg ha^{-1}) of above and below ground components of soybean and wheat

Treatment	Grain	Straw	Leaf fall	Root	Nodule	Rhizodeposition
			Soybean			
Control	849	1188	382.9	633.5	83.6	252.1
100% N	1064	1484	479	792.4	104.5	318 .0
100% NP	1759	2512	802.9	1328.2	175.3	533.8
100% NPK	1921	2778	883.4	1461.4	192.8	587.3
150% NPK	1978	2836	904.8	1496.8	197.4	601.6
100% NPK+FYM	2096	3180	991.8	1640.8	216.5	659.5
100% NPK-S	1789	2555	816.6	1350.9	178	543.0
CD (*P*=0.05)	180	230	90.5	110	17.4	52.7
			Wheat			
	Grain	Straw	Stubble	Root		
Control	1108	1735	116.2	1464.0		
100% N	1454	2285	153.1	1886.1		
100% NP	3829	5472	366.6	4071.2		
100% NPK	4088	6297	421.8	4465.7		
150% NPK	4387	6489	434.7	4704.2		
100% NPK+FYM	4504	6644	445.0	4927.2		
100% NPK-S	3835	5707	382.3	4165.8		
CD (*P*=0.05)	215	430	45			

Application of major nutrients (N, P and K) resulted increase in amount of leaf fall and root biomass in soybean. This is due to increase in plant growth and productivity. Larger is the productivity greater is amount of leaf fall and root biomass is expected. As roots help in providing the nutrient and water to plant whereas leaves contribute to photosynthesis. Studies reported in literature indicated that leaf fall root and nodule biomass is proportional to above ground biomass and has a definite relationship in a crop (3). A similar trend of increase in grain and straw yield of wheat was recorded on application of N and then followed by P and K. Response of wheat to applied P was larger than soybean. Increase in root and stubble biomass on increase in productivity of wheat was also observed which is obvious.

Assimilation of carbon from atmosphere

Carbon assimilated by crop was calculated by estimating carbon content in different part of plants

and the total carbon content in plant parts (Table 3). Data on assimilation of carbon revealed that carbon assimilated by wheat is larger than soybean at each nutrient management options. Moreover, wheat crop has got 2-3 folds more potential to assimilate more CO_2 -carbon from atmosphere and proportionately higher amount of carbon is added to soil by wheat. For instance, on application of 100% NPK, total amount of carbon derived from atmosphere by soybean and wheat was 2667.1 kg ha^{-1} and 9066.8 kg ha^{-1}, respectively and the amount of carbon added to soil by soybean (leaf fall, root nodule and rhizodeposition) was 1071 kg ha^{-1} whereas amount of carbon added by wheat (stubble, root and rhizodeposition) was 4683 kg ha^{-1} which is almost 4 times to that of soybean. It indicates that the crop like wheat has got more potential not only to assimilate more carbon but also has potential to sequester carbon as well as environment mitigation potential.

Table 3 - Carbon derived from atmosphere (kg ha^{-1}) by above and below ground biomass of soybean and wheat

Treatment	Soybean			Wheat				Total Carbon derived from atmosphere
	Above ground biomass	Below ground biomass	Total	Above ground biomass	Below ground biomass	Total	Total C added to soil	
Control	690.9	739.8	1430.7	1200.3	1524.8	2725.1	2264	4155.8
100% N	864.1	580.8	1444.9	1578.7	1967.0	3545.7	2597	4990.6
100% NP	1449.6	973.9	2423.5	3922.9	4261.5	8184.4	5234	10607.9
100% NPK	1595.6	1071.4	2667	4383.8	4683.0	9066.8	5754	11733.8
150% NPK	1634.1	1097.4	2731.5	4588.9	4928.7	9517.6	6025	12249.1
100% NPK+FYM	1794.6	1203	2997.6	4703.6	5157.8	9861.4	6360	12859.1
100% NPK-S	1474.4	990.4	2464.8	4026.4	4363	8389.4	5301	10854.2

Carbon sequestration in soil by soybean-whea

Carbon sequestration in soil was calculated by taking into account the carbon stock in soil at the time of initiation of experiment and current carbon stock in soil. The difference between these two gave amount of carbon sequestered in soil over a period time. Perusal of data (Table 4) indicated that amount of carbon sequestered in different treatments varied from 2.06 to 10.88 Mg ha^{-1} in 40 years. Data further revealed that annual carbon sequestration varied from 52 to 272 kg ha^{-1} yr^{-1} depending upon the level of nutrient application. Thus, amount of carbon sequestered in soil is dependent on productivity of crops, larger is the productivity greater will be the amount of carbon sequestered in soil. From this study it is clear that application of nutrients is essential not only to enhance productivity (9) but also to enhance net carbon sequestration in soil.

Table 4 - Carbon stock (Mg ha^{-1}) and sequestration (kg ha^{-1} yr^{-1}) as influenced by nutrient management at Jabalpur

Treatment	Current bulk density (Mg M^{-3})	Current status C (%)	Carbon stock (Mg ha^{-1})		Mean carbon sequestered	
			Initial	Current (After 40 yrs)	Change in carbon stock (Mg ha^{-1})	Carbon sequestered (kg^{-1} ha^{-1} yr^{-1})
Control	1.34	0.60	14.82	16.88	2.06	52.0
100% N	1.38	0.62	14.82	17.96	3.14	77.0
100% NP	1.30	0.75	14.82	21.78	4.50	173.0
100% NPK	1.32	0.84	14.82	22.20	7.38	184.5
150% NPK	1.32	0.94	14.82	24.80	9.98	249.5
100% NPK+FYM	1.30	0.99	14.82	25.70	10.88	272.0
100% NPK-S	1.33	0.73	14.82	19.4	4.58	176.0
CD (*P*=0.05)	0.05	0.16	-	2.1	2.2	50.4

Initial carbon content 0.57% and bulk density (B.D.) 1.3 Mg M^{-3}

Rate constant (h) of added biomass

The relationship between amount of carbon added to soil through below ground biomass of crops and the change in carbon content observed has followed first order kinetic equation (Figure 1)

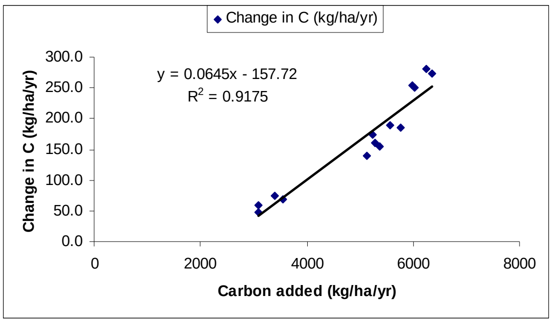

Figure 1-Relationship between C added through plant and changes in carbon in soil under soybean-wheat cropping system at Jabalpur

$$y = 0.0645x - 157.72; \quad R^2=0.9175^{**}$$

The change in soil carbon based on relationship ranged from 33.6 to 379.7 kg ha^{-1} on depending upon the amount of carbon added into the soil through residual biomass of soybean and wheat. Whereas the observed values of annual rate of change in carbon varied from 52 to 272 kg ha^{-1} (Table 4). Which are more or less similar to values predicted through relationship of change in carbon in soil and carbon added through residual biomass.

The minimum amount of carbon added annually to maintain the status of soil carbon was found to be was 2434 kg ha^{-1}. It means this much amount of carbon is required to be added each year to maintain the initial carbon content soil in the climate of Jabalpur. However, C added to soil even in control plot was 2264 kg ha^{-1} yr-^{1}, that was more or less equal to amount of C lost from the system and this is the reason that in control plot also there is neither gain nor depletion in soil C content even after 40 years. But the carbon added in other treatments is much larger than the loss of carbon and this is the reason that in those treatments proportionate increase in carbon in soil is recorded. Kundu *et al*. (2001) in soybean system reported substantial increase in soil carbon in soybean-wheat system and reported 900 kg carbon required to be added annually in Bhopal climate (3).

Nutrient Management and Productivity Above and Below Ground Plant Parts of Sorghum and Wheat Perusal of yield data presented in table 5 revealed increase in grain, straw, stubble and residual biomass of root on application of all the three nutrients (N, P and K). Increase in productivity further increased on increase in nutrient dose from 100% NPK to 150% which means 100% NPK dose defined is not sufficient to get the potential yield of sorghum. Data further revealed that integration of FYM with 100% NPK resulted in maximum production. A similar kind of increase in productivity of grain, straw and stubble and root biomass was recorded on application of nutrients (N, P, K) in wheat.

Table 5 - Productivity of above and below ground biomass (kg ha^{-1}) of sorghum and wheat as influenced by nutrient management

Treatments	Sorghum				Wheat			
	Grain	Straw	Root	Stubble	Grain	Straw	Root	Stubble
Control	325	589	182	6.0	70	133	60.9	9.0
100% N	1877	4195	1214	419	888	1420	892	211.9
100% NP	3002	6622	1805	662	1425	2280	1111.5	340.0
100% NPK	3697	8524	2444	852	2788	4460	2174.4	665.6
150% NPK	4490	10327	2963	1032	3213	4932	2443	739.0
100% NPK+FYM	5000	11500	3300	1150	3388	5285	2601	788.0
CD (*P*=0.05)	478	1126	460	180	381	454	231	170

Increase in yield of both sorghum and wheat on application of nutrient is due to supply of nutrient in less quantity from soil. Soils are low in N and P and with time due to no supply of K, available K status has also gone down from 370 to 231 kg K_2O ha^{-1} which resulted in inadequacy of K supply from soil and both the crops responded to applied K with time (11).

Assimilation of Carbon by Sorghum-Wheat

Assimilation of C from atmosphere was calculated by using carbon content in each part of the plant and their sum is presented in table 6. Data on carbon content derived from atmosphere by both the crops revealed that application of nutrient increased total assimilation of carbon which is due to increase in biomass production of different plant parts. Both sorghum and wheat are cereals and carbon assimilated by sorghum is 2 to 3 folds larger than wheat (Table 7). Similarly amount of assimilated carbon added to soil is larger in case of sorghum compared to wheat. The total amount of carbon added to soil through root biomass, stubble and rhizodeposition varied from 220 kg ha^{-1} to 6576 kg ha^{-1} depending upon the productivity level of treatment. Whereas amount of carbon derived from atmosphere ranged from 691.7 kg ha^{-1} to 17128 kg ha^{-1}.

Table 6 : Carbon derived (kg ha^{-1}) from atmosphere by above and below ground biomass of sorghum and wheat and added to soil

Treatment	Sorghum			Wheat				Total Carbon derived from atmosphere
	Above ground biomass	Below ground biomass*	Total	Above ground biomass	Below ground biomass*	Total	Total *Carbon added to soil	
Control	389.2	185.0	574.2	82.4	35.1	117.5	220	691.7
100% N	2596.6	1406.8	4003.4	930.3	596.6	1526.9	2003.	5530.3
100% NP	4114.5	2565.6	6680.1	1493.4	819.7	2313.1	3385	8993.2
100% NPK	5229.4	3443.4	8672.8	2921.5	1604.5	4526	5057	13198.8
150% NPK	6339.9	4186.6	10526.5	3277.4	1794.9	5072.3	5980	15598.8
100% NPK+FYM	7060.0	4664.0	11724	3492.2	1912.4	5404.6	6576	17128.6

*Carbon added through stubble, root and rhizodeposition of sorghum and wheat

Table 7 : Carbon stock and sequestration potential of sorghum-wheat system under different nutrient management options at Akola

Treatment	Current OC (%)	Bulk density (Mg M^{-3})	Carbon stock (Mg ha^{-1})			Carbon added (+)/ depleted (-) (kg ha^{-1} yr^{-1})
			Initial	Current	Difference	
Control	0.29	1.46	12.2	8.46	-3.74	-143.8
100% N	0.45	1.40	12.2	12.6	0.40	15.0
100% NP	0.49	1.46	12.2	13.7	1.5	57.0
100% NPK	0.53	1.38	12.2	14.6	2.4	92.0
150% NPK	0.66	1.36	12.2	17.9	5.7	219.2
100% NPK+FYM	0.78	1.3	12.2	20.0	7.8	300.0
CD (*P*=0.05)	0.12	NS	-	1.21	-	-

Initial Carbon 0.46% and bulk density.= 1.35, 26 years

Carbon Sequestered / Depleted in Soil

The change in carbon stock varied from - 3.74 Mg ha^{-1} to 7.8 Mg ha^{-1}. It means in control plot there has been net depletion of carbon stock to the tune of - 3.74 Mg ha^{-1} or -143.8 kg ha^{-1} yr^{-1}. Whereas amount of carbon derived from the relationship ranged from 119.0 to 261.0 kg ha^{-1} yr^{-1} which is more or less similar to the similar to what observed and given in table 7. The net loss of carbon is due to addition of fresh carbon through residual biomass in less quantity than the amount of carbon lost each year from the system. In control plot amount of carbon added through root biomass is 220 kg ha^{-1} whereas minimum amount of carbon required is 2217 kg ha^{-1}.

The relationship worked out between changes in carbon content in soil and the amount of carbon added to soil followed first order kinetic and represented following equation (**Figure 2**)

$$y = 0.0599\,x - 132.82 \qquad R^2=0.92$$

Where, y = change in carbon content in soil; x = amount of carbon added

The annual change was calculated through relationship ranged from -119.6 to 261.1 kg ha^{-1}. Though little deviation is observed but highly correlated. The loss in carbon control plot is due to addition fresh carbon net in less quantity through root/stubble or rhizodeposition than the amount of carbon oxidized/lost from the system. The amount of loss of carbon using above expression comes out to be 2217 kg C ha^{-1} yr^{-1} assuming change in carbon zero then dy/dx =0

$$y = 0.0599\,x - 132.8$$

When there is no change in soil carbon then y = 0

Then -x = -132.8 /0.0599; Thus, x = 2217 kg C

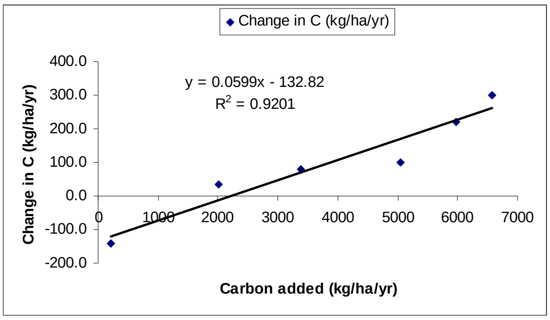

Figure 2 - Relationship between C added through plant and changes in carbon in soil under sorghum-wheat cropping system at Akola

So under the climate of Akola to maintain the initial carbon content one has to add at 2217 kg C ha^{-1} annually. Since in control plot amount of carbon added is far less than the amount of carbon lost through oxidation process from the system. Whereas in 100% N plot amount of carbon added is more or less similar to amount of carbon lost from the system and this is the reason that in this particular plot there is win-win situation as far as soil carbon status is concerned. Data further suggest that a very small portion of carbon added is retained by soil. For example in soybean wheat system only 2.3 to 4.4 percent of carbon is retained in soil and in case of sorghum wheat system the amount of carbon retained varied from 0.75 to 4.5 percent of carbon added through residual biomass. Similarly the rate of humification was also similar at both the sites. Humification rate at Jabalpur was 0.06 tons ha^{-1} whereas at Akola it was o.0599 tons ha^{-1}. Thus result suggest that majority of carbon added is lost from the system. The amount of carbon added to soil varied from 2264 to 6360 kg ha^{-1} yr^{-1} in soybean wheat system and this amount varied from 220 to 6576 kg ha^{-1} yr^{-1} in sorghum wheat system and the amount carbon retained in soil did not vary much. It means we should not apply too much organic manure to soil with the apprehension to increase soil carbon. Long term fertilizer experiment proved that increase in organic carbon in soil was almost similar on application of 5-15 tons of FYM each year. Results support the theory that instead of applying manure in large quantity to a field and then return back to same field after three years (farmers follow this practice). Application of manure to all plots each year in less quantity would give better output

Conclusion

From the results it is concluded that both the cropping systems have potential for sequestering the carbon in soil provided crop is well nourished. However, if we compare the net carbon sequestration potential then soybean-wheat has got potential to sequester more carbon in soil. But, carbon assimilation potential from atmosphere is more in case sorghum-wheat system.

References

- Jenkinson, D.S. *Soil organic matter and its dynamics*. In A. Wild: Russell's soil Conditions and Plant Growth, 11th Edition. Longman Group U.K. Limited. pp. 564-607 (1988)
- Jha Promod, Biswas A.K., Brij Lal Lakaria, Saha R., Subba Rao A. and Singh M. Predicting Total Organic Carbon Content of ***Soils.*** *Communications in Soil Science and Plant Analysis* 45:713–725 (2014)
- Kundu Samaresh, Muneshwar Singh, Jayanta K. Saha, Ashish Biswas, Awdhesh K. Tripathi and Chunni L. Acharya. Relationship between Carbon addition and storage in a Vertisol under soybean-wheat cropping system in subtropical capital India. *J. Plant Nutrition and Soil Science* 20: 483-486 (2001)
- Lal, R., 1997. Residue management, conservation tillage and soil restoration for mitigating green house effect by CO_2-enrichment. Soil Till. Res. 43, 81-107.
- Lal, R. Science, Soil carbon sequestration impacts on global climate change and food security, Science, 304, 623-627 (2004)
- Regmi, A.P. *Long term effects of organic amendment and mineral fertilizer on soil fertility in a rice*-rice-wheat cropping system in Nepal. M.S. Thesis, University of the Philippines, Los Banos. (1994)
- Singh M., Wanjari R.H., Anil Dwivedi and Ram Dalal. Yield response to applied nutrients and estimates of N_2 fixation in 33-year-old soybean–wheat experiment on a Vertisol. *Experimental Agriculture* 48 (3) 311-325 (2012)
- Singh M., Wanjari R.H., Manna M.C., Lakaria B.L., Jha Promod. Soil carbon management: Issues and strategies. *Indian J. Fert.* 10(5): 118-132 (2014).
- Singh, M., Tripathi A.K., Kundu S. and Takkar P.N. Nitrogen requirement of soybean-wheat cropping and biological N-fixation as influenced by integrated use of fertilizer N and farm yard manure in typic Haplustert. *Indian Journal Agriculture Science* 69: 73-75 (1998)
- Singh, M., Takkar P.N. and Tripathi A.K Response of soybean to applied fertilizer N and soil test calibration of available N and organic carbon in vertisols. *J. Indian Society of Soil Science* 44: 336-338 (1996).
- Singh, M., Wanjari R.H. Potassium response in Vertisols in long term fertilizer experiments. *International Potash Institute – eifc* no. 37**:** 10-15 (2014)
- Singh Muneshwar and Wanjari R. H. Annual Report – 2012-13. *All India Coordinated Research Project on Long-Term Fertilizer Experiments to Study Changes in soil quality, crop productivity and sustainability*. AICRP-LTFE, Indian Institute of Soil Science (ICAR), Nabibagh, Bhopal. pp. 1-142 (2013)

Mitigation of climate change impacts on agriculture through intervention in soil fertility management

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Introduction

The climate change has emerged as a major threat to agricultural production and has been found to have considerable adverse effects on performance and management of agro-ecosystems. These effects are being observed on the global scale, but countries like India are more susceptible in view of the huge population dependent on agriculture, more exploitation of natural resources, and meager coping mechanisms. Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2-4 ºC. Another vital aspect of climate change is the increase in the incidence of extreme events such as droughts, floods, cyclones and earthquakes, which will have expected adverse impacts on agriculture, water resources and livelihoods (Chary *et al.*, 2013).

For the past some decades, the gaseous composition of earth's atmosphere is undergoing a significant change, largely through increased emissions from energy, industry and agriculture sectors; widespread deforestation as well as fast changes in land use and land management practices. These anthropogenic activities are resulting in an increased emission of radiatively active gases, viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), popularly known as the 'greenhouse gases' (GHGs). These GHGs trap the outgoing infrared radiations from the earth's surface and thus raise the temperature of the atmosphere. The global mean annual temperature at the end of the 20th century, as a result of GHGs accumulation in the atmosphere, has increased by 0.4–0.7 ºC above that recorded at the end of the 19th century. The past 50 years have shown an increasing trend in temperature @ 0.13 °C/decade, while the rise in temperature during the past one and half decades has been much higher (Pathak *et al.*, 2012).

The IPCC (2007**)** report has projected that by 2100 earth's mean temperature will rise by 1.4 to 5.8ºC, precipitation will decrease in the sub tropical areas, and frequency of extreme events will increase significantly. IPCC reported that eleven of the last twelve years (between 1995 to 2009) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the ocean which has already started affecting the climatic phenomenon in different parts of world (Venkateswarlu, 2013)

1. Climate resilient sustainable agriculture

Climate Resilient Sustainable Agriculture is an initiative that revolves around the concept and practices of sustainable agriculture. It represents an effort to incorporate in our work the new challenges posed by climate change and its impacts on poor people's lives. It is based on the identification of the major risks and challenges local communities face, and/or are likely to face in the near future, and on the design and implementation of site-specific adaptation strategies aimed at reducing vulnerabilities and increasing the resilience of the smallholder production systems. (www.actionaid.org)

2. Adaptation strategies for resilient agro-climatic system

Chary *et al.*, (2013) gave the main adaptation strategies which include: (a) development of new genotypes, (b) intensifying search for genes for stress tolerance across plant and animal kingdom, (c) development of heat and drought tolerant genotypes, (d) attempting conversion of C_3 plants to C_4 plants, (e) development of new land use systems, (f) to explore opportunities for restoration of soil health, (g) use of multipurpose adapted livestock species and breed, (h) development of spatially differentiated operational contingency plans for weather related risks (i) supply management through market and non-market interventions in the event of adverse supply changes, (j) enhancement in research on applications of short, medium and long range weather forecasts for reducing production risks, and (k) development of knowledge based decision support systems for translating weather information into operational weather management sources

3. Soil management strategies for adaptation of climate resilient sustainable agriculture system

Better land, water and tillage management practices have potential in adaptations towards moisture stress, soil carbon management and a better combination of soil, tillage and water management practices considerably decrease GHGs emissions from agriculture both in irrigated and dry land agriculture and play important role in soil carbon sequestration. For that reason, management of soil in combination with optimum soil moisture and soil carbon management are necessary to guard the crops during weather aberrations and overall decline of CO_2, N_2O and CH_4 from soil. Placement of fertilizer materials and split application of nutrients into soil will also significantly improve the nutrient and water use efficiency (Srinivasarao and Rani, 2013).

4.1 Soil fertility management

Proper fertility management of soil is an important part of soil conservation technique. The conservation of soil implies utilization without misuse so as to maintain higher crop productivity as well as improving simultaneously the environmental quality. Soil conservation, in practice refers to the protection of surface deposits as well as subsurface deposits. Some of the methods used to maintain soil fertility consist of the in-situ moisture conservation practices, balanced use of fertilizer nutrients, efficient use of fertilizers, site specific nutrient management, taking care of nutrient needs of cropping systems, optimum fertilizer rates, following the principles of crop rotation, mixed cropping, use of biofertilizers, sowing of cover crops, use of organic manures, green manuring and efficient utilization of either rainwater or irrigation water given from harvested rain water etc (Nayyar & Sudhir, 2009).

3.2 Site- specific nutrient management

Site- specific nutrient management (SSNM) can be prescriptive, corrective or a combination of both (Dobermann and Cassman, 2004). SSNM has potential to mitigate adverse effects of climate change (Srinivasarao *et al.*, 2008). SSNM approach follows the principles of participatory soil sampling and development of soil health cards, which is very helpful for recommendation of nutrients. Based on the expected crop demand, targeted yield, soil test data, fertilizer efficiency and crop grown in each field, SSNM sheet could be developed in each farmer’s field. With this, farmers will invest only on deficient nutrients and omit nutrient application which was in sufficient range in soils. Thus, it reduces the input cost and improves the use efficiency of nutrients significantly. Nitrogen content of the standing crop is measured by employing certain diagnostic tools such as chlorophyll meter and leaf colour chart, which helps in deciding the most suitable time for application of nitrogen during period of crop growth. Various benefits of SSNM practice include lowering input cost, higher nutrient use efficiency, higher water use efficiency and reducing GHGs particularly N_2O (Mohanty *et al.*, 2009).

4.3 Integrated nutrient management

One of the very useful findings of the long term fertilizer experiments under different agro-climatic conditions points out that addition of organic manures along with chemical sources of nutrients (NPK), results in higher yields over period of time as compared to a decrease in yield over time when only chemical fertilizers were applied, besides improving organic carbon content of the soil both in normal rainfall years and deficient rainfall years. INM also provides overall resilience to soil system against mid-season droughts (Srinivasarao and Rani, 2013).

4.4 Application of biochar for soil carbon sequestration and mitigate GHGs emission

The current availability of biomass in India (2010-2011) is estimated at about 500 million ton/ year. Studies sponsored by the Ministry of New and Renewable Energy, Govt. of India have estimated surplus biomass availability at about 120-150 million ton/annum (MNRE, 2009). Of this, about 93 million ton of crop residues are burnt each year. Generation of crop residues is highest in Uttar Pradesh (60 million ton) followed by Punjab (50 million ton) (IARI, 2012). Efficient utilization of this biomass by converting it as a valuable source of soil amendment is one approach to manage soil quality, fertility, mitigate GHGs emission and increase carbon sequestration (Srinivasarao *et al.*, 2013b).

Biochar has a condensed aromatic structure that makes it a stable solid rich in carbon content which is known to be highly resistant to microbial decomposition, thus it can be used to lock carbon in the soil. Biochar application has received a growing interest as a sustainable technology to improve highly weathered or degraded tropical soils (Lehmann and Rondon, 2006; Ogawa *et al.*, 2006; and Woolf, 2008). Biochar has capacity to reduce N_2O emission from soil which might be due to inhibition of either stage of nitrification and/or inhibition of denitrification, or encouragement of the decrease of N_2O, and these impacts could occur simultaneously in a soil (Berglund *et al*., 2004; DeLuca *et al*., 2006). Several workers have reported that applications of biochar to soils have shown positive responses for yield of several crops (Chan *et al.,* 2008; Chan and Xu, 2009; Major *et al.,* 2009 and Spokas *et al.,* 2009). Similarly, biochar has also been found to have significant positive interaction with plant growth promoting rhizobacteria for improving total dry matter yield of rice (Singh *et al.*, 2015)

4.5 Conservation agriculture for carbon sequestration

Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels (Fig.1). Tillage is one of the important pillars of conservation agriculture which disrupts inter dependent natural cycles of water, carbon and nitrogen. Conservation agriculture enhances the carbon sequestration potential of the soil, which helps in maintaining and/ or enhancing the carbon content of the soil. There are several reports on the influence of conservation agricultural management practices of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change (Srinivasarao *et al.*, 2013a).

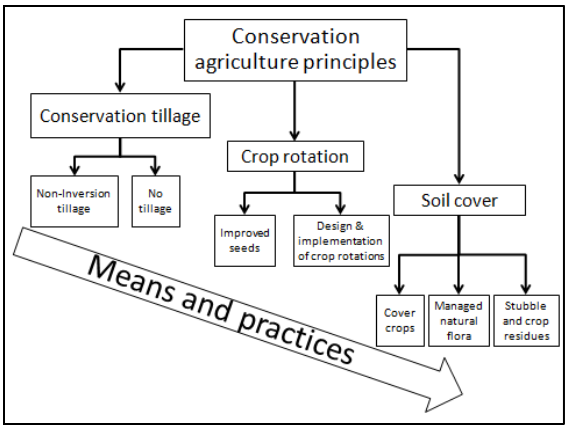


Fig. 1. Three principal components of conservation agriculture (Srinivasarao *et al.*, 2013a).

Key features of conservation agriculture

Srinivasarao *et al.*, (2013a) gave the important practices, which are generally followed in conservation agriculture to cope with climate change. These are: (a) no ploughing, disking or soil cultivation, (b) leaving crop and cover crop residues on the surface, (c) no burning of crop residues, (d) permanent crop and weed residue mulch that protects the soil, (e) replication of the closed-nutrient cycling of the forest, (f) continuous cropland use, (g) crop rotations and cover crops to maximize biological controls (more plants and crop diversity), and (h) use of specialized equipments

4.6 Precision agriculture

Precision agriculture or soil/site-specific technology includes a set of practices that are based on appropriate combination of sensors, information technology and appropriate machinery designed to optimize the use of inputs on the basis of variability in soil properties and other attributes of the landscape that affect agronomic production (Gebbers & Adamchuk, 2010, & Rattan Lal, 2014). These technologies based on specific soil units optimize resource use, minimize the environmental footprint and improve production.

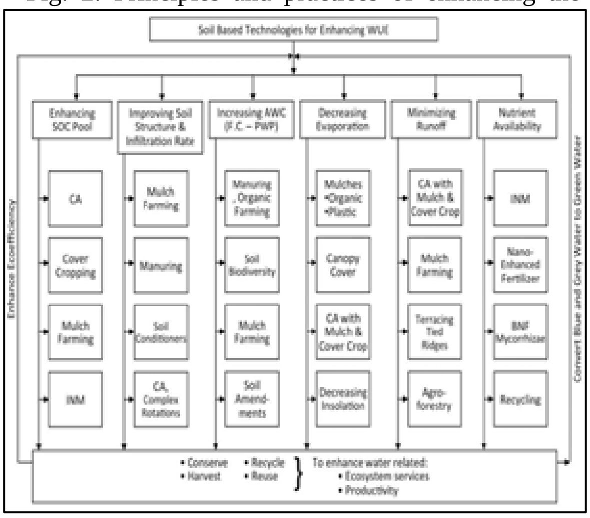
4.7 Watershed approach

The conservation measures of soil and water in the lower catchment areas are prone to be damaged due to excessive runoff from the upper areas. Therefore, it is essential to protect the upper catchment areas through the watershed approach. The main objectives of watershed approach for managing the soil, water and vegetation resources are: (a) to construct a watershed for conserving and upgrading crop and degraded lands, (b) to develop and demonstrate location-specific technologies for soil and water conservation and for crop production stabilization, and (c) to augment the fodder, fruit and fuel resources through alternate land–use systems. For steep hill slopes some more aspects are to be considered: (a) ensuring adequate protection of land against soil erosion with the use of local resources and skill-based soil conservation measures, (b) maximum retention of rainfall within the area without affecting the crops, and (c) storage of runoff water, its use for pisciculture and irrigation (Samra *et al.*, 2009).

4.8 Enhancing water use efficiency

Management of water is a highly critical area for climate resilient agriculture. Soil based technologies for enhancing water use efficiency have been nicely out lined by Rattan Lal (2014). The same is given in figure 2.

Fig. 2: Principles and practices of enhancing the



water use efficiency (Rattan Lal, 2014)

<u>*Notes*</u>: CA, conservation agriculture; INM, integrated nutrient management; BNF, biological nitrogen fixation; F.C., field moisture capacity;

PWP, permanent wilting point; WUE, water-use efficiency; AWC, available water capacity.

5. Conclusions

Global soil and water resources are limited and are exposed to exploitation and negligence and strongly attached with the processes that also govern climate change. Soil quality is the key that determines the resilience of crop production under changing climate. A number of interventions are designed to build carbon content of soil, prevent soil loss due to erosion and improve water holding capacity of soils, all of which will collectively build resilience in soil. Mandatory soil testing is required to be done in all the farmers' fields, to make sure balanced use of chemical fertilizers, improved methods of fertilizer application, matching with crop requirement to reduce nitrous oxide emission. Conservation agriculture, biochar application to the soil, watershed management, enhancing water use efficiency, precision agriculture and techniques of carbon sequestration in soils and ecosystems, site specific nutrient management, and integrated nutrient management are proven technologies of soil management for climate resilient agriculture.

References

- Berglund, L.M., DeLuca, T.H. and Zackrisson, O. (2004) Activated carbon amendments to soil alters nitrification rates in Scots pine forests. *Soil Biology & Biochemistry*, 36: 2067-2073.
- Chan, K.Y. and Xu, Z. (2009) Biochar: nutrient properties and their enhancement. In: Biochar for environmental management (J. Lehmann and S. Joseph eds.), Science and Technology, Earthscan, London. pp 67-84.
- Chan, Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2008) Using poultry litter
- biochars as soil amendments. *Australian Journal of Soil Research*, 46: 437-444.
- Chary, G. R., Srinivasarao, Ch., Srinivas, K., Marurhi Sankar., G.R., Kumar, R.N. and Venkateswarlu, B. (2013) Adaptation and Mitigation Strategies for Climate Resilient Agriculture. Central Reasearch Institute for Dryland Agriculture, ICAR, Hyderabad, India.
- DeLuca, T.H., MacKenzie, M.D., Gundale, M.J. and Holben,W.E. (2006) Wildfire-produced charcoal directly influences nitrogen cycling in forest ecosystems. *Soil Science Society America Journal*, 70: 448-453.
- Dobermann, A. and Cassman, K.G. (2004) Environmental dimensions of fertilizer nitrogen. What can be done to increase nitrogen use efficiency and ensure global food security? In: Agricultural and Nitrogen Cycle: Assessing the Impacts of Fertilizer Use of Food production (Mosier, A.R., Syers, J.K. and Freney, J.R., Eds), Scope 65, Paris, France, pp.261-278.
- Gebbers, R.; Adamchuk, V.I. Precision agriculture and food security (2010) *Science*, 327: 828–831
- IARI (2012) Crop residues management with conservation agriculture: Potential, constraints and policy needs. Indian Agricultural Research Institute, New Delhi, 32 p.
- IPCC (2007) Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds: S.Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, UK. 996 p.
- Lehmann, J. and Rondon, M. (2006) 'Bio-char soil management on highly weathered soils in the humid tropics', in N. Uphoff (ed) Biological Approaches to Sustainable Soil Systems, CRC Press, Boca Raton, pp 517–530.
- Major, J., Steiner, C., Downie, A. and Lehmann, J. (2009) Biochar effects on nutrient leaching. In: Biochar for environmental management (J. Lehmann and S. Joseph eds.), Science and Technology, Earthscan, London. pp 271-287.
- MNRE (2009) Ministry of New and Renewable Energy Resources, Govt. of India, New Delhi. www.mnre.gov.in/biomassrsources.
- Mohanity, S.K., Singh, T.A. and Aulakh, M.S. (2009) Nitrogen In: Fundamental of Soil Science. Second edition: Indian Society of Soil Science.
- Nayyar, V.K. and Sudhir, K. (2009) Soil Fertility Management. In: Fundamental of Soil Science. Second edition: Indian Society of Soil Science.
- Ogawa, M., Okimori, Y. and Takahashi, F. (2006) Carbon sequestration by carbonization of biomass and forestation: Three case studies. *Mitigation and Adaptation Strategies for Global Change*, 11: 429-444.
- Pathak H, Aggarwal PK and Singh SD (2012) Climate Change Impact, Adaptation and Mitigation in Agriculture: Methodology for Assessment and Applications. Indian Agricultural Research Institute, New Delhi. pp xix + 302.

- Rattan Lal (2014) Climate Strategic Soil Management, Challenges, 5, 43-74 doi:10.3390/challe5010043.
- Samra, J.S., Sharma, U.C. and Dadhwal, K.S. (2009) Soil Erosion and Soil Conservation. In: Fundamental of Soil Science. Second edition: Indian Society of Soil Science.
- Singh, A., Singh, A.P., Singh, S.K. and Singh, C.M. (2015) Effect of biochar along with plant growth promoting rhizobacteria (PGPR) on growth and total dry matter yield of rice. *Journal of Pure and Applied Microbiology*. 9(2):1627-1632
- Spokas, K.A., Koskinen, W.C., Baker, J.M. and Reicosk, D.C. (2009) Impacts of woodchip biochar additions on greenhouse gas production and sorption/degradation of two herbicides in a Minnesota soil. *Chemosphere*, 77: 574-581.
- Srinivasarao, Ch., Vittal K.P.R., Gajbhiye P.N., Sumanta Kundu and Sharma, K.L. (2008) Distribution of micronutrients in soils in rainfed production systems of India. *Indian Journal of Dryland Agricultural Research and Development*, 23:29-35
- Srinivasarao, Ch., and Rani, Y.S. (2013) Soil Management Strategies for Adaptation and Mitigation. In: In Adaptation and Mitigation Strategies for Climate Resilient Agriculture. Central Reasearch Institute for Dryland Agriculture, Hyderabad.
- Srinivasarao, Ch., G Ravindra Chary and Pravin B Thakur (2013a) Conservation Agriculture Practices for Soil Carbon Sequestration and Sustainbility of Rainfed Production Systems of India. In: Adaptation and Mitigation Strategies for Climate Resilient Agriculture. Central Reasearch Institute for Dryland Agriculture, ICAR, Hyderabad, India.
- Srinivasarao, Ch., Gopinath, K.A., Venkatesh, G., Dubey, A.K., Wakudkar, H, Purakayastha, T.J., Pathak, H., Pramod Jha, Lakaria, B.L., Rajkhowa, D.J., Mandal,S., Jeyaraman, S., Venkateswarlu, B., and Sikka, A.K. (2013b) Use of Biochar for Soil Health Enhancement and Greenhouse Gas Mitigation in India: Potential and Constraints, Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh. 51p.
- Venkateswarlu, B. (2013) Climate Change Scenario in India and its Impact on Agroecosystems. In: Adaptation and Mitigation Strategies for Climate Resilient Agriculture. Central Reasearch Institute for Dryland Agriculture, Hyderabad.
- Woolf, D. 2008. Biochar as a soil amendment: A review of the environmental implications. (Accessed online at http://orgprints.org/13268/1/Biochar_ as_ a _soil_ amendment_- _a_ review. pdf).
- www.actionaid.org, Climate Resilient Sustainable Agriculture, Experiences from ActionAid and its partners.

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Protocol for evaluation of soil resilience and its field level validation

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In India, soil degradation (~ 57% of the cultivated rea) is a major threat to agricultural sustainability and environmental quality both in irrigated and rain-fed agro-ecosystems**.** A perceived decline or stagnation in crop yield, partial factor productivity of inputs and also quality of the produce is the fall out of such degradation. In rain-fed regions, the degradation is caused mainly by erosion resulting in loss of all important topsoil and productivity. Decline in soil organic matter and its associated nutrients supply in soil is the major factor for yield decline (Dawe et al. 2000) under intensive cropping systems. In addition, stresses due to acidity, salinity, alkalinity, waterlogging etc. are also there for a considerable land area in different parts of the country. These degradative forces and processes impair soil's essential ecosystem functions and ultimately its health/quality. Therefore, for sustainable use of soil and its protection against degradation soil quality assessment- fitness for use, and its resilience– ability to recover, and identification of diagnostic recovery modules are the only options available to address this critical issue.

The concept of soil quality and the methods for evaluating it with respect to various soil functions have been evolved to a considerable extent for identifying major soil quality indicator. Though the indicators are put in use for monitoring soil quality (Andrews et al. 2004), such indicators for resilience purpose are yet to be developed to assess the ease and degree of recovery of degraded systems (Kuan et al. 2006). Theoretically, soil resilience has been defined as the capacity of soil to recover its functional and structural integrity after a disturbance (Lal 1997). Agriculture is one of the important stresses and disturbances to the soil environment (Brussard 1994). Although, there is a conceptual framework for evaluating soil resilience but there is limited field level validation. Soil resilience and resistance are affected by both inherent and dynamic soil characteristics and thus, will vary substantially from one area to the next and will change over time (MacEwan 1997) and management practices (Lal 1998).

Management practices that increase soil organic matter levels will improve most soil functions. Recent investigations (Glaser et al. 2000, 2001) also showed that carbonized materials from the incomplete combustion of organic material (i. e. black C, pyrogenic C, charcoal) are responsible for maintaining high levels of SOM and available nutrients in anthropogenic soils (Terra Preta) of the Brazilian Amazon basin (Zech et al. 1990) and savannas of South Africa (Blackmore et al. 1990). Thus, an investigation was carried out to develop a protocol for evaluating soil resilience capacity of degraded soil with field level validation under different management interventions.

Site selection for resilience study based on SQI value: Stratified multistage stratified random sampling method was followed for selecting farmers/field in each identified district (Sehore and Vidisha), where Tehsil/block was considered as strata. From each district, 20 - 25 villages have been selected randomly. From each selected villages, six farmers/fields have been selected based on high, medium and low resource use following participatory rural appraisal (PRA) technique. From each site (approx. 1000 m^2), composite soil sampling have been carried out using core sampler as per standard soil test method. Soil samples have been analyzed for various soil properties viz. MWD, bulk density, plant available moisture (physical properties), pH, EC, SOC, TOC, available N, P, K, Cu, Zn, Mn, Fe, S, B, total N, total organic P, total inorganic P, non exchangeable K, different carbon pools (chemical parameters), microbial biomass carbon, alkaline phosphatase, dehydrogenase enzyme (biological properties) following standard procedure.

Significant variables were chosen for minimum data set (MDS) formation through principle component analysis (PCA) (Andrews et al. 2002a, 2002b; Shukla et al. 2004). After determining the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method (Andrews et al. 2002b). Once transformed, the MDS variables for each observation were weighted using the PCA results and then summed up the weighted MDS variables scores for each observation using the following equation:

$$SQI = \sum_{i=1}^{n} W_i S_i$$

Where, S is the score for the subscripted variable and Wi is the weighing factor derived from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. Based on these PCA derived SQI value, ten farmer's fields having varying SQI value (gradient of SQI value ranging from low to high) were selected for field experiment to validate the protocol developed for resilience study.

Treatment details, crop harvest and sampling of plant and soil samples: The charcoal used for experimental purpose was collected from the local vendor in bulk. Representative samples were sieved, grinded through rotar blade mill and analyzed for its physico-chemical properties (table 1). Graded levels of wood charcoal were applied to the soil at selected sites having different SQI value in order to study the recovery of major indicators and the SQI values. Each of the ten identified sites was divided into four plots (minimum size 20 m x 20 m) and the soil was amended with wood charcoal @ 0, 5.4, 10.8 and 16.2 t ha^{-1} at the time of land preparation before the sowing of soybean crop. Thereafter, soybean followed by wheat crops was raised (with uniform recommended fertilizer management practice for soybean and wheat) and yields were recorded. From each plot, four sampling unit for biomass yield was done using 1 m x 1 m sampling grid method. Similarly for each treatment biomass sampling was done and dry matter yield was recorded separately for each crop. After the harvesting of wheat crop, soils samples were collected from all the sites and analyzed for quantity values of the key indicators indentified through PCA method (TOC, non-exch. K, total Zn, total Mn, BD, $CaCO_3$, available S and alkaline phosphatase activity). Again the soil data were used to derive SQI value to determine the effect of charcoal management interventions on resilience index of Vertisol.

Table 1: Chemical Composition of Charcoal.

Properties	Range	Mean	± SD
Carbon (%)	60.11-72.42	65.95	4.48
N (g/kg)	7.9-12.9	10.4	2.08
K (g/k)	0.67-0.85	0.80	0.08
Ca (g/kg)	1.02-1.31	1.12	0.10
Mg (g/kg)	0.87-1.12	0.97	0.08
P (mg/kg)	573-639	609	23.68
S (mg/kg)	290-338	314.8	19.74
Fe (mg/kg)	65.6-81.8	73.75	6.33
Mn (mg/kg)	45.4-60.8	54.06	6.46
Zn (mg/kg)	21.8-33.4	27.71	4.56
Cu (mg/kg)	8.9-17.4	12.5	3.10
Ash (%)	5.43-6.08	5.76	0.26
pH	7.9-8.8	8.5	0.39
Co (mg/kg)	5.8-8.91	7.13	1.15
Cr (mg/kg)	13.26-23.40	18.72	4.18
Cd (mg/kg)	0.981.65	1.39	0.25
Ni (mg/kg)	9.50-15.71	11.46	2.49
Pb (mg/kg)	6.40-10.61	8.14	1.50

Resilience index value computation: Based on quantitative value of the key indicators, SQI values were computed for all the interventions of the ten sites. The resilience index (RI) of the soils of each of the ten sites due to application of charcoal @ 5.4 t ha^{-1} (I_1), 10.8 t ha^{-1} (I_2) and 16.2 t ha^{-1} (I_3) was computed using the following expression

$$RI = \frac{SQI(I) - SQI(D)}{SQI(p) - SQI(d)} \times 100$$

Where, SQI (I): The computed SQI value of soil after management intervention (I)

SQI (d): The computed SQI value of soil before the management intervention (I)

SQI (p): The computed SQI value of pristine soil near the corresponding site.

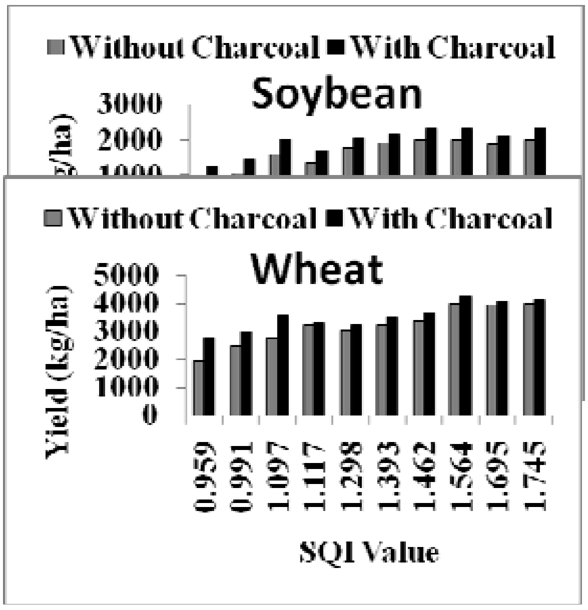
The numerator in the above expression indicates the recovery of SQI value due to management intervention where as the denominator indicates the loss of SQI value due to soil degradation processes.

Effect of charcoal on soybean and wheat yield

Addition of charcoal in all the sites showed a significant positive effect on yield (table 2) and the corresponding mean soybean and wheat yield increased from 1630 kg ha^{-1} to 1974 kg ha^{-1} and 3211 kg ha^{-1} to 3561 kg ha^{-1}, respectively. Significant increase in soybean and wheat crop yield due to charcoal application might be due to increased physical, chemical and biological properties of soil. Several studies and field observations have also demonstrated that the addition of carbon rich material to soils often results in increased crop productivity. Steiner et al. (2007) also observed that application of charcoal increased crop growth and doubled the grain yield if fertilized with NPK in comparison to NPK fertilizer without charcoal. In all the ten sites with varying SQI values, soybean and wheat crop responded upto 16.2 t ha^{-1} of charcoal application. Increasing levels of charcoal increased the crop yield, but significant differences were observed when charcoal was applied at 10.8 and 16.2 t ha^{-1}, respectively over control (in the absence charcoal). Moreover, yield response to charcoal application was much greater in soybean as compared to wheat crop in all the sites (figure 1). It was clear from the result that the per cent increase in wheat yield as a result of charcoal application was highest (40%) at the site having lowest SQI value (0.959) whereas, the per cent increase in yield was lowest (3%) at the site having highest SQI value (1.745). Similar trend were also observed in soybean yield with highest per cent increase in yield (50%) was observed at the site having lowest SQI value (0.959). The per cent increase in soybean and wheat yield were in agreement with findings of Lehmann et al. (2003) who reported that the cowpea and rice yield were 39% to 45% higher yield in the charcoal amended plots that un-amended plots. The result from our experiment was obvious that the soils which are relatively poorer in soil quality (sites having lower SQI value) responds better to the addition of carbon enriched material than the soil having relatively better SQI value.

Table 2 Effect of charcoal on soybean and wheat grown on soil having different SQI value at Sehore and Vidisha (Grain Yield kg/ha).

Site No.	SQI	Charcoal Application Rate (t/ha)				CD (p=0.05)	Charcoal Application Rate (t/ha)				CD (p=0.05)
		0	**5.4**	**10.8**	**16.2**		**0**	**5.4**	**10.8**	**16.2**	
		Soybean					Wheat				
1	0.959	845	904	1321	1580	106.95	1963	2012	2980	3342	236.83
2	0.991	1040	1323	1406	1628	120.08	2512	2580	2912	3446	251.90
3	1.097	1580	1735	2046	2286	183.53	2780	2830	3940	3940	313.64
4	1.117	1321	1453	1721	1872	144.84	3230	3310	3270	3420	NS
5	1.298	1768	1798	2105	2280	186.84	3030	3090	3230	3300	187.75
6	1.393	1908	2061	2120	2335	202.17	3250	3080	3480	3990	320.85
7	1.462	1991	2071	2363	2485	198.24	3380	3521	3700	3870	336.45
8	1.564	1983	2059	2372	2463	201.95	4000	4120	4340	4410	305.35
9	1.695	1893	2037	2171	2207	182.77	3970	4030	4080	4210	NS
10	1.745	1971	2177	2398	2452	215.95	4020	4080	4100	4230	NS



carbon component in charcoal provides food source to microbes for multiplication. After the harvest of wheat crop, the soil analysis was carried out and it showed that out of the eight key indicators identified for Vertisol of Sehore and Vidisha district, only two indicators, namely, TOC and Alkaline Phosphatase activity had significant improvement due to application of charcoal. Also we observed significant improvement in microbial biomass C content in the soil due to charcoal application. The results also showed that the MBC, TOC and Alkaline phosphatase activity were increased with increasing level of charcoal application from 5.4 to 16.2 t ha^{-1}, respectively. Our experimental results were also in line with the findings of Kolb et al. (2009) and Wardle et al. (2008) who also reported that microbial biomass carbon and activity was increased with increasing charcoal application.

Management interventions of charcoal addition on SQI value at different sites are presented in table 3. The result showed that the loss of soil quality as compared to respective pristine soil are different in different sites and the values ranged between 0.114 unit (site no. 9) to as high as 0.650 unit (site no. 2). After imposition of interventions (different levels of charcoal addition), there was improvement in SQI values in each site, however, magnitude of improvement in SQI value varied from site to site. Under intervention I_1 (5.4 t ha^{-1}), I_2 (10.8 t ha^{-1}) and I_3 (16.2 t ha^{-1}) the improvement in SQI values ranged from 0.026 unit (site no. 10) to 0.246 unit (site no. 4), 0.051 unit (site no. 9) to 0.287 unit (site no. 2) and 0.067 unit (site no. 9) to 0.392 unit (site no. 2), respectively.

Table 3 Effect of charcoal on soil quality index (SQI) value and resilience index (RI) on soil having different SQI Value at Sehore and Vidisha.

	Soil Quality Index value					CD (p=0.05)	Resilience Index (RI) (%)		
Site No.	**SQI(p)**	**SQI(d)**	**SQI(I_1)**	**SQI(I_2)**	**SQI(I_3)**		**RI (I_1)**	**RI (I_2)**	**RI (I_3)**
1	1.564	0.959	1.067	1.215	1.308	0.218	17.85	42.31	57.68
2	1.641	0.991	1.116	1.278	1.383	0.247	19.23	44.15	60.30
3	1.512	1.097	1.266	1.340	1.462	0.223	40.27	58.55	87.95
4	1.541	1.117	1.363	1.393	1.470	0.261	58.01	65.09	83.25
5	1.593	1.298	1.373	1.433	1.504	0.128	25.42	45.76	69.83
6	1.564	1.393	1.452	1.498	1.512	0.090	34.50	61.40	69.59
7	1.678	1.462	1.514	1.541	1.641	0.103	24.07	36.57	82.87
8	1.805	1.564	1.593	1.633	1.738	0.082	12.03	28.63	72.19
9	1.809	1.695	1.728	1.746	1.762	NS	28.94	44.73	58.77
10	1.982	1.745	1.771	1.812	1.852	NS	10.97	28.27	45.14

Soil resilience index value under different management interventions: Carbon–rich material of conventional charcoal or biochar addition to agricultural soils is receiving considerable interest due to its carbon sequestration potential, agronomic benefits and its potential to recover (resilience) soil functional properties of degraded soil (Quayle 2010). Recent evidences also suggest that application of black carbon (biochar/charcoal) to soil substantially improves soil health, fertility and resilience. Resilience index after imposition of management interventions were computed for each of the ten sites are presented in table 3. The resilience index under each intervention showed wide variation. Under intervention I_1, I_2 and I_3 the resilience index ranged from 10.97% (site no. 10 having SQI 1.745) to 58.01% (site no. 4 having SQI 1.117), 28.27% (site no. 10 having SQI 1.745) to 65.09% (site no. 4 having 1.117) and 45.14% (site no. 10 having 1.745) to 87.95% (site no. 3 having SQI 1.097), respectively (table 3). Logically it was expected that the soils with low SQI value should show higher degree of resilience but the observed results are not in line with this expectation. The mean resilience index (summed over effect of I_1, I_2 and I_3) increased gradually from 28.12% (site no. 10, SQI (d) = 1.745) to 68.78% (site no. 4, SQI (d) = 1.117) and thereafter no definite trend was observed (figure 2). It was further observed that out of the ten sites the value of resilience index ranged from 28.12 to 68.78% which resulted in gain in soybean yield ranging from 264 kg ha^{-1} to 442 kg ha^{-1} and gain in succeeding wheat yield ranging from 103 kg ha^{-1} to 815 kg ha^{-1} (figure 3). The results indicate that soil resilience capacity of soil as a measure of soil function was increased significantly mainly due to increase in total carbon content as a result of charcoal application. The microbial activity as a measure alkaline phosphatase and microbial biomass carbon (MBC) were also increased and therefore these three parameters (TOC, MBC and alkaline phosphatase) were found to be responsible for increased resilience in Vertisol. Novotny et al. (2009) demonstrated that the presence of recalcitrant nature of carbon in Terra *Preta de Índios* soils ensures crop sustainability and resilience of soil fertility. In spite of intensive and degradative use of *Terra Preta de Indios* soil, high soil fertility maintenance and its resilience capacity is attributed to high levels of carbon as compared to adjacent soil (Sombroek et al. 1993; Glaser et al. 2001).

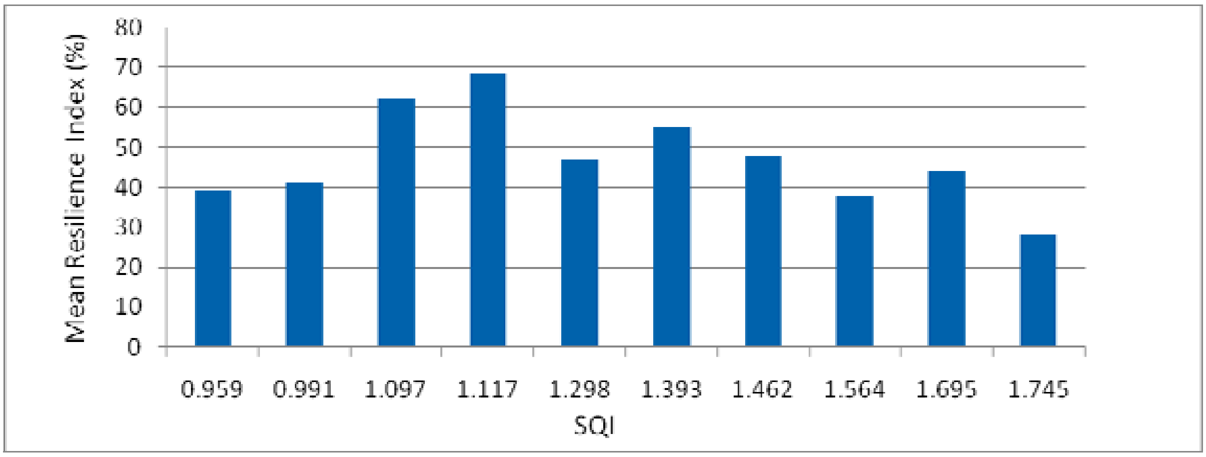


Figure 2 Mean resilience index (%) of Vertisol at ten sites having different degree of degradation as measured by Soil Quality Index

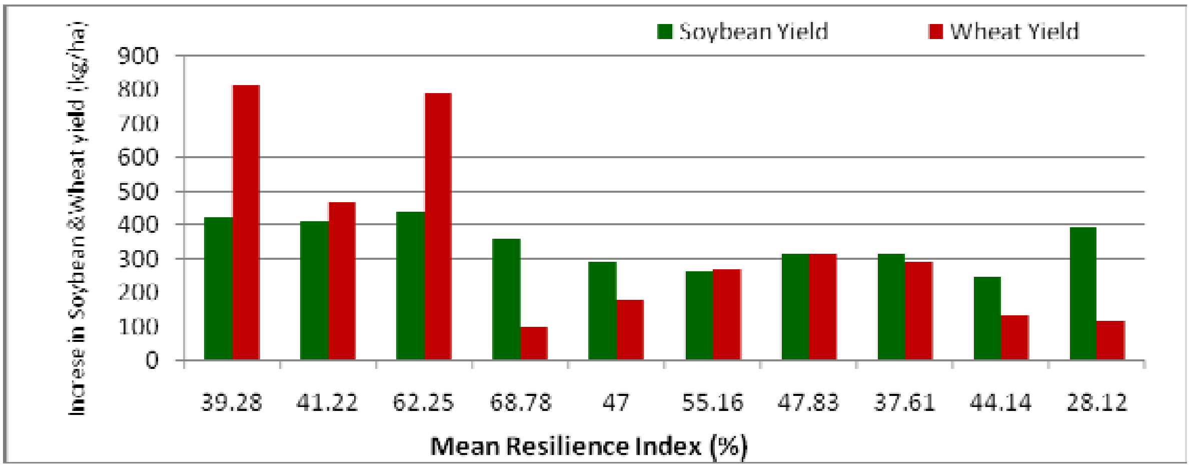


Figure 3 Average gain in soybean and succeeding wheat yield at different values of measured resilience index in Vertisol.

Summary and Conclusion

The conceptual framework for evaluating soil resilience has been designed with field level validation. The developed protocol for measuring soil resilience can successfully be used to measure the resilience power of degraded soils in response to management interventions. Among the different management interventions, application of wood charcoal was found appropriate remedial options to improve soil resilience index. Further, it was observed that the farmers fields soils which had initially low soil quality index values showed maximum improvement in both resilience index as well as soil quality index values due to balance fertilization/charcoal addition.

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References

- Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework. Soil Science Society of America Journal 68: 1945-1962.
- Blackmore, A.C., M.T. Mentis, and R.J. Schols. 1990. The origin and extent of nutrient-enriched patches within a nutrient-poor savanna in South Africa. Journal of Biogeography 17: 463-470.
- Brussard, L. 1994. Interrelationships between biological activities, soil properties and soil management. *In* Soil Resilience and Sustainable Land Use, eds. D.J. Greenland and I. Szabolcs, 309-352, CAB Int. Wallingford, Oxon, UK.
- Dawe, D., A. Dobermann, P. Moya, S. Abdulrachman, B. Singh, P. Lal, S.Y. Li, B. Lin, G. Panaullah, O. Sariram, Y. Singh, A. Swarup, P.S. Tan, and Q.X. Zhen. 2000. How widespread are yield declines in long-term rice experiments in Asia? Field Crop Research 66: 175-193.
- Glaser, B., L. Haumaier, G. Guggenberger, and W. Zech. 2001. The Terra Preta phenomenon – a model for sustainable agriculture in the humid tropics. Naturwissenschaften 88: 37-41.
- Glaser, B., E. Balashov, L. Haumaier, G. Guggenberger, and W. Zech. 2000. Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. Organic Geochemistry 31: 669-678.
- Kolb, S.E., K.J. Fermanich, and M.E. Dornbush. 2009. Effect of charcoal quantity on microbial biomass and activity in temperate soils. Soil Science Society of America Journal 73: 1173-1181.
- Kuan, H.L., P.D. Hallett, B.S. Griffiths, A.S. Gregory, C.W. Watts, and A.P. Whitmore. 2006. The biological and physical stability and resilience of a selection of Scottish soils to stresses. *European Journal of Soil Science* 58(3): 811-821.
- Lal, R. 1997. Degradation and resilience of soils. Philosophical Transactions of the Royal Society of London B 352: 997-1008.
- Lal, R. 1998. Soil quality and sustainability. *In* Methods for Assessment of Soil Degradation, eds. W.H. Blum, C. Valentine and B.A. Stewart, 17-30, CRC Press, Boca raton, FL.
- Lehmann, J., Jr. J.P. da Silva, C. Steiner, T. Nehls, W. Zech, and B. Glaser. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil 249: 343-357.

- MacEwan, R.J. 1997. Soil quality indicators: Pedological aspects. *In* Soil Quality for Crop Production and Ecosystem Health, eds. E.G. Gregorich and M.R. Carter, 143-166, Elsevier Science, Ameterdam.
- Novotny, E. H., T.J. Bonagamba, E.R. deAzevedo, and M.H.B. Hayes. 2009. Solid-State ^{13}C Nuclear Magnetic Resonance Characterisation of Humic Acids Extracted from Amazonian Dark Earths (*Terra Preta De Índio*). *In* Amazonian Dark Earths: Wim Sombroek's Vision, eds. W.I. Woods, W.G. Teixeira, J. Lehmann, C. Steiner, A. WinklerPrins, and L. Rebellato, 373-391, Springer Science: Heidelberg.
- Quayle, W.C. 2010. Biochar potential for soil improvement and soil fertility. In: IREC Farmers Newsletter, Large Area No. 182.
- Sombroek, W.G., F.O. Nachtergaele, and A. Hebel. 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. Ambio 22: 417-426.
- Steiner, C., W. Teixeira, J. Lehmann, T. Nehls, J. de Macêdo, W. Blum, and W. Zech. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered central Amazonian upland soil. Plant and Soil 291: 275–290.
- Wardle, D.A., M.C. Nilsson, and O. Zackrisson. 2008. Fire-derived charcoal causes loss of forest humus. Science 320 (5876): 629-629.
- Zech, W., L. Haumaier, and R. Hempfling. 1990. Ecological aspects of soil organic matter in tropical land use. *In* Humic substances in soil and crop science, eds. P. McCarthy, C.E Clapp, R.L. Malcolm and P.R. Bloom, 187-202, American Society of Agronomy and Soil Science Society of America, Madison Wis. USA.

Soil carbon sequestration: Need for new research initiatives to mitigate the impact of climate change

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As soil scientists, we are happy that the world scientific communities and policymakers have recognized that soil is a strategic asset of a nation and soil carbon, specifically in the form of soil organic matter, plays a central role in the functioning of soil to provide wide range of vital environmental goods and services. The SOM, as humas, has been recognized as a "source of human wealth on this planet" (Waksman 1938). All the under pinning physical, chemical and biological processes of soil function are directly dependent on the quality and quantity of soil organic matter and make the soil a natural capital the means of production for the ongoing supply of beneficial goods and services (Robinson et al. 2013). Thus , soil carbon is vital for all 4 classes of soil ecosystem services namely, supporting services, regulating services, provisioning services and cultural services (MEA 2005). Schmidt et al. (2011) mentioned soil fertility, water quality, erosion resistance and climate mitigation as important ecosystem services related to SOM

Soil Carbon Sequestration: Soil carbon sequestration (SCS) is a natural process in which biomass carbon is humified and incorporated into the SOC pool. The attendant increase in SOC poll through SCS improves soil quality and set-in-motion land restorative processes, and advances food security (Lal, 2006). In the context of Indian agriculture, soil fertility improvement and climate mitigation are very much demanding as they are intimately linked to national food security. The vision 2020 document of the government of India (Planning Commission 2002) envisages a production level of rice and wheat as 207 and 173 million tones after giving due consideration to biophysical factors restricting crop production. Resource demand is set against the reality of limited land availability and therefore, we need our soils to deliver requisite productivity while avoiding the environmental costs of intensive agriculture. In other words, we need unprecedented intensification in the productivity of currently used land in order to achieve economic growth. Population carrying capacity of given land is determined by the level of management and flow of off-farm inputs. The average carrying capacity for traditional farming is 1 to 9 persons per hactre, while it may go up to more than 20 persons per hactre for modern specialized farming (Smil 1998). At present population level, carrying capacity of our Indian soils hardly exceeds 8 persons per hactre. Under the pressure of increasingly intensive land use, it is essential to protect and to enhance the full range of the essential life sustaining benefits that soil provide. The beneficial management of soil carbon is perhaps the most important means of human intervention to face this daunting challenge. The risks of losing soil organic C are many folds because of the potential consequences of a) Loss of soil fertility, reduced crop production and diminished other soil functions, and b) Increased green house gas emissions and accelerated climate change.

The national stocks of soil carbon particularly in the degraded lands in the hands of marginal and small farmers of the dryland areas are under threat. In contrast, there are ample evidences to indicate that adoption of management interventions recommended by our National Agricultural Research System not only able to maintain the SOC but also enhanced SOC in most of the soils in two major food production zones, namely, Indo Gangetic plains (IGP) and Black soil regions (BSR) of the country after 25 years of intensive cultivation. (Bhattacharya et al., 2007; Manna et al., 2006). However, it is to be recognized that the maximum feasible carbon sequestration potential at any given location of these productive belts is seldom be achieved due to a number of biological, physical and social constraints. The most pertinent questions are therefore: (*i*) if more SOC sequestration is associated with overall improvement of soil health and societal benefits why is its enhancement is not extensively practiced? (*ii*) What are the limitations for its implementation? (*iii*) What research innovations are required to improve the situation?

Factors affecting soil carbon sequestration: The primary control of soil organic carbon distribution is rainfall and/or irrigation which supports increased production of above ground vegetation, resulting in increased allocation of carbon to the soil through greater root biomass and associated carbon inputs by root exudates and increased plant residue returned to the soil. On the other hand, the primary reason of loss of soil carbon is the physical disturbance such as intense tillage practices which break up larger soil aggregates and expose occluded carbon within aggregates to biodegradation and erosion, thus creating conditions that allow greater soil carbon loss. In India, majority of the land holdings are in the hands of marginal and small farmers and majority of them are located in the dryland/rainfed areas. Due to low water availability vis-à-vis low productivity and relatively high decomposition due to dry well aerated warm soils, it is very rational for individual farmer of our vast dryland areas to manage the SOC at levels that are sub-optimal from a national natural capital perspective. Therefore, we need to design suitable soil management options with strong policy support so as to affect the stocks and composition of soil carbon in these soils in a manner to render real economic benefits to the practicing farmers. Currently, most of the best management practices favoring SOC accumulation are available in the domain of resource rich farmers while very few are available for our vast resource poor marginal and small farmers.

We must recognize that building up SOC is a slow process. Understanding the factors that control SOC level offers clues to strategies that can maintain and increase SOC contents. The technological options for enhancing soil carbon sequestration generally include a strategic and judicious combination of practices such as,

i) Tillage methods (conservation tillage, minimum use of mechanical tillage).
ii) Ensuring better nutrient supply and sound nutrient cycling mechanisms to minimize losses.
iii) Efficient water management to support optimal crop growth.
iv) Controlling soil erosion through cover crop, mulch farming and residue management.
v) Use of deep rooted cultivars of improved crop varieties.
vi) Practice of crop rotation with high biomass yielding legumes.

India has witnessed tremendous improvement in crop yield and land productivity due to increased and widespread use of chemical fertilizer which has already created new carbon pathways from the rural production areas to the expanding urban centers of consumption, breaking the traditional approaches of recycling organic matter. The lack of appreciation of the integrative function of SOM with soil clay in forming organic- mineral complexes and aggregate formation is very common in neo farming communities of our country. The attainable potential of carbon sequestration can be achieved with widely known and tested sequestration techniques. Suitable management practices to build up SOC are those that increase the input of organic matter to the soil and decrease the rate of SOM decomposition (FAO 2011). The magnitude and rate of SOC sequestration that may be achieved depends on several factors, including the reference SOC stock (for a given soil), cropping intensity, soil type and soil and water conservation practices. Therefore, we need to identify site specific most appropriate practices to build up SOC in a given agro-climatic condition.

Which components of crop residues contribute towards SOC sequestration? Crop residues are composed of ligno-cellulosic materials (made up of hemi-cellulosic, cellulose and lignin). Hemi-cellulosic and cellulose can be degraded to simple sugars by the process of saccarhization and successive enzymatic hydrolysis (as is being done in industrial production of ethanol from crop residues). In soil also, similar process operates with relatively slower rate resulting in gradual disappearance of hemi-cellulosic, and cellulosic components of the crop residues, while lignin component undergoes transformation to humus. Structural features of lignin vary from crop to crop. Rice straw contains less lignin than corn stovar and wheat straw. Therefore, the extent of SOC sequestration largely depends on the quantity as well as quality of the biomass input added to the soil. Following the adoption of best management practices, the average rate of SOC sequestration is about 300 kg C/ha/year. It can be well illustrated with an example. Assuming that 10 tonnes of rice or wheat residues (containing 40% C,0.5% N, 0.1% P and 0.05% S) is incorporated into soil, which will result formation of humus or SOC(containing 50% C, C:N ratio 12, C:P ratio 50 and C:S ratio 70) after humification .The original biomass(10 tonnes) contains 4000 kg C, 50 kgN, 10 kgP and 5 kg S. If the SOC sequestration rate is 20%, the resultant SOC will contain 800 kg C, 66.5 kg N, 16 kg P and 12 kg S, indicating that for the formation of 800 kg SOC, it will require additional 17 kg N, 6 kg P and 7 kg S. If the sequestration rate is 10%, the resultant SOC will contain 400 kg, 33.5 kg N, 8 kg P and 6 kg S, suggesting that the formation of 400 kg SOC will release 16.5 kg N and 2 kg P only. Therefore, when rice/whear/other cereal residues are incorporated into soil for nutrient cycling, the SOC sequestration is much less than 10%. It is important to note that to allow higher rate of SOC sequestration in soil, it requires additional amount of N, P & S. Richardson et al (2014) estimated that increasing SOC by 1 Mg C ha^{-1} into humus requires 73, 17 and 11 kg ha^{-1} of N, P & S respectively. Without the availability of these essential nutrients, SOC concentration does not always increase even with long-term application of crop residues (Baker et al. 2007; Bisett et al. 2011). Hence, leguminous crop residues containing higher amount of N,P ,S and lignin are best suited for SOC sequestration as well as nutrient cycling.

Soil carbon sequestration is a slow process. How slow the process is?

Example with Rice –Wheat rotation with productivity of 5 ton/ha each. Biomass input from rice consists of straw (40% HI) and root biomass (30% of the total above ground biomass) = 7.5 ton straw + 4 ton root biomass. Assuming that whole straw will be returned back to field after feeding animals, the amount of cow-dung likely to be produced is about 5.25 tonnes (assuming 30% digestibility). During the process of transformation to manure, 30% is lost due to decomposition. Thus, net manure biomass is 3.675 tonnes. Assuming that the root biomass and manure biomass contain 42% C, total biomass C available from root is 4 x 0.42 = 1.68 tonnes and total biomass C available from manure is 3.675 x 0.42 = 1.543 tonnes. Thus, total biomass C available from both rice and wheat is 3.086 tonnes from manure and 3.36 tonnes from root biomass . Following soil incorporation, the above biomass will undergo humification. Assuming 10 % humification rate of manure and root biomass, total amount of humified C in soil is 3.086x 0.10 + 3.36 x 0.10 = 0.6446 tonnes/ha/year or 645 kg C/ha/year. This amount of C is likely to be distributed in 0-45 cm soil depth in the ratio of 50:30:20 in 0-15, 15-30 and 30-45 cm depth, respectively. If the bulk density of the soil is 1.4 g/cc, about 2100 kg C is required to raise the organic C content by 0.1% or 1 g/kg soil. Following distribution in soil, about 322.5, 193.5 and 129 kg C is likely to be retained in 0-15, 15-30 and 30-45 cm soil depth, respectively, which will result increase in SOC content by 0.015 %, 0.009% and 0.006%, respectively. This, in turn, indicates that it will take roughly 7, 11 and 17 years to increase the SOC by O.1% in 0-15, 15-30 and 30-45 cm soil depth. In case of Rice- wheat system in IGP, the average productivity of rice is 2622.55 kg/ha and of wheat is 3274.27 kg/ha (average of 2000-2010). Similar calculation showed that on an average, 378 kg carbon is annually got incorporated into the soil with the distribution of 189, 113.4 and 75.6 kg C in 0-15, 15-30, and 30-45 cm soil depth resulting in increase in SOC by 0.009%, 0.005% and 0.003% respectively. It indicates that it will take roughly 12, 20 and 34 years to increase the SOC content by 0.1% in 0-15, 15-30 and 30-45 cm depth.

Carbon sequestration and climate mitigation

Increase in atmospheric abundance of CO_2 and other greenhouse gases (GHGs), gradually since the dawn of settled agriculture through deforestation and soil cultivation and rapidly since the onset of industrial revolution in 1750, has greatly heightened the interests of scientists and policy makers about identifying strategies for stabilizing the atmosphere. Among two possible strategies of mitigating the climate change, reducing emissions and sequestrating emissions, C sequestration in terrestrial soils is considered a low-hanging fruit and a win-win strategy. Soil organic Carbon (SOC; concentration and pool) and its dynamics are key determinants of soil quality (soil health) and for the provisioning of essential ecosystem services (Stockman et. al. 2013). Major concerns of the modern civilization, especially peace and tranquility (Lal 2014), are intricately connected with soil and its quality, sustainable intensification of agriculture, and climate-resilient farming through recarbonization of soil and the terrestrial biosphere.

In developing countries like India, farmers' key concern is to secure productivity of their farming operation. After the recorded observation of rapid rise of CO_2 concentration in the atmosphere in 1976 (Keeling et al. 1976) and recognization of the linkage between atmospheric and soil carbon, climate mitigation has become an important ecosystem services related to SOC, which has led to renewed interest in SOM research with a more holistic approach to material and life sciences. At the global and national level, climatic change is a major issue but at farmers level climate change mitigation is considered much less important than crop productivity and economic return from farming. We, therefore, need to look for new innovations to bridge the current gaps between short and long term objectives of soil carbon management.

New research initiatives to enhance SOC *vis a vis* climate mitigation:

- As on today, we do not have robust tool to measure sequestered SOC and need to attempt to develop a measurement protocol of SOC which is physically protected and biochemically recalcitrant.
- We have not yet made tangible research efforts in understanding the dynamics of SOC binding with soil mineral matrix which is very essential for understanding the processes controlling the quantity, quality and turnover of SOC attached to the colloidal mineral particles in specific soil climatic conditions. Early research proposed a monolayer coverage of OM on clay mineral surfaces (Mayer, 1994) and direct analysis by transmission electron microscopy challenged the monolayer coverage concept and suggested that OM exists in patches associated with mineral surfaces.(Ransom et al., 1997: Chenu and Plante, 2006). Only some of the clay sized mineral surfaces, namely those with rough surfaces, react with OM and thus contribute to OC and ON sequestration. These rough surfaces are the nuclei for additional OM accumulation and therefore, control the C and N sequestration potential of the soil. Less than 19% of the visible mineral areas show an OM attachment and these results provide evidence that only a limited proportion of clay-sized surfaces contribute to OM sequestration, (Cordula Vogel et al., 2014). Using amount of clay as a proxy to predict the sequestration potential of soils is not sufficient. There is necessity for careful identification and quantification of the reactive mineral complexes

that are responsible for OM sequestration and that control the OM saturation capacity of soils.

- There is considerable amount of transport of biomass C from non agricultural lands to Indian agriculture and no systematic program monitors or assesses this flow of C and plant nutrients.
- In India more than 50 percent of the irrigated area is irrigated with ground water. The present rate of annual withdrawal is nearly more than 20 M-ha metre. As majority of the ground water contain significant amount of CO_3 and HCO_3, no study assessed the impact of such inorganic C on soil health and natural C cycle.
- In contrast, the pedogenic carbonate carbon(inorganic C) in our calcareous and neutral soils are strongly influenced by the buildup of SOC, which, in-turn, helps in dissolution of carbonates and improves soil environment. However, the intricate relationship between SOC build up and dissolution of carbonate C in our large calcareous belt is not properly understood and may counter the potential of climate mitigation of SOC build up in soil.
- We have nearly 300 class I cities and generates more than 20000 MLD of sewage water and contains about 600-1000 ppm of total C (as organic and inorganic).One irrigation(10 ha-cm) with this waste water can supply 0.6 to 1.0 tonne C/ha in the peri-urban areas .Down ward flow of this soluble C in the soil profile and its fate in the context of soil C sequestration is an important researchable issue. India generate about 70 million tonnes of MSW(which contains 10-15 percent C) and optimal management of this C can reduce the adverse impact on our environment and benefits Indian agriculture both in terms of nutrient supply as well as soil C sequestration and again limited work has been carried out in the past.
- Transport of Biomass C in to the soil (advertently and inadvertently) also transport considerable amount of biogenic Si to the soil and possibly plays an important role not only in plant nutrition but also in the sequestration of boimass C, which needs to be explored through organized research agenda. .Silica complexes with carbonaceous materials and have been shown to reduce C bio-degradation (Martin and Haider,1986) and may play an important role in C sequestration in soil. .
- Another upcoming issue in soil C research is the Phytolith occluded C which is considered to be an important fraction of SOC and substantially contributes to the terrestrial C sequestration for long periods. In India, an estimate indicates that cultivation of phytolith rich crops may annually contribute about 0.87 mt of phytolith C (Rajendiran et.al.2012) and therefore we need to explore the potential of growing high phytolith containing crop cultivars to enhance terrestrial C sequestration.
- As the rate of synthesis of humus in soil is directly proportional to the rate of disappearance of lignin C of the added biomass C, we need to develop designer crops using biotechnology / genetic engineering to enhance the content of lignified C in the plants. There is a strong need to develop cultivars that contain recalcitrant compounds (such as phenolics) with long residence time and have a favorable root/shoot ratio.
- Apparently, C sequestration in our terrestrial agro-ecosystems may appear to be cost-effective but still it is a priority issue to assess the cost evaluation of C sequestration by natural and anthropogenic strategies. Achieving higher crop productivity using BMPs involve hidden carbon cost of inputs and therefore, we need to quantify net SCS per unit cost of inputs based on carbon foot prints.

The process of "farming carbon" as a marketable commodity is possible if we are able to develop suitable scientific techniques related to measurement, monitoring, verification and cost evaluation of soil sequestered C. Beneficial management of soil C offers the opportunity not only to avoid the negative consequences but also to enhance the wide range of available soil functions and ecosystem services. The knowledge of the role of soil C, and the existing methods and innovation potential to manage it effectively for this wide range of benefits, is collectively substantial but is fragmented between many different disciplines .The growing demands of effective SOC management in Indian agriculture have become more diverse and intense, and necessitate a paradigm shift in our research strategies for sustainable management of our limited and often fragile soil C resources.

References

- Martin, J.P., and K. Haider, 1986. Influence of mineral colloids on turnover of soil organic carbon. In: Interactions of soil minerals with natural organics and microbes. P.M. Huang and M. Schnitzer (eds.). SSSA Spec. Publ. 17. Soil Society of America, Madison WI, pp. 283-304.
- Rajendiran, S., Coumar, M.V., Kundu, S., Ajay, Dotaniya, M. L. and Rao, Subba A. (2012) Role of phytolith occluded carbon of crop plants for

enhancing soil carbon sequestration in agro-ecosystems. *Current Science*; 103:

- Bhattacharya, T., Chandran, P., Ray, S.K., Pal, D.K., Venugopalan, M. V., Mandal, C. and Wani, S. P. (2007) Changes in levels of carbon in soils over years of two important food production zones of India. Current Science: 93: 1854-1863.
- Manna, M.C. et al., Soil organic matter in West Bengal Inceptisol after 30 years of multiple cropping and fertilization. *Soil Sci. Soc. Am* J., 2006, **70**, 121-129.
- Waksman, S.A. (1938) Humus. Origin, Chemical Composition and Importance in Nature, 2nd edn. The Williams and Wilkins Company, Baltimore, London (revised).
- Keeling, C.D., Bacastow, R.B., Bainbridge, A.E., Ekdahl, C.A., Guenther, P.R. and Waterman, L.S., (1976) Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. *Tellus* 28, 538-551.
- FAO (2011) The State of The World's Land and Water Resources for Food and Agriculture (SOLAW)- Managing Systems at Risk. Food and Agricultural Organization of the United Nations and Earthscan, Rome.
- Schmidt, M.W.I., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kogel-Knabner, I., Lehmann, J., Manning, D.A.C. et al. (2011). Persistence of soil organic matter as an ecosystem property. *Nature* 478, 49-56.
- MEA (Millennium Ecosystem Assessment) (2005) Ecosystems and Human Well-being: Synthesis. Island of Sciences USA 104, 13268-13272.
- Robinson, D.A. Hockley, N., Cooper, D.M., Emmett, B.A., Keith, A.M., Lebron, I., Reynolds, B., Tipping, E., Tye, A.M., Watts, C.W. et al., (2013) Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. *Soil Biology and Biochemistry* 57, 1023-1033.
- Planning Commission Report, Report of the Committee on India Vision 2020, Govt of India, New Delhi, December 2002.
- Smil, V. 1998. China's energy and resources uses: continuity and change. *China* Q. 156: 935-951.
- Lal R., 2006 Enhancing crop yields in developing countries through restoration of soil organic carbon pool in agricultural lands. *Land Degrad. Dev*. 17, 197-206.
- Mayer, L.M. 1994 Surface area control of organic carbon accumulation in continental shelf sediments. Geochim. Cosmochim. Acta 58, 1271-1284.
- Ransom, B., Bennett, R. H., Baerwald, R. & Shea, K. 1997 TEM study of in situ organic matter on continental margins: occurrence and the monolayer' hypothesis. Mar. Geol. 138, 1-9.
- Chenu, C. & Palnte, A. F. 2006 Clay-sized organo-mineral complexes in a cultivation chronosequence: revisiting the concept of the 'primary organo-mineral complex'. Eur. J. Soil Sci. 57, 596-607.
- Cordula, V., Carsten, W. M., Carmen, H., Franz, B., Katja, H., Stefanie, S., Schloter, M. and Ingrind, K. K. 2014 Submission structures provide preferential spots for carbon and nitrogen sequestration in soils. Nature Communications 5:2947
- Baker, J.M., Ochsner, T.E., Venterea, R.T. and Griffis, T.J. 2007 Tillage and soil carbon sequestration-What do we really know? Agricultural Ecosystems Environments 118:1-5.
- Bissett, A., Richardson, A.E., Baker, G., and Thrall P.H. 2011 Long term land use effects on soil community structure and function. Applied Soil Ecology 51: 66-78.
- Lal, R., 2014 Soil peace nexus: our common future. Soil Science and Plant Nutrition. In press.
- Richardson A.E., Kirby, C.A., Banerjee, S., and Kirkegaard J.A. 2014 The inorganic nutrient cost of building soil carbon. Carbon Management. In Press.
- Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henkaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., Courcelles, V.de R.de, Singh, K., Wheeler, I., Abbot, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Patron, W.J., Whitehead, D., and Zimmerman, M.J., 2013 The knowns, known unknowns, and unknowns of sequestration of soil organic carbon. Agriculture Ecosystems and Environment 164: 80-99.

Weed management under the regime of climate change –Recent advances

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Rapid global industrialization and other anthropogenic activities resulted in production of greenhouse gases and continue at its alarming pace. Direct effects of climate change influence not only the performance of individual organism but also impact interaction with other organisms at various stages in their life history via changes in physiology, morphology and chemistry. Change in any climatic factor influences not only the performance of an organism but also impact interaction with other organisms at various stages in their life history. Global industrialization resulted in production of greenhouse gases and continues at its alarming pace. Carbon dioxide is one of the major contributors of greenhouse gases which had a significant impact on plant metabolism and performance? Although, there is broad agreement that higher atmospheric CO_2 levels enhance photosynthesis in C_3 crop plants, yet, no such clue is available on how rising CO_2 levels will affect the physiology of associated weeds, which provide a tough competition to the crop plants. The argument that rising atmospheric CO_2 concentration will reduce weedy competition because the C_4 photosynthetic pathway is over represented among weed species (e.g. Holm *et al.*, 1977) does account neither the range of already available C_3 weed species, nor those environmental factors (e.g. precipitation and temperature) which may influence their relative proportion following emergence leading to the change in crop-weed interaction.

Agricultural weeds evolved in response to domestication of wild plants and continue making a significant loss to agricultural production. However, what is real mechanism of unwanted weed growth in abundance to the despair of the farmers is still unclear. The atmospheric CO_2 concentration is continuously increasing and perhaps will be double by the end of this century (IPCC, 2007). It is well established that plants grown under elevated CO_2 exhibit enhanced photosynthesis and biomass production ‘at least’ during the short term exposure (Ziska and George, 2004). Till date, only a few studies have focused on the impact of high CO_2 concentration on the response of weeds and their interaction with crop plants which significantly can influence the yield potential. Poorter (1993) reviewed the literature on the growth response of plants to an elevated CO_2 concentration and suggested a large inter-specific variation in growth stimulation which was found to be larger for C_3 species than for C_4 plants (41% for C_3 *vs*. 22% for C_4). Most of the terrestrial plants respond positively to the atmospheric CO_2 enrichment by increasing there photosynthetic rates and biomass production. However, greater responsiveness of weeds to high CO_2 atmosphere as compared to crop plants might be a point of focus and concern for scientists, and if it happens, then weeds may increase their dominance in agro ecosystem. In several studies, weeds have been shown to increase their growth and productivity in response to atmospheric CO_2 enrichment (Rogers *et al*., 2008; Awasthi and Kumar, 2010). Further, it was emphasized that greater promotion of water use efficiency in weed species than crops species might convey a competitive advantage to the weeds and by virtue of that weed species may be more invasive in a future high-CO_2 world.

Response of crop and weed species to the increasing atmospheric CO_2 concentration may vary resulting change in weed–crop competition and hence crop yield. In order to evaluate the impact of rising atmospheric CO_2 on crop production losses due to weeds (Ziska, 2000) suggested that (i) rising CO_2 would increase yield losses due to competition with weeds; (ii) weed control will be crucial in realizing any potential increase in economic yield of agronomic crops; and (iii) instead of C4 weeds, C_3 weeds would pose more serious threat to crop production in future high CO_2 atmosphere.

Less quantum of work has been done in developing countries like India, so far, on the subject especially with regard to impact on crop-weeds interaction. However, some research work is evident on the effect of elevated CO_2 on crop plants. Uprety *et al*. (1995) observed that drought susceptible species, viz. *Brassica campestris* and *B. nigra* responded to elevated CO_2 markedly as compared to less sensitive *B. carinata* and *B. juncea* plants in terms of increased stomatal resistance and/or increased root growth and hence, improved water status of plants. Increase in biomass at high CO_2 concentration was noticed in rice (Uprety *et al.,* 2002), mungbean (Srivastava *et al.,* 2001; Das *et al*., 2002) and mungbean and weed species (*Euphorbia geniculata* and *Commelina diffusa*) (Awasthi and Kumar, 2010).

Plants exposed to elevated CO_2 often show increased growth and water use efficiency (Allen and Amthor, 1995). Elevated atmospheric CO_2 attracts biological scientists, especially ecologist and plant physiologist, because of the potential biological impacts from CO_2 induced global warming and from direct effects of elevated CO_2 on vegetation that are independent of global warming. Recently, most of the research has been focused on the effect of CO_2 enrichment on plant growth, leaf photosynthesis but only few studies have examined the effect of elevated

CO_2 on at metabolic and molecular level. The ability of plants to respond to future elevated CO_2 levels will undoubtedly hinge upon physiological characteristics such as sink strength, efficiency of N and water use and photosynthetic pathway. The exclusive use of gas exchange data to predict plant success has been over-valued and over-represented in literature addressing plant response to elevated CO_2. However, performance of a particular crop can not be predicted on the basis of performance of an individual plant but need to be studied at various levels considering the interaction with other organisms and environmental factors i.e. interactions between crop-weeds, crop-insects and crop-microorganisms.

Different plant species respond elevated CO_2 in different ways starting right from germination up to maturity depending upon their growing habits and photosynthetic pathways and several other metabolic processes (Bunce, 1993). Crops and weeds co-exist in agriculture system and certainly a point of focus among scientists, agriculturists and environmentalists. Numerous studies can be found in literature regarding the crops-weeds interaction in field conditions suggesting that weeds pose a very serious and potential threat to agricultural production resulting approximately one third yield loss by virtue of their competitiveness with special mention to "noxious" or "invasive" weeds like *Euphorbia geniculata* which outplay the crop plants in almost every aspect and led to big loss to crop production in India. Recently, focus of agriculture scientists turned towards crops-weeds competitiveness in high CO_2 environment (Ziska and George, 2004) and it was suggested that possibly recent increases in atmospheric CO_2 during the 20^{th} century may have been a factor in the selection of weed species and may be contributing factor of invasiveness of these species.

Future challenges

Several questions need to be answered by researchers regarding weeds and weed management under climate change conditions, the most important are:

- How elevated CO_2 and other associated factors will affect crops, weeds, and associated micro-organism?
- How changes in climate will affect the relative competitiveness of crop, weeds and microbes?
- How efficacy of herbicide will be change under climate change conditions?
- What effects does increased temperature (global warming) have on weeds?
- How does a change in precipitation (seems to be almost certain) effect weed growth?
- What is physiological and molecular basis and mechanism of dominance?
- Is it possible to sustain/increase the productivity of crops in change climate?
- Can we borrow something from the weeds to strengthen crops? If yes, what?
- If climate change/CO_2 alters weed biology, will this impact human health?

How elevated CO_2 will affect crop, weeds and associated micro-organism and their competitiveness?

Weeds are a reservoir of genetic diversity. Consequently, if a resource (light, water, nutrients or CO_2) changes within the environment, it is more likely that weeds will at more advantage than crop. It can be argued that many weed species have the C_4 photosynthetic pathway and therefore will show a smaller response to atmospheric CO_2 relative to C_3 crops. However, this argument does not consider the range of available C_3 and C_4 weeds already present in any agronomic system. Currently, more than 450 "troublesome" weed species (both C3 and C4) associate with approximately 50 major crops throughout the world. Hence, if a C_4 weed species does not respond, it is likely that a C_3 weed species will. In addition, many researchers recognized that the worst weeds for a given crop are similar in growth habit or photosynthetic pathway; indeed, they are often the same uncultivated or "wild" species, e.g. oat and wild oat, sorghum and shattercane, rice and weedy rice.

To date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favored as CO_2 is increased. In addition to agronomic weeds, there is an additional category of plants that are considered "noxious" or "invasive" weeds. These are plants, usually non-native whose introduction results in wide-spread economic or environmental consequences. Many of these weeds reproduce by vegetative means (roots, stolons, etc.) and recent evidence indicates that as a group, these weeds may show a strong response to recent increases in atmospheric CO_2 (Ziska and George, 2004). How rising CO_2 would contribute to the success of these weeds *in situ* however, is still unclear. Overall, the data that are available on the response of weeds and changes in weed ecology are limited. Additional details, particularly with respect to interactions with other environmental variables (e.g. nutrient availability, precipitation and temperature) are also needed.

How elevated temperature will impact weed growth?

Rise in atmospheric CO_2 concentration and other gases like ozone and methane associated with concurrent increase in temperature affects growth and development of plants (IPCC, 2007). Increase in temperature is the phenomenon associated with the 'greenhouse effect'. Sionit *et al.* (1987) pointed out differences in temperature optima for physiological process in C_3 and C_4 species and suggested that C_4 species will be able to tolerate higher temperature change associated with high CO_2 concentration than C_3 species. Therefore, C_4 weeds may benefit more than the C_3 crops from any temperature increase associated with elevated CO_2 levels. Temperature plays an important role in biological and metabolic activity, defining the length of the available season suitable for growth, phonological development, incidence of heat or freezing stresses, and the level of enzymatic activity associated with photosynthesis, respiration and other metabolic pathways. Plant growth and development are reduced or halted at low temperatures, cells are damaged by freezing temperatures, and high temperatures can be devastating during flowering and initial stages of yield formation. The interaction of these factors will determine the impact on crop productivity, management, and economics of agriculture under climate change. Increasing temperatures may cause an expansion of new weeds into temperate regions. Invasive weeds that are currently found in the south and central part of the country and are limited in the northern hilly states due to low temperature. An increase in temperature due to climate change (global warming) may cause an expansion of weeds towards north hilly regions.

In USA, many C4 grass weeds are serious problems in the southern U.S. but do not occur at problem levels in the U.S. corn belt. Studies have shown that itchgrass, a profusely tillering, robust grass weed could invade the central Midwest and California with only a 3 °C warming trend (Patterson, 1995). Witchweed, a root parasite of corn, is limited at this time to the coastal plain of North and South Carolina, however, with an increase of temperature of 3°C it is speculated that this parasite weed could become established in the Corn Belt with disastrous consequences. Similarly, the current distribution of both Japanese honeysuckle and kudzu is limited by low winter temperatures which may be further expand its invasion into the cooler regions by several hundred miles in USA. In India, not much work has been done on this aspect, but DWSR has taken initiative to study the climate change effects on weed management.

How does a change in precipitation effect weed growth?

With the rise in concentration of atmospheric greenhouse-gases and average temperature, global average precipitation will increase, however it will also lead to changes in the timing and regional patterns of precipitation. Changes in the pattern of the rainfall will cause the alteration in the water availability which eventually will lead to weed shift. Response to drought in agronomic conditions is dependent on species and cultural conditions. Any factor which increases environmental stresses on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds (Patterson, 1995).

Will weed management be affected under climate change conditions?

Any direct or indirect effect from a change in climate will definitely have a significant impact on management of weeds. Changes in temperature, wind speed, soil moisture and atmospheric humidity can influence the efficacy of herbicides application. For example, drought can result in thicker cuticle development or increased leaf pubescence, with subsequent reductions in herbicide entry into the leaf. Overall, pesticides are most effective when applied to plants that are rapidly growing and metabolizing, i.e. those free from environmental stress. But does rising CO_2 per se alter chemical management? There are an increasing number of studies (Ziska and George, 2004) that demonstrate a decline in chemical efficacy with rising CO_2. The basis for this reduction is unclear. Recent work with Canada thistle grown in monoculture under field conditions suggested a greater root to shoot ratio and subsequent dilution effect of glyphosate when grown at elevated CO_2 (Ziska and George, 2004). However, it is not clear if this is a ubiquitous response. In any case, if CO_2 does reduce efficacy, then additional work is needed to determine herbicide specificity, concentration and application rates as possible means of adaptation. Biological control of weeds by natural or manipulated means is likely to be affected by increasing atmospheric CO_2 and climatic change.

Climate as well as CO_2 could alter the efficacy of weed bio-control agents by potentially altering the development, morphology and reproduction of the target pest. Direct effects of CO_2 would also be related to changes in the ratio of C: N and alterations in the feeding habits and growth rate of herbivores. As pointed out by Patterson (1995), warming could also result in increased insect populations and changes in their potential range. However, this could increase both the biological control of some weeds, yet, it could also increase the incidence of specific crop pests, with subsequent indirect effects on crop-weed competition. Overall, synchrony between development and reproduction of bio-control agents and their selected targets is unlikely to be maintained in periods of rapid climatic change or climatic extremes. Whether this will result in a positive or negative benefit remains unclear. Tillage (by mechanical means) is regarded as a global method of weed control in agronomic systems. Elevated CO_2 could lead to further below ground carbon storage with subsequent increases in the growth of roots or rhizomes, particularly in perennial weeds (see Rogers *et al.,* 2008 for a review). Consequently, mechanical tillage may lead to additional plant propagation in a higher CO_2 environment, with increased asexual reproduction from below ground structures and negative effects on weed control (e.g. Canada thistle, Ziska and George, 2004).

In nutshell, there are many strong reasons for expecting climate and/or rising CO_2 to alter weed management. Adaptation strategies are available, but the cost of implementing such strategies (e.g. new herbicides, higher chemical concentrations, new biocontrol agents) is a matter of further extensive research work. Herbicide use is controlled by individual state regulations. If an increase in CO_2 and temperatures allow invasive weed species to expand their geographical locations new herbicides may be needed to combat them. Often it takes a period of time to receive state approval of a new chemical or a chemical that has not been previously used.

If climate change/CO_2 alters weed biology, will this impact human health?

Weeds 'in general' are recognized by public as significantly affecting human health either through allergenic reactions, skin irritations, mechanical injury or internal poisoning (Ziska, 2001). For the most part, we are only in the initial stages of quantifying how changes in climate and/or CO_2 may affect those specific weeds associated with public health. One exception has been changes in pollen production and allergenicity in common ragweed (a recognized cause of allergic rhinitis) with changing CO_2 and temperature in both indoor (Wayne *et al*., 2002) and in situ experiments (Ziska, 2003). Additional research on how rising CO_2 can affect both poison ivy growth and toxicity is currently ongoing. No information is available on how CO_2 could alter the toxicity of secondary compounds associated with mortality in weedy species.

What is physiological basis and mechanism of dominance?

Nitrogen fixation and gas exchange are important aspects which are expected to be influenced at high CO_2 concentration. A positive effect of CO_2 enrichment on nodule growth and development was observed in term of fresh weight, size and functionality of nodules (Lee *et al.*, 2003; Awasthi and Kumar, 2010). An increase in N_2-fixation at elevated CO_2 could result form an increase in nodule size, nodule number per plant, or an increase in specific nitrogenase activity. Presence of a positive feedback loop between nitrogen fixation and photosynthesis has been advocated and emphasized that such feedback may be an important way in which the potential carbon drain of nitrogen fixation on the host plant could be compensated in terms of increased nitrogen availability and these two factors together stimulate the growth and development of plants (Arnone and Gordon, 1990). Increase in rate of photosynthesis and instantaneous water use efficiency was observed in mungbean and *Commelina diffusa* when plant were subjected to CO_2 enrichment. On the other hand, stomatal conductance, rate of transpiration and transpiration cooling were decreased at elevated CO_2 as compared to that at ambient CO_2 in mungbean and *Commelina diffusa* and at both the sampling stages. However, variation to the above results, exposure of *Euphorbia geniculata* plants to high CO_2 led to increase in stomatal conductance and transpiration and hence transpirational cooling, and decrease in instantaneous water use efficiency despite of increase in rate of photosynthesis. These unusual results in *Euphorbia geniculata* may be a point of focus for future studies and may be considered as a unique adaptive potential of this weed to grow in adverse conditions. In summer crops, high temperature is always a threat for the operation of a number of metabolic reactions and situation even become worse due to rise in temperature associated with high atmospheric CO_2 level. Transpirational cooling is a way to keep plants cool at high temperature, thus enables plant to sustain functionality of many temperature sensitive reactions, and hence achieve good growth in adverse conditions.

In present study, high growth of *Euphorbia geniculata* at elevated CO_2 can be ascribed 'at least partly' to its ability to maintain high transpiration and transpiration cooling at high temperature at elevated CO_2. However, this ability of this weed species might be considered as a potential threat to crop species like mungbean as it act as drain of available resources too. If it is so, then definitely crop-weed interaction will be change in favour of weeds in high CO_2 atmosphere. Further, some more efforts at biochemical and molecular level are required to unravel the puzzle of crop-weed interaction. At present, no evidence for high transpiration rate and stomatal conductance is available in literature, thus need further investigation on this aspects (Awasthi and Kumar, 2010).

Carbonic anhydrase is an important enzyme which catalyses the reversible inter-conversion of CO_2 and HCO_3^- and is widely distributed in all plant species (Ynalvez *et al*., 2008). It plays a fundamental role in many physiological processes including decarboxylation and/or carboxylation reactions of photosynthesis. Elevated CO_2 resulted an increase in activity of carbonic anhydrase in mungbean and weed species *Euphorbia geniculata* and *Commelina diffusa* as compared to that at ambient CO_2 (Awashti and Kumar, 2010). Proteins, being a macromolecule, play an important role for any living organism including plants. Unfortunately, not much work has been taken up to explain the extent and nature of the effects of elevated CO_2 on protein metabolism in plants. In a study at DWSR (Awashti and Kumar, 2011), increase in soluble protein in leaves was observed which can be considered as an adaptive strategy of plants to a newer situation which involves synthesis and regulation of many new proteins.

All together, available results suggest that elevated CO_2 affect the overall growth of plants. Promotion in growth of plants can be attributed mainly to the high rates of photosynthesis. Crop-weed interaction can be changed in favor of weeds on account of higher benefit to weed species in terms of growth and development and photosynthesis. Another point which can go in favour of weed species is their unique adaptive potential as mentioned above in case of *Euphorbia geniculata* which showed higher transpiration and stomatal conductance to cope up with high temperature associated with rising CO_2. Molecular analysis of crops and associated weed species can further provide some deeper insights into the real mechanism for the response of plants to 'almost certain' rise in atmospheric CO_2 and warming effects. An integrated approach involving physiology, biochemistry and molecular biology will be even more effective for the mechanistic study of crop-weed interaction in future high CO_2 world.

Potential strategies

Weeds have greater adaptation potential than crops by virtue of huge genetic diversity. If environmental and land resources change, it is almost likely that weeds will be the winner in the race and over compete the crop plants for the utilization of resources, hence creating the problem of weed management. One important point emerges from available studies is that the most competitive weed in a given crop is similar in growth habit or photosynthetic pathway to that particular crop e.g. *Phalaris minor* in wheat, wild oat in oat and weedy rice and rice crop. Recently, in a pioneer study, Ziska and coworkers have shown that weedy rice has immense potential to compete the cultivated rice in elevated CO_2 condition.

Increasing concentration of ozone into troposphere is another concern of scientist around the world. A rise in the ozone can potentially suppress the growth of crop plant but some weeds like *Cyperus esculentus* have the potential to escape or minimize the impact of increasing ozone. Tolerance to ethanol and the ability to metabolize key intermediary substrates under anaerobic conditions makes *Echinochloa crus-galli* (L.) tolerant to flooding conditions which are expected to be arise from climate change condition due to over-melting of glaciers and change in rainfall pattern. *Alternanthera philoxeroides* has been shown to possess capability to survive under worse environmental conditions like drought, salinity, low temperature and flooding thus can be a plant for future from the point of view of crop improvement. From the above mentioned studies, it can be inferred that weeds possess better ability to survive and perform under adverse environmental conditions which make them sturdy and highly competitive with crop plants. Now a big question arises in this context, can we exploit these attributes of weeds for the crop improvement? If yes, then there is no other alternate better than weeds simply because of the co-existence of weed and crop plants. An advantage using weeds as a source of gene(s) may be other co-ordinated regulatory aspects of the transgene(s). As both weeds and crops grow in the same environment, so it is expected that internal machinery (at least partly) which is required for the functioning of transgene(s) might be present already in crop plants. Development and availability of the sophisticated molecular tools provide us liberty to play at molecular level and to transfer the genetic material into crop plants, thus breaking the reproductive barriers for inter-specific and inter-generic transfer of the genetic material. However, success of such approaches requires integration and collaborative efforts from all the corners of scientists to bring together expertise in weed science, molecular biology, plant physiology. Following strategies can be beneficial to fight with the problem of climate change which seems to be certain in years to come.

- Identification of crop cultivars resilient to climate changes.
- **Preventive measures:** Early planting of crops can be effective by means of avoiding the high temperature.
- **Return to conventional tillage practices**: Looks difficult as it required again lots of labor work, fuel and feed.
- **Engineering of crops:** Most viable and dynamic strategy is to engineer the crop plants which can perform better under futuristic climate change conditions. For this purpose, weeds can be a good source of genetic materials for raising transgenic crops.

References

- Allen, L.H. and Amthor, J.S. 1995. Plant physiological responses to elevated CO_2, temperature, air pollution, and UV-B radiation. *In:* Biotic feedbacks in the global climatic system will the warming feed the warming? (eds. Woodwell, G.M. and Mackenzie F.T.): Oxford University Press, New York, pp. 51-84.
- Arnone, J.A. and Gordon, J.C. 1990. Effect of nodulation, nitrogen fixation and CO_2 enrichment on the physiology, growth and dry mass allocation of seedling of *alnus rubro* Bong. New Phytol. **116**:55-66.
- Awasthi, J.P. and Kumar B. 2010. Effect of elevated CO_2 on physiological and biochemical aspects in mungbean and associated weeds (*Euphorbia geniculata* and *Commelina diffusa*). [Personnel communication]
- Bunce, J.A. 1993. Effect of doubled atmospheric carbon dioxide concentration on the response and conductance to humidity. Plant cell Environ. **16**:189-197.

- Das, M., Zaidi, P.H., Pal M. and Sengupta U.K. 2002. Stage sensitivity of Mungbean (*Vigna radiata* L. Wilczek) to an elevated level of carbon dioxide. J. Agron. Crop Sci. **188:** 219-224.
- Holm, L.G., Plucknett, D.L., Pancho, J.V. and Herberger, J.P. 1977. The world's worst weeds. Distribution and biology. University Press of Hawaii, USA.
- IPCC. 2007. Climate change 2007: Synthesis report. Intergovernmental Panel for Climate Change, Fourth Assessment Report.
- Lee, T.D., Tjoelker, M.G., Reich, P.B. and Russelle, M.P. 2003. Contrasting growth response and N_2-fixation in fertile grassland is an important trait for a strong response of plants to elevated atmospheric CO_2. Global Change Biol. **6**:655-662.
- Patterson, D.T. 1995. Weeds in a changing climate. *Weed Sci.,* **43**: 685-701.
- Poorter, H. 1993. Interspecific variation in the growth response of plants to an elevated ambient CO_2 concentration. Plant Ecol. **104/105**:77-97.
- Rogers, H.H., Runion, B., Prior, S.A., Price, A.J. and Torbert, H.A. 2008. Effects of elevated atmospheric CO_2 on invasive plants: comparison of purple and yellow nutsedge (*Cyperus rotundus* L. and *C. esculentus* L.). J. Environ. Qual. **37**:395-400.
- Sionit, N., Strain B.R. and Flint, E.P. 1987. Interaction of temperature and CO_2 enrichment on soybean: Growth and dry matter partitioning. Can. J. Plant Sci. **67**:59-67.
- Srivastava, G.C., Pal, M., Das, M. and Sengupta, U.K. 2001: Growth, CO_2 exchange rate and dry matter partitioning in mungbean (*Vigna radiata* L.) grown under elevated CO_2. Indian J. Exp. Biol. **39:**572-577.
- Uprety, D.C., Mishra, R.S., Abrol, Y.P. 1995. Effect of elevated CO_2 on the photosynthesis, growth and water relation of *Brassica* species under moisture stress. J. Agron. Crop Sci. **175**:231-237.
- Uprety, D.C., Dwivedi, N., Jain, V. and Rajat, M. 2002. Effect of elevated carbon dioxide concentration on the stomatal parameters of rice cultivars. Photosynthetica **40**:315-319.
- Wayne, P.S., Foster, S., Connolly, J., Bazzaz, F.A., Epstein, P.R. 2002 Production of allergenic pollen by ragweed (*Ambrosia artemissiifolia* L.) is increased in CO_2-enriched atmospheres. Ann. Allergy Asthma Immunol. **80**: 669-679.
- Ynalvez, R.A., Xiao Y., Ward, A.S., Cunnusamy, K. and Moroney, J.V. 2008. Identification and characterization of two closely related β-carbonic anhydrase from *Chlamydomonas reinhardtii*. Physiol. Planta 133: 83-94.
- Ziska, L. H. 2000. The impact of elevated CO_2 on yield loss due to C_3 and C_4 weed in field grown soybean. Global Change Biol. **6**:889-905.
- Ziska, L.H. 2001. My View: Weed science and public health. Weed Sci. **49**:437-438.
- Ziska, L.H. 2003. Evaluation of the growth response of six invasive species to past, present and future atmospheric carbon dioxide. J. Exp. Bot. **54**:395-404.
- Ziska, L.H. and George, K. 2004. Rising carbon dioxide and invasive, noxious plants: Potential threats and consequences. World Resource Rev.**16**:427–447.

Weeds as source of novel plant growth promoting microbes for crop improvement

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Introduction

Agriculture manages plant communities to obtain useful materials from small set of species called crops. Weeds comprise the other set of plant species found in agro-ecosystems. Although they are not intentionally sown, weed species are well adapted to environments dominated by humans and have been associated with crop production since the origin of agriculture. The ecological role of weeds is seen in different ways depending on one's perspective and most commonly perceived as unwanted intruders into agro-ecosystem since they compete for resource, reduce crop yields and force the use of large amounts of human labour and technology to prevent greater crop losses. At the other end of the spectrum, weeds can be viewed as valuable agroecosystem components. In Indian subcontinent and Mexico, farmers consume *Amaranthus*, *Brassica* and *Chenopodium* species as nutritious foods before the crop attains maturity. In western Rajasthan, yields of sesame and pearl millet can be increased by allowing the crops to grow in association with the leguminous weed *Indigofera cordifolia* (Bhandari and Sen, 1979). Spahillari *et al*. (1999) re-examined the value of weeds as genetic resources for food agriculture and pharmaceutics and as indicators of agro-ecosystem biodiversity. These types of beneficial effects indicate that weeds are not just agricultural pests, but can also play beneficial roles in agroecosystems. However, little consideration has given to the soil conditioning properties of weeds, especially with regard to their influence on soil microbial diversity and subsequent soil health and quality. Soil health is a relative term used to define the efficiency of the soil functional processes (e.g. nutrient cycling, energy flow) are able to support viable, self-sustainable (micro) faunal and microfloral ecosystems, which constitute the living soil. It is often considered that soil microbial biodiversity is critical to the integrity, function and long-term sustainability of soil ecosystems. While the rhizosphere of crop plants have been well studied with the objective of screening PGPR, weeds which play an important role in maintaining ecological balance have largely been ignored and therefore a more complete understanding of the diversity and function of diazotrophic microorganisms is required. Especially, those that have symbiotic relationship with weed species particularly experiencing abiotic stress, is of great value for agricultural application. Some recent progress in this field of plant growth promoting microbes associated with different weeds was discussed in this review.

Bioprospecting in weed rhizosphere

The rhizosphere is characterized as a zone of intense microbial activity and represents the close interaction among the plants, soil and soil microorganisms. The rhizosphere is enriched with energy rich carbon compounds, leaked photosynthates from plant roots including sugars, amino acids and organic acids. The composition of plant exudates is unique to the plant species, which determines the microbial community of that rhizosphere.

Soil microorganisms play an important role in soil processes that determine plant productivity. Diversity and community structure in the rhizosphere is however influenced by both, plant and soil type. Plant-species-specific selective enrichment of microflora in the rhizosphere milieu has been exploited in legumes from the point of view of N_2-fixation under nitrogen limiting conditions (Coutinho *et al.*, 1999). Likewise, non-leguminous crops also favour specific bacterial groups in its rhizosphere. Nitrogen fixation is one of the essential beneficial biological processes for the economic and environmental sustainability of agriculture worldwide. Globally, annual inputs of fixed nitrogen from crop legume–rhizobia symbioses are estimated as 2.95 million tonnes for pulses and 18.5 million tonnes for oilseed legumes (Howieson, 2005). In spite of the in-depth knowledge about the biochemical and molecular steps involved in legume-rhizobium symbiosis, the holy grail of N_2 fixation by other plants especially, weedy plants are yet to be realised. New knowledge on soil microbial diversity can lead to the discovery of new generation inoculants as well as improve survival and performance of beneficial microbes in situ following their introduction into foreign environments. The association of weeds with plant growth promoting rhizobacteria in Indian soil is poorly understood.

Sturz *et al*. (2001) studied the influence of plant growth promoting (PGP) activity of bacterial communities recovered from each of six weed species (barnyard grass (*Echinochloa crusgalli*), corn spurrey (*Spergula arvensis* L.), goldenrod (*Sonchus* sp.), Italian ryegrass (*Lolium multiflorum* L.), lamb's-quarters (*Chenopodium album* L.), and quack grass (*Agropyron repens*) was examined in relation to the effect it had on the growth of the potato. Bacterial species composition and community structure were compared, species-abundance relationships were determined, and those members conferring positive benefits for potato growth and development were identified. Of the genera identified, *Bacillus*, *Arthrobacter*, *Stenotrophomonas*, *Acinetobacter* and *Pseudomonas* were the most common, and *Stenotrophomonas maltophilia* was the most frequent species recovered across all sources. It considered that complementary crops and soil-conditioning treatments should not preclude the examination of weed species as possible beneficial, as alterations in rhizobacterial biodiversity and functional versatility can influence the numbers and types of PGP bacterial strains, and consequently may serve to improve soil quality.

Weed as a source of plant growth promoting rhizobacteria in agricultural soil

Plant growth promoting rhizobacterial have the potential to contribute to sustainable plant growth promotion. Generally, PGPR function in three different ways: synthesizing particular compounds for the plants, facilitating the uptake of certain nutrients from the soil, and lessening or preventing the plants from diseases. Plant growth promotion and development can be facilitated both directly and indirectly. Direct plant growth promotion includes symbiotic and non-symbiotic PGPR which function through production of plant hormones such as auxins, cytokinins, gibberellins, ethylene and abscisic acid. Production of indole-3-ethanol or indole-3-acetic acid (IAA), the compounds belonging to auxins, have been reported for several bacterial genera. Some PGPR function as a sink for 1-aminocyclopropane-1-carboxylate (ACC), the immediate precursor of ethylene in higher plants, by hydrolyzing it into α-ketobutyrate and ammonia, and in this way promote root growth by lowering indigenous ethylene levels in the micro-rhizo environment. Indirect plant growth promotion includes the prevention of the deleterious effects of phytopathogenic organisms. This can be achieved by the production of siderophores, *i.e.* small metal-binding molecules. Biological control of soil-borne plant pathogens and the synthesis of antibiotics have also been reported in several bacterial species. Another mechanism by which PGPR can inhibit phytopathogens is the production of hydrogen cyanide (HCN) and/or fungal cell wall degrading enzymes, e.g., chitinase and ß-1,3-glucanase.

Biological nitrogen fixation (BNF)

Nitrogen fixation is an ancient microbial process which evolved early in the history of our planet and is of central importance to the biosphere. All known forms of life require fixed nitrogen for biosynthesis and microbial nitrogen fixation provides the largest natural source of fixed nitrogen in the biosphere, accounting for the production of 100 to 290 t N yr^{-1} in terrestrial systems alone (Cleveland *et al.*, 1999). Free-living diazotrophs in soils provide the dominant natural source of fixed nitrogen in many of these terrestrial systems and yet we still have much to learn about the ecology and evolution of these organisms.

In Brazil, a number of tropical weedy grasses, including *Brachiaria humidicola*, *B. decumbens*, *Paspalum notatum* and *Panicum maximum* have shown relatively high N_2 fixation rates in ^{15}N isotope dilution studies, and may derive up to 40% of their N-needs from fixation (Olivares *et al.*, 1996). High nitrogen fixation by kallar grass in Pakistan has also been reported by Malik *et al.* (1997).

Production of plant growth promoting substances

Phytohormones also called plant growth regulators (PGRs), are well known for their regulatory role in plant growth and development. PGRs are organic substances that influence physiological processes of plants at extremely low concentrations. Because the concentration of hormonal signals is critical to the regulation of various physiological processes in plants, local changes of phytohormone levels can lead to characteristic changes in plant growth and development. Eighty per cent of microorganisms isolated from the rhizosphere of various crops have the ability to produce auxins as secondary metabolites. The rhizosphere of a luxuriantly growing, medicinal weed, *Cassia occidentalis* was analysed by enumerating PGPR on N free media from the most diverse stage of plant. Each isolate was tested for other plant growth promotion assays including production of cellulase, indole acetic acid (IAA), ammonia, HCN, siderophore and chitinase to select for ones possessing multi-trait plant growth promoting (PGP) properties. In Thailand, first report about nitrogen fixing and IAA production abilities of plant growth promoting rhizobacteria isolated from rhizosphere of Vettiver grass. The isolates were identified as *Stenotrophomonas maltophilia*, *Aurantimonas altamirensis*, *Agrobacterium tumefaciens*, *Rhizobium Bacillus*, *Paenibacillus polymyxa*, *Serratia marcescens*, *Klebsiella*, *Alcaligenes faecalis* and *Azospirillum* sp. (Bhromsiri and Bhromsiri, 2010). Similarly in India, from rhizosphere of bermuda grass, all the rhizobacterial isolates shows the ability to produce phytohormones such as indole-3-acetic acid and Gibberellic acid (Sarathambal *et al.*, 2013).

Synthesis of enzymes that can modulate plant growth and development

Ethylene is a potent plant growth regulator that affects many aspects of plant growth, development and senescence In addition to its recognition as a "ripening hormone", ethylene promotes adventitious root and root hair formation, stimulates germination, and breaks the dormancy of the seeds. However, if the ethylene concentration remains high after germination, root elongation (as well as symbiotic N_2 fixation in leguminous plants) is inhibited. It is widely believed that many plant growth promoting bacteria may promote plant growth by lowering the levels of ethylene in plants. This is attributed to the activity of the enzyme 1–aminocyclopropane-1–carboxylate deaminase, which hydrolyzes ACC, the immediate biosynthetic precursor of ethylene in plants. The products of this hydrolysis, ammonia and α-ketobutyrate, can be used by the bacterium as a source of nitrogen and carbon for growth (Honma and Shimomura, 1971). In this way the bacterium acts as a sink for ACC and as such is lowering the ethylene level in plants, preventing some of the potentially deleterious consequences of high ethylene concentrations. Inoculation of crops with ACC deaminase-containing PGPR may assist plant growth by alleviating deleterious effects of salt stress. In nature, ACC deaminase has been commonly found in soil bacteria that colonize plant roots. Many of these microorganisms are identified by their ability to grow on minimal media containing ACC as its sole nitrogen source. Similar findings by Sarathambal (2013) reported that 43% of rhizosphere diazotrophs from different weedy grasses (*B. subtilis, K. pneumoniae, Serratia* sp., *B. licheniformis, S. Marcescens* and *Bacillus* sp.) are all found to use ACC as the sole nitrogen source for growth.

Antagonistic Activity

Rhizobacteria can suppress the growth of various phytopathogens in variety of ways like competing for nutrients and space, limiting available Fe supply through producing siderophores, producing lytic enzymes and antibiosis. Among PGPRs, fluorescent pseudomonads are widely reported for their broad spectrum antagonistic activity against number of phytopathogens. Recently different PGPR isolates from weedy grass (Sarathambal, 2013) to control the rice plant pathogens such as *P. oryzae*, *R. solani* and *S. oryzae*. Many rhizospheric and endophytic bacteria are reported to have antagonistic activity against a variety of plant pathogens. Cibichakravarthy *et al*. (2011) reported that *Bacillus subtilis* isolated from the *Parthenium* rhizosphere has the ability to suppress the plant pathogens such as *Macrophomina phaseolina*, *Sclerotium rolfsi*, *Lasiodiplodia theobromae*, *Colletotrichum gloeosporioides* and *Alternaria solani.*

Mineral Solubilzation

One of the various mechanisms by which rhizobacteria promote plant growth is by solubilization of insoluble minerals. Phosphorus is the second most important macronutrient next to nitrogen in limiting crop growth. More than 40% of the world soils are deficient in phosphorus and the acid weathered soils of tropical and sub- tropical regions of the world are particularly prone to phosphorus deficiency (Vance, 2001). A survey of Indian soils revealed that 98 per cent of these need phosphorus fertilization either in the form of chemical or biological fertilizer. Application of chemical phosphatic fertilizers is practised though a majority of the soil P reaction products are only sparingly soluble. Under such conditions, microorganisms offer a biological rescue system capable of solubilizing the insoluble inorganic P of soil and make it available to the plants. P solubilization by plant-associated bacteria has been well documented in a number of studies. This group covers bacteria, fungi and some actinomycetes. These organisms solubilize the unavailable forms of inorganic-P like tricalcium, iron, aluminum and rock phosphates into soluble forms by release of a variety of organic acids like succinic, citric, malic, fumaric, glyoxalic and gluconic acids (Venkateswarlu *et al*, 2007).

Apart from phosphorus, micronutrients like Zn, Fe and Mn are found to be deficient in most of the soils with Zn as a foremost nutrient throughout the world (Alloway, 2001). Zn is mainly transformed into zinc carbonate in highly calcareous soils, reacts with Fe and Mn oxide minerals, and while converted into zinc phosphate in higher P fertilizing soils. Inclusion of a bacteria solubilizing zinc, as a bioinoculant in crop production technology is really beneficial for a country like India having high incidence of zinc deficiency (more than 70 per cent). A term called zinc solubilizing bacteria (ZSB) was coined for those bacteria that are capable of solubilizing the insoluble zinc compounds / minerals in agar plate as well as in soil (Saravanan *et al.*, 2007).

Siderophore Production

In the case of iron uptake, it was suggested that plants can benefit from the siderophores produced by several plant growth promoting rhizobacteria. Although iron is one of the most abundant minerals on Earth, in the soil it is relatively unavailable for direct assimilation by microorganisms. Iron is an essential growth element for all living organisms. The scarcity of bioavailable iron in soil habitats and on plant surfaces foments a furious competition. Under iron-limiting conditions PGPB produce low-molecular-weight compounds called siderophores to competitively acquire ferric ion. Siderophores (Greek: "iron carrier") are small, high-affinity iron chelating compounds secreted by microorganisms such as bacteria, fungi and grasses. Microbes release siderophores to scavenge iron from these mineral phases by formation of soluble Fe^{3+} complexes that can be taken up by active transport mechanisms. Rhizosphere bacteria of weedy grass (*Brachiaria reptans*, *Cenchrus glaucus*, *Saccharum spontaneum*, *Panicum repens*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Chloris barbata*, *Cyanodon dactylon* and *Setaria verticillata)* able to produce under *invitro* conditions (Sarathambal, 2013). Cibichakravarthy *et al*. (2011) mentioned that *A. brasilense* from *Prosopis julifera* able to produce the siderophore.

Conclusion

As discussed in this review, a new dimension to the significance of weeds in agricultural ecosystems. The study opens up possibilities for utilization of this property of weeds in plant growth promotion, and subsequent enhancement of yield for agricultural crops. This study also emphasise the multifaceted plant growth promoting activity obtained from the weedy grass rhizosphere under stressed condition may be employed in nutrient deficient and problematic soils for stress mitigation and sustainable crop cultivation with fewer chemical inputs. This preliminary analysis indicated that the rhizosphere of weeds is colonized by certain characteristic microbial communities, representing a good starting point for further analyses. It would be very interesting to investigate the molecular understanding between these plants and microbes in rhizosphere for further exploitation of these potential novel microbes in the nutrient management of crops growing under stress conditions.

References

- Alloway, B.J. (2001). Zinc – The vital micronutrient for healthy, high-value crops. International Zinc Association. Brussels, Belgium, p. 8.
- Bhanderi and Sen. (1979). Agro-ecosystem analysis of the Indian arid zone *Indigofera cordifolia* as a weed. *Agro-ecosystems*, 5(3):257-262
- Bhromsiri, C. (2009). Use of soil microbial inoculation for improving the effectiveness of vetiver grass and the effect on natural soil microbial ecology. Ph.D. Thesis Chiang Mai University.
- Bhromsiri, C. and Bhromsiri, A. (2010). Isolation, screening of growth-promoting activities and diversity of rhizobacteria from Vetiver grass and rice plants. Thai *Journal of Agricultural Science*, 43(4): 217-230.
- Cibichakravarthy, B., Preetha, R., Sundaram, S.P., Kumar, K. and Balachandar, D. (2011). Diazotrophic diversity in the rhizosphere of two exotic weed plants, *Prosopis juliflora* and *Parthenium hysterophorus*. *World J. Microbiol. Biotechnol*., 11(9): 274-285.
- Cleveland, C.C., Townsend, A.R., Schimel, D.S., Fisher, H., Howarth ,R.W., Hedin, L.O., Perakis, S.S., Latty, E.F., Von Fischer, J.C., Elseroad, A. and Wasson, M.F. (1999). Global patterns of terrestrial biological nitrogen (N_2) fixation in natural ecosystems. *Global Biogeochem. Cycles*, 13: 623-645.
- Coutinho, H.L.C., Oliveria, V.M., Lovato, A., Maia, A.H.N., and Manfio, G. (1999). Evaluation of the diversity of rhizobia in Brazilian agricultural soils cultivated with soybeans. *Appl. Soil Ecol.*, 13: 159–167.
- Glick, B.R. (1995). The enhancement of plant growth by free living bacteria. *Can. J. Microbiol*., 41:109–117
- Glick, B.R., Penrose, D.M. and Li, J. (1998). A model for the lowering of plant ethylene concentrations by plant growth-promoting bacteria. *J. Theor. Biol*., 190: 63– 68.
- Honma, M. and Shimomura ,T. (1971). Metabolism of 1-aminocyclopropane -1- carboxylic acid. *Agrl. Biol. Chem.*, 42: 1825-1831.
- Howieson, J.G. (2005). Application of rhizobial inoculants to Australian agriculture – Foreword. *Aust. J. Exp. Agric*., 45:12-15.
- Malik, K.A., Bilal, R., Mezhnez, S.G., Rasul, M.S., Mirza and Ali, S. (1997). Association of nitrogen-fixing, plant-growth-promoting rhizobacteria (PGPR) with kallar grass and rice. *Plant Soil*, 194: 37-44.
- Olivares, F.L., Baldani, V.L.D., Reis, V.M., Baldani, J.I. and Dobereiner, J. (1996). Occurrence of the endophytic diazotrophs *Herbaspirillum* spp. in roots, stems and leaves predominantly of graminae. *Biol. Fertil. Soil.*, 21: 197–200.
- Sarathambal, C. and K. Ilamurugu. (2013). Saline tolerant plant growth promoting diazotrophs from rhizosphere of bermuda grass and their effect on rice. *Indian Journal of Weed Science* , 45(2): 80–85
- Sarathambal, C., Ilamurugu, K. and Srimathi Priya, L. (2013). Isolation of elite diazotrophic bacterial isolates from *Cyanodon dactylon* rhizosphere of saline soils. *Research Journal of Chemistry and Environment*, 17 (12):70-77.
- Sarathambal,C. (2013). Assessment of functional microbial diversity in the rhizosphere of selected Semi-arid tropical grasses. Ph.D thesis. Tamil Nadu agricultural University,Coimbatore, Tamil Nadu
- Saravanan.V.S., Madhaiyan, M. and Thangaraju, M. (2007). Solubilisation of zinc compounds by the diazotrophicus, plant growth promoting bacterium *Gluconoacetobacter diazotrophicus*. *Chemosphere*, 66: 1794-1798.
- Spahillari, M., Hammer, K., Gladis, T. and Diederichsen, A.(1999). Weeds as a part of agrobiodiversity. *Agriculture*, 28:227-232.
- Sturz, A V., Matheson, B. G., Arsenault, W., Kimpinski, J. and Christie, B. R. (2001). Weeds as a source of plant growth promoting rhizobacteria in agricultural soils. *Canadian Journal of Microbiology*, 47(11): 1013-1024,
- Vance, C.P. (2001). Symbiotic nitrogen fixation and phosphorus acquisition: plant nutrition in a world of declining renewable resources. *Plant Physiol*., 127: 390-397.
- Venkateswarlu, B., Balloli, S.S. and Ramakrishna, Y.S. (2007). Organic farming in rainfed Agriculture.

Central research institute for dry land agriculture, Hyderabad, p: 88.

Statistical methodologies for climate resilient soil management

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Statistics provide scientific tools for representative data collection, appropriate analysis and summarization of data and inferential procedures for drawing conclusions in the face of uncertainty. It is indeed true that statistical tools have wide applicability to almost any branch of science dealing with the study of uncertain phenomena involving aggregates. However, in agricultural research, statistics finds some of the very interesting applications which often lead to the development of newer statistical techniques or at least a refinement of existing ones.

In soil science also, statistical analyses help to understand the meaning of experimental results and biological explanation. ANOVA and Regression are most common techniques used in these experiments. Even though ANOVA and regression have played an important role in soil science for a long time, several relatively new techniques may be more effectively used in some common experimental situations. For example when we have several response variables, then multivariate statistics can be used, which may be very useful in the case of multivariate entities. Some other statistical techniques may be used based on the requirement and the nature of the data. In statistics, accuracy does not necessarily imply complexity and difficulty. On the contrary: excessively complex analyses may indicate that the experiment was poorly conceived, the objectives were poorly defined or the researcher tried to fit too many things into one experiment.

"Statistical analysis and interpretation are the least critical aspects of experimentation, in that if purely statistical or interpretative errors are made, the data can be reanalyzed. On the other hand, the only complete remedy for design or execution errors is repetition of the experiment." (Hurlbert 1984, p. 189)

In this notes some statistical methods which are generally used in soil science, will be discussed.

1. Experimental Designs

There are many experimental designs which are generally used in the field of soil science. Some of them are: Completely Randomized Design (CRD), Randomized Block Design (RBD), Split Plot design, Strip plot design, etc. The experimental design yields the inferences that can be reliably drawn from an experiment. A proper design is thus a requirement, not only for field and glasshouse experiments, but for all kinds of studies.

CRD is followed predominantly when the experimental units are homogenous all through and there is hardly any variation exists in the growing environment. Pot culture or petri-dish studies in the green and glass houses or in the laboratories are usually analyzed by CRD since they are in controlled environment and less or not exposed to variation. However, there may exist variation in sunlight interception across the pots due to space limitation on account of a large number of pots put for study or several studies being carried out simultaneously. So, it is better if such studies are analyzed by RBD instead of CRD to obtain greater precision.

RBD is frequently followed in weed control research and it is best suited if there is only one set up of treatments and one objective to be satisfied. It cannot evaluate interaction between two or more set up of treatments. Then factorial RBD or split plot design is to be adopted. In split plot design, treatments, which require a large area of plot for easy management, should be put in the main plots, e.g. tillage, irrigation, variety etc. and treatments for which more precise information has to be generated are put under sub-plots e.g. herbicides, dose of ferilizers etc.. While using any experimental designs some points should be carefully considered:

1. Are the experimental units clearly defined?

2. Has randomization been applied correctly?

3. Is the presence of controls appropriately accounted for in the analysis?

4. Are blocking units appropriately accounted for during data analysis?

5. Is the experiment independently repeated in space or time?

Some appropriate action needs to be taken during data analysis while having some doubts in answering these questions. In the following sections some basic concepts regarding experimental design are considered for discussion.

Experimental unit: The experimental unit is the smallest unit to which the process to allocate the treatment in randomized order is applied. For example, if a pot is receiving same dose of fertilizer, the experimental unit is the pot and not each of the five plants. Experimental units should be independently chosen; otherwise any casual event influencing one of them will also influence all the others, making the treatment effect indistinguishable from background noise.

Replicates: Experiments may need replicates. In this case, it is important to recognize the difference between a true replicate and a pseudoreplicate. We can talk about true replicates when the randomization process to allocate the treatment is applied to several independent experimental units. This must be clearly distinguished from pseudoreplication (sub-sampling), where several measurements are taken on a single sample and thus they are not independent, because they share the same sample. Some typical examples would be: (i) spraying a pot with five plants (as above) and measuring separately the weight of each plant, (ii) treating one soil sample with one herbicide and making four measurements of concentration on four subsamples of the same soil, (iii) collecting one soil sample from a field plot and repeating four times the same chemical analysis. In all the above cases, the treatments are applied only to one unit (pot or soil sample) and there are no true replicates, no matter how often the unit is sub-sampled. Pseudoreplication should never be mistaken for true replication, even in the case of laboratory experiments.

Randomization: Another basic aspect of experimental design relates to randomization, which justifies the use of a model with independent errors and avoids biased estimates of effect sizes. It should be clear that randomization is performed correctly in any kind of experiments, including controlled environment studies. However, many classical designs (randomized complete blocks, split plot, etc.) constrain the complete randomization of the experiment, which is not a problem, as long as constraints are taken into account in the analysis, including the proper terms (blocks, rows, columns, etc.) in the ANOVA or other models used for analysis.

Control: When including a control in the analysis, it is very important to make sure that variances are homogeneous. Indeed, the control may often show a very high (or very low) variance with respect to all the other treatments, which may lead to biased results, lower efficiency or the unnecessary adoption of a stabilizing transformation. In this case, the control should preferably be erased from data analysis and, if the ranges of data clearly do not overlap, it may be acceptable to conclude that control and treatments differ, without a formal test of significance. A more advanced solution may be to fit a mixed model with heterogeneous variances between control and treatments.

Blocking units: Blocking techniques are often used to control the contribution of nuisance factors to error variability. Several forms of blocking have been available for a long time (complete blocks, Latin square, incomplete blocks, rows and columns; see e.g Cochran & Cox, 1957; John & Williams, 1995). If some of those forms of blocking are introduced into the experiment, this should be clearly mentioned and justified. In the case of a split-plot design, the experimental layout for all error strata (main and subplots), should be explained as different forms of blocking may be introduced in each stratum. For example, subplots can be completely randomized or laid out according to an incomplete block design. Similarly, main plots may be completely randomized, or laid out in complete blocks or in rows and columns.

Repeated measures and repeated experiments: In some cases, the same experimental unit is repeatedly measured with respect to a factor of interest (generally time or space). Some examples are: (i) weekly measurements of height to estimate growth curves, (ii) sequential harvests of perennial crops, (iii) daily recording the number of germinated seeds on a Petri dish, (iv) collecting samples at different depths on the same plot. These examples lead to the concept of repeated measures or longitudinal data (when measurements are taken over time). The concept is similar to subsampling, with the major difference that the repeated factor (time or space) is not randomly selected within the experimental unit, but it is ordered along a temporal or spatial metric. Therefore, observational units are not independent, but they may exhibit some autocorrelation pattern, that is also known as “serial correlation”. Similar to the concept of repeated measures, we can mention the concept of repeated experiments, when the whole experiment is repeated in a different time or place. This does not pose relevant problems in terms of data analysis.

2. Appropriate use of traditional techniques

ANOVA and regression techniques are very well established among weed scientists, but in many experiences they are not always used appropriately. It is necessary that all the following issues should be appropriately considered before applying these techniques:

1. Check for the basic assumptions before performing an ANOVA and/or regression?

2. If necessary, take the appropriate correcting measures?

The following part of this section is aimed to provide solution to these problems.

Checking for basic assumptions (Outliers)

It should never be forgotten that ANOVA and regression (as well as any other type of linear model) make assumptions and it is necessary to ensure that these assumptions are satisfied. Without this basic check, it is not possible to guarantee that results are reliable and unbiased. The three main distributional assumptions that should always be verified relate to normality, homogeneity of variances (homoscedasticity) and independence of experimental errors. Possible outliers should also be inspected, as they may adversely affect parameter estimation and inference. The lack of independence in weed science may arise when observations are grouped, such as in case of pseudoreplication, repeated measures, split-plot designs and so on.

The lack of normality and homoscedasticity, as well as the presence of outliers, affect the distribution of residuals and thus a graphical inspection of these latter may be crucial. In the common case of fixed effects models, a graph of "residuals vs. predicted" and a quantile–quantile (Q–Q) plot may suffice, even though more advanced methods exist, that are thoroughly discussed, for example, in Faraway (2004). In any case, authors should always state whether basic assumptions were carefully checked and how. This is particularly important (i) with counts and proportions based on a small number of replicates, which cannot be assumed as normally distributed and (ii) when results differ by more than an order of magnitude, so that their variances may not be homogeneous.

Transformation: The simplest action is to adopt a suitable transformation of the response variable, chosen by theoretical considerations or previous experience. Instead of making an arbitrary selection, authors may consider several families of transformations, such as the Box and Cox (1964) family. Even though stabilizing transformations represent a useful and mathematically simple solution to non-normality and variance heterogeneity, they may result in several complications during the interpretation and presentation of results. Following are the conditions to perform suitable transformation:

(I) Logarithmic - used when:

- the variances are not equal (heterogeneity of variances)
- standard deviations are proportional to the means (CV's are equal) or
- when the data is positively skewed

Procedure

i) Convert raw data into their logarithms

$$X_i' = \log (X_i) \text{ or } \log (X_i+1)$$

ii) Perform analysis on log data

iii) Convert back into units of the raw data by taking the antilog of the results

(II) Square Root - used usually

- with counts (number of ......) data and
- when the variance is proportional to the mean (i.e., variance increases with increasing size of the mean).

Procedure

i) Convert raw data into square root transformation

$X_i' = \sqrt{(X_i+0.5)}$

ii) Perform analysis on square root data

iii) Convert back into units of the raw data by subtracting .5 and squaring the results

(III) Arcsine - used to normalize data in percentages or proportions whose distribution fits the binomial distribution.

Procedure

1) Convert raw data into arcsine transformations

$p_i' = \text{arcsine}\sqrt{(p_i)}$

where, p_i is percentage or proportion

2) Perform analysis on arcsine data

3) Convert back into units of the raw data by taking the sine of squared the results

3. Multivariate Techniques: A great part of datasets collected by weed scientists are multivariate, in the sense that several variables are measured in each subject. More specifically, the weed flora (vegetation dataset of species abundances in sites or quadrates) in itself is a perfect example of a multivariate entity. Very frequently, the different variables are isolated and analyzed separately; in some cases this approach works well, but in other cases it does not permit insights into possible relationships among variables and key features of interest. As the consequence, multivariate analysis has been used in vegetation research since the 1950s, with the aim of exploring and summarizing very complex datasets. Several examples may also be found in soil science.

Multivariate techniques are very useful in the analysis while dealing with more number of variables. Multivariate data arise in all branches of science, ranging from medical to agriculture, and methods of analyzing this data constitute an increasingly important area of statistics. Analysis through these techniques provides easily interpretable results. A wide variety of multivariate techniques is available. The choice of the most appropriate technique depends on the nature of the data, problem and objectives. Two important multivariate techniques are listed below:

(i) Principal Component Analysis: When the observations are recorded on a number of variables from same objects then sometimes they do not follow the assumption of independence which is considered as most important assumption for applying multiple regression technique. In this case, dependent nature of data restricts us to use multiple regression technique. Other problem with more number of variables is plotting of data altogether. One way to deal with such type of data is to use some data reduction technique such as principal component analysis.

Principal Component Analysis (PCA) is standard technique which converts correlated variables into set of few uncorrelated variables. Thus it reduces a complex data set to a lower dimension to reveal simplified structures that often underlie it and helpful in extracting useful information from huge data sets. This technique aims to transform the observed variables to a new set of variables which are uncorrelated and arranged in decreasing order of importance.

In principal component analysis, if first few components account most of the variation in the original data, then first few components' scores can be utilized in subsequent analysis in place of original variables. Thus, it is often possible to account for most of the variability in the data by first few components, and it is possible to plot the values of first few components score for each individual. Particularly, detection of outliers or clustering of individuals will be easier through this technique. Often, use of principal component analysis reveals grouping of variables which would not found by other means. Also, regression analysis can be carried out using principal components as repressors in place of original variables. This is known as principal component regression.

(ii) Cluster Analysis: Cluster analysis is a very powerful technique and it is relatively easy to apply. Thus, it is very commonly used in several branches of plant science, for example molecular biology and genetics, and, sometimes, it is considered more exact or precise than ordination techniques (e.g. PCA), that, by retaining a reduced set of new variables (or components), result in a loss of information. Note, however, that classification methods also produce a loss of information when forming the clusters, because all agglomerative clustering algorithms distort the relationships between individuals by changing the definition of the original distances (or similarities) by the choice of the aggregation method. It is recommended that one should be very careful while using these techniques.

It is a technique used for combining observations into groups such that:

(a) Each group is homogenous or compact with respect to certain characteristics i.e. observations in each group are similar to each other.

(b) Each group should be different from each other groups with respect to the characteristics i.e. observations of one group should be different from the observations of other groups.

Steps in Cluster analysis

The objective of cluster analysis is to group observations into clusters such that each cluster is as homogenous as possible with respect to the clustering variables. The various steps in cluster analysis

(i) Select a measure of similarity.
(ii) Decision is to be made on the type of clustering technique to be used.
(iii) Type of clustering method for the selected technique is selected.
(iv) Decision regarding the number of clusters.
(v) Cluster solution is interpreted.

No generalization about cluster analysis is possible as a vast number of clustering methods have been developed in several different fields with different definitions of clusters and similarities. There are many kinds of clusters namely:

- Disjoint cluster where every object appears in single cluster.
- Hierarchical clusters where one cluster can be completely contained in another cluster, but no other kind of overlap is permitted.
- Overlapping clusters.
- Fuzzy clusters, defined by a probability of membership of each object in one cluster.

A measure of closeness is required to form simple group structures from complex data set which is called similarity measure. A great deal of subjectivity is involved in the choice of similarity measures.

4. Forecasting models in agriculture

Forecasting technique is an essential component of research in agriculture and allied sciences including soil science and useful for the policy makers, agricultural scientists and farmers to plan their operations. Forecasting is the process of making statements about phenomena whose actual outcomes have not been observed. An example might be estimation of yield of a particular crop in the mid of that season. Prediction is a similar, but more general term. Both might refer to formal statistical methods employing time series, cross-sectional data, or alternatively to less formal judgmental methods. Forecasting methods in agriculture include forecasting of production/yield/area of crops and forewarning of incidence of crop pests and diseases. It is very useful for policy makers, agricultural scientists and farmers to plan their operations. In agriculture, reliable and timely forecast of crop production are required for various policy decision relating to storage, distribution, pricing, marketing, import-export etc. Many statistical models are used for forecasting purposes. Some of these are listed below:

(i) Linear regression model: It is the simple statistical model which is used for forecasting purposes. It measures the average relationship between two or more variables. Those variables which are used for prediction are called explanatory variables and which is to be predicted, is called dependent variable. The model is of the form

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots\ldots\ldots + \beta_p X_p + e$,

where, β_i's are regression coefficients, X_i's are independent/explanatory variables, Y variable to forecast, e random error.

(ii) Non-Linear regression models: These models can be used for forecasting when the response variable is qualitative in nature. Many situations exists where the response variable is qualitative for example occurrence/non-occurrence or low/high incidence of a disease or pest etc.. Logistic regression is widely used method in these situations. This model is used to describe the relationship of several independent variables to the binary dependent variable. The model is of form

$$P(Y = 1) = \frac{1}{1 + \exp(-L)} + e$$

where, $L = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_n X_n$

X_1 , X_2 , X_3 ,…X_n are weather variables/weather indices, e = random error

Under this model Forecast / Prediction rule can be defined as: If $P<0.5$, then the probability of epidemic occurrence will be minimal or If $P \geq 0.5$, then there is more chance of occurrence of epidemic.

5. Spatial data analysis: Geostatistical tools

Geostatistics studies spatial variability of regionalized variables. Regionalized variables are variables that have an attribute value and a location in a two or three dimensional space. Geostatistics are also described sometimes as a set of techniques/tools used to analyze and predict values of a variable distributed in space or in time. With geostatistics, it is possible to explore our sample data, construct variogram models and produce interpolated surfaces. A point interpolation (also known as gridding) performs an interpolation on randomly distributed point values and returns regularly distributed point values. The input for point interpolation is mostly a point map with the domain type value or a point map with domain type class or identifier that is linked to an attribute table, in which the attribute values are stored in a column with domain type value. The output of a point interpolation is a raster map in which each pixel has a value calculated by an interpolation on the input point values.

An alternative to the above mentioned straightforward deterministic methods is kriging. Kriging is a statistical method based on the theory of regionalized variables. Kriging approach takes into account the spatial dependence between different points in a surface. Kriging, which is a weighted average of observed phenomenon, is the only estimator that gives an estimate of the variance. Furthermore, kriging ensures that the estimation is unbiased and has minimum variance. It has four steps: (1) Transformation of data to ensure normality; (2) calculation of semivariogram which describes the variation between data points separated by a certain distance; (3) fitting a model to the semivariogram; and (4) estimate the response on the rest of the field using parameters from the semivariogram model. Some commonly used kriging methods are: Ordinary Kriging, Simple Kriging, Indicator Kriging, Universal Kriging, Anisotropic Kriging and Co-Kriging.

References

- Box, G.E.P., and Cox, D.R. (1964). An analysis of transformations. *Journal of the Royal Statistical Society* B-26, 211–252.
- Cochran, W.G. and Cox, G.M. (1957). Experimental Designs, 2nd edn. John Wiley & Sons, New York, USA.
- John, J.A. and Williams, E.R. (1995). Cyclic and Computer Generated Designs. Chapman & Hall, London, UK.
- Faraway J.J. (2004). Linear Models with R. Chapman & Hall ⁄ CRC, Boca Raton, FL, USA.

Biological control of problematic invasive weed Parthenium, water hyacinth and *Salivina*

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Introduction

Biological control of weed is the intentional manipulation of natural enemies by man for the purpose of controlling harmful weeds. Biological control does not advocate complete eradication of the unwanted organism, but rather mean to maintain its population at lower than average that would occur in the absence of the bio-control agent. Insects, fungi, nematodes, snails, slugs, competitive plants and microorganism may be bio-control agents for Parthenium. So far, insects have received maximum attention in biological control of Parthenium followed by competitive plants and pathogens.

Singh (1997) considered use of biological control agents and exploitation of competitive plants, the most economic and practical way of managing Parthenium. During last few years much emphasis has been given to control Parthenium through various biological agents like pathogens and competitive plants. In past, attempts were made to review work on biological control of Parthenium in context to India, Australia and global situations (Singh 1989, 1997, Sushilkumar 1993, Sushilkumar and Bhan 1995, McFadyan, 1985, 1992; Evans, 1997; Dhileepan, 2009).

Parthenium hysterophorus L., (Asteraceae) is a weed of global significance occurring in many countries of Asia (Bangladesh, India, Israel, Pakistan, Nepal, southern China, Sri Lanka, Taiwan and Vietnam), Africa (Ethiopia, Kenya, Madagascar, Mozambique, South Africa, Somalia, Swaziland and Zimbabwe), Australia and the Pacific (New Caledonia, Papua New Guinea, Seychelles and Vanuatu (Dhileepan, 2009). It has been well established that Parthenium is responsible for severe human and animal health related problems, agricultural losses besides serious environmental problems like loss of biodiversity (Sushilkumar and Varshney, 2007). The weed was first reported in India in 1955 (Rao, 1956) and now occurs throughout the country (Yaduraju *et al*. 2005) in about 35 million hectares of land (Sushilkumar and Varsheny 2010).

Out of 8 lakh hectares of freshwater available in India for pisciculture, about 40% is rendered unsuitable for fish production because of invasion by aquatic weeds (Mitra, 1964). Out of about 140 aquatic weeds, water hyacinth (*Eichhornia crassipes* Mart (Solmns.) has been considered one of the most problematic weeds in India followed by

Hydrilla vercillata. Water hyacinth is a free-floating, annual or perennial aquatic plant of Brazilian origin. Water hyacinth was introduced into India as an ornamental plant in West Bengal in early 20th century but by now it has spread in all types of fresh water bodies throughout the country. This weed is estimated to cover over 0.4 million hectares of water surface. Water hyacinth is the most gregariously growing aquatic weed in 5 tropical and sub-tropical nations of the world including India. It has been categorized as one of the worst 10 weeds of the world (Holm *et al.,* 1991).It has been recorded from all types of water bodies like ponds, canals and drainages in all most all the cities including major river systems like Ganga, Cauvery, Brahmaputra *etc.* It was reported that evapotranspiration through water hyacinth is 3-4 times higher than evaporation from an open water surface. It is estimated that 25-30% of the total utilizable water in India is currently infested with water hyacinth while in the state of Assam, West Bengal, Orissa and Bihar, it is 40%. It affects irrigation, navigation and hydro-electric generation besides being responsible for drastic reduction of fish production and increase in diseases caused by mosquitoes. A great problem of water hyacinth was faced by the managers of Public Health Services) & Ethics, Utilities & Services Company Ltd. (JUSCO), Jamshedpur (Jharkhand) in January to July 2010. In 2009 and 2010, the two river leading towards Jamshedpur namely Kharkai and Subamarekha were totally blocked with water hyacinth in a course of almost 14 km. The managers of Tata Iron and Steel Company (TISCO) of the city faced great problem in water supply to the TISCO plant from the river owing to heavy water hyacinth infestation during 2004.

The water fern (*Salvinia molesta*) has become a big problem in Kerala. Most of the water canals and streams became infested with water fern. This weed has also entered into paddy fields along with flooded water. A bioagent *Cyrtobagous salvinae* was introduced to control *Salvinia* in Kerala

(A) Biological control of Parthenium using insects and competitive plants

Biological control has been considered one of the most effctive approaches against Parthenium in waste land, pasture, orchards and forest ecosystems by introduction of bioagent. In past, attempts have been made to review the work on biological control of Parthenium in context to India and, Australia (Sushilkumar 1993, Sushilkumar and Varsheny, 2007[a]).

(a) By indigenous insects: So far, none of indigenous insect was found host specific (Kumar *et al*., 1979, Sushilkumar, 2005) in spite many reports (Singh, 1997). A cerembycid *Nupserha* sp. was. found doing widespread damage (5-95%) to Parthenium (Sushilkumar, 1998, 2005) but this species was found to attack on sunflower and *Xanthium strumarium* also.

(b) By exotic insects: Attempts were initiated in India in 1983 at Bangalore to import host specific bioagents from the native home of Parthenium based on well documented success in Australia after their introduction. Three insects namely defoliating beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae), the flower feeding weevil *Smicronyx lutulentus* Dietz (Coleoptera: Curculionidiae) and the stem boring moth *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) were imported in India (Singh 1993). *S. lutulentus* could not be multiplied in the laboratory while *E. strenuana* was found to complete its life cycle on a oil seed crop niger (*Guizotia abyssinica* L.(Asteraceae) hence its culture was destroyed (Jayanth 1987) in spite of the fact that this insect was considered to be a potential biocontrol agent in Australia (Mcfadyen 1985). Study of host specificity and damage potential revealed *Zygogramma bicolorata*, a safe bioagent (Jayanth and Visalakshy, 1994).

After first released of *Z. bicolorata* in Bangalore region in 1984 (Jayanth, 1987), due to deliberate introductions and natural spread, the bioagent has widely spread across the country (Sushilkumar, 2005; Sushilkumar and Varsheny, 2007[a]). Incidence of *Z. bicolorata* has been recorded mild to heavy in most of the states wherever it has been introduced. In India, *Z. bicolorata* has well established in Karnataka, Maharashtra, Madhya Pradesh, Bihar, Delhi, Haryana, lower hills of Himachal Pradesh, Punjab, Uttar Pradesh and lower hills of Uttrankhand while it has medium established in Andhra Pradesh, Orissa, Rajasthan Tamil Nadu, upper hills of Uttrakhand and Himachal Pradesh. The bioagent spread and establishment has been noticed low in Assam, Jharkhand, Gujrat, Kerala and West Bengal. *Z. bicolorata* has nil to negligible spread in Andman &Nicobar, Arunachal Pradesh, Goa, Meghalaya, Mizoram, Manipur., Sikkim, Goa etc. In Tamil Nadu and Andhra Pradesh *Z. bicolorata* has been well spread only in western and northern and north and west regions, respectively. In general, the incidence and spread of *Z. bicolorata* was recorded very limited in all the coastal regions besides cold and hot deserts of India (Sushilkumar and Varshney, 2010).

This could be possible because of increased biological control efforts by Directorate of Weed Science Research during last 10 years by sending the beetles by postal services to almost all the Krishi Vigyan Kendras (KVKs) and All India Coordinated Research Project on Weed control (AICRPWC), located in each district and states of India, respectively. This widespread occurrence of *Z. bicolorata* in India is in contrast to earlier predictions (Jayanth and Bali, 1993), which suggested that *Z. bicolorata* would not be suitable for hot regions of central and west India and cold regions of Himachal Pradesh, Uttrakhand, Punjab and Western Uttar Pradesh. In India, establishment of *Z. bicolorata* has been reported from many states corresponding to the level of infestation (Sushilkumar and Varshney, 2010).

Ecological benefit in the form of re-germination of lost vegetation and hence saving of loss of biodiversity has been reported (Sushilkumar 2005). A study was made at Jabalpur by Sushilkumar (2006) to find the economic benefit by Z. *bicolorata* after release of 6000, 7500, 7500 beetles in the year 2000, 2001 and 2002, respectively. Based on the herbicide cost which would have incurred in the area controlled by beetle, the net economic return by third year was calculated 135% per annum, which increased to 608, 2700, and 12150% per annum for single application of herbicides by 4th, 5th and 6th years, respectively. The total benefits by the biological control in six years had been Rs 62.34 million; 15585% benefit over initial investment (Sushilkumar, 2006).

(c) Biological management of Parthenium by competitive replacement through plants

After reports of Singh (1983) that *Cassia sericea* (= *C. uniflora*) may be used in biological management of Parthenium, the efforts were made to control Parthenium by deliberate use in Mysore, Dharwad and Banguluru (Mahadevappa, 1997, 1999). In Jabalpur (M.P.,India), replacement of Parthenium by marigold showed encouraging results and this practice was also advocated for Parthenium suppression (Sushil Kumar 2005).

In a nationwide survey under coordinated project sponsored by Department of Biotechnology (DBT), India, plant species namely *Xanthium strumarium*, *Tephrosia purpurea*, *Achyranthes aspera*, *Vitex negundo*, *Cassia sericea*, *Cassia tora*, *Cassia* spp. and *Cannabis sativa* were found to be competitive against *P. hysterophorus*. *Xanthium. strumarium*, *T. purpurea*, *Cassia sericea* and *Cassia tora* were found most abundant species in waste land, community land and along the road and railway track sides. After considering the plant characteristics of all above species, *C. tora* was advocated and demonstrated (Yaduraju *et a*l. 2005; Sushilkumar 2005).

(B) Biological control of Water hyacinth

(i) Biological management of water hyacinth using insects

After wide spread of water hyacinth in India, surveys were made to find out effective and host specific bioagents. Many indigenous insect species were recorded feeding on water hyacinth from all over India but none of the species was found host specific hence it was concluded that indigenous insect species use water hyacinth as an alternate host and are not of much use. Therefore, Singh (1989) advocated the use of proven exotic insects under classical biological control programme. Sushilkumar and Ray (2007) studied the development of *Spodoptera litura* on 24 weed plants. Out of 24 weed plants tested, high consumption of leaves was recorded on eight species among which *Eichhornia crassipes* was one of them.

Neochetina spp. was introduced first in India at Bangalore for controlling water hyacinth, in 1982-1983. Between February, and July1984, a total of 7 releases consisting of 1700 weevils was made into a 20-ha tank fully infested with water hyacinth. Thereafter, releases of these bioagent were made throughout India by several workers. The effect and impact of these weevils have been expressed in many ways but reduction in size and density and clearing of water bodies in due course after release are the frequently observed effects. Up to 95% control in a 20 ha tank in Bangalore within 32 months of release by *N. eichhorniae* and 90% control in another 20 ha tank by *N. bruchi* have been reported (Jayanth, 1988). The weevils were in fact established in 4-6 months of release in all the tanks. In the 344 ha Bellandur tank (Bangalore) only *N. eichhorniae* was released but *N. bruchi* entered the tank through an irrigation channel from Agram tank by traveling about 2 km. Similarly in Varthuru tank (Bangalore) where weevils were not released both the species entered this tank through an irrigation channel from Bellandur tank 7 km away (Jayanth 1988).

In Jabalpur, successful biological control of water hyacinth by *Neochetina* spp was achieved in 5 ponds which were badly infested with the water hyacinth (Sushilkumar 2005[b]; Sushilkumar and Varshney, 2007[b]). *Neochetina* spp. was found to control water hyacinth in cycles depending on the intensity and duration of infestation in the water body. In general, weevils may take about 18 to 48 months to achieve first cycle of control after initial release but, this depend on the inoculation load. In general, early control of water hyacinth is dependent on more number of releases of bioagent. Second and subsequent cycles of control may occur in 9-24 months depending on the population build-up of the beetle. At Jabalpur, many ponds have been cleared by the *Neochtina* spp. but a pond of about 3 hectares was controlled by 100% after 3-5 waves of collapse (Sushilkumar and Varsheny, 2007[b]). After biological control of water hyacinth, other weeds mainly alligator weed (*Alternanthera philoxeroides*), Typha *angusta* and *Ipomoea aquatia* occupied the niche vacated by water hyacinth due to action of *Neochetina* spp. (Sushilkumar and Bhan, 1998). Spectacular success of biological control of water hyacinth was achieved in Loktak lake (286 sq km) in Manipur in three years after weevil's release (Jayanth and Visalakshy, 1989) and in north India (Mishra *et al* 1989). In Bangalore (Jayanth, 1996), Hyderabad (Gupta *et al*. 1993), Jabalpur (Sushilkumar and Varsheny 2007[b]) and many other towns, water hyacinth was controlled in 2-4 years by the *Neochtina* spp. Ghassan and Kadam (2002) found that *Neochetina* spp. have potential to suppress water hyacinth in Mahrashtra.

Shenhmar *et al* (2004) introduced *N. eichhorniae, N. bruchi* and *O. tenebrantis* in Punjab, for the control of water hyacinth in a pond at Landhowal near Ludhiana in 1992. By 1995, weevils were well established and controlled the water hyacinth in the pond. In 2002, from these ponds, the weevils were collected and further released in 4 ponds each at Hadiabad near Phagwara, Goraya, Nawanshahar and Hoshiarpur. However, the weevils were recovered only from Hadiabad. Sushilkumar and Varsheny (2007[b]) described the successful control of water haycienth in 5 ponds at Jabalpur (Madhya Pradesh, India). Seven year study revealed impact of these insects in suppression of water hyacinth.

Weevils may be released at any time of year in water hyacinth infested water bodies but the optimal time for initial releases, especially in tanks and lakes is after the commencement of rains. Water bodies, which are likely to dry during summer season, should be avoided for release. In rivers and irrigation canals, release should be made after monsoon to avoid water hyacinth mat carried away by flooded water (Sushilkumar, 2005[b]). Although, the weevils are very good colonizers but it is suggested that at least 3000 weevils may be released per hectare of weed mat, divided in many sections according to the size of water hyacinth infestation and in each section 50-100 weevils can be scattered over the weed mat. By this way, bioagent will be established quickly and homogenously in the water body in question. More releases mean quicker establishment of the bioagent therefore, better control (Sushilkumar, 2005[b]).

Integration of biological and chemical/plant product for water hyacinth management

It has been observed that bioagent take long time to control water hyacinth if used alone through inoculative releases. However, the time of collapse of one cycle by bioagent can be reduced drastically by treating 10-25% area of the water body with a herbicide like glyphosate, 2,4-D or paraquat. Biological and chemical integration is effective to control water hyacinth in shorter time as well to help to reduce the chemical load in the aquatic body. Bioagent can also be used along with mycoherbicide or with plant product/extracts having ability to kill water hyacinth. Gnanavel and Kathiresan (2007[c]) achieved control in shorter time by integration of bio-control agents *Neochetina* spp. with plant product of *Coleus amboinicus/aromaticus.* Kathiresan (2009) argued the feasibility and sustainability of concept of Integrated Farm Management (IFM) for small-farm holdings which may serves as a tool for linking environmental safety with weed control besides offering scope for conservation of agro-biodiversity. Sushilkumar and Viswakarma (2006) demonstrated the reduction in time to achieve one cycle of control by integration of *Neochetina* spp. and spraying of herbicides in 10-15% area. About 1000 weevils were released in May 2003 as an inoculation over an area of 3000 m^2 in an one-hectare pond of a village, severely infested with water hyacinth for more than 20 years. Two doses of recommended herbicides namely 2,4-D (1.5 and 2.0 kg/ha), glyphosate (2.0 and 2.5 kg/ha) and paraquat (0.7 and 1.0 kg/ha) were applied in rest of the area in three replication in the second fortnight of June 2003. Results revealed that 2,4-D @ 2.0 kg/ha proved the best herbicide to control water hyacinth at 21 DAA while glyphosate and paraquat were at par with each other. The pond was again fully infested by the mid September 2003 due to re-growth, which was highest in paraquat treated area, followed by 2,4-D and glyphosate. The achieving of two cycles of control within a period of 20 month after initial release of weevils could be possible due to integration of herbicide with the bioagent, which would otherwise have taken minimum 20-36 month by the bioagent alone to control one wave of water hyacinth.

(ii) Biological management of water hyacinth through allelochemicals

The concept that some crop plants may be allelopathic to certain weeds is receiving increased attention in the search for weed control strategies. Kauraw and Bhan,(1994) demonstrated the effect of dry *Cassytha* powder (0.5, 1.0, 1.5 and 2 per cent respectively) on water hyacinth plants grown in plastic tubs. All the treatments showed reduction in number of leaves and biomass in treated as compared to untreated check. *Cassytha* powder (1 to 2% w/v) could completely kill the leaves and reduced the biomass Chaturvedi and Sharma (1998) did not find allelopathic effect of litter extract of *Lantana camara* on water hyacinth. Inhibitory effect of Parthenium (*Parthenium hysterophorus L.*) leaf residue on growth of water hyacinth was established by Pandey *et al.(*1993). Further work also established the potential of allelochemicals on water hyacinth in particular and on other aquatic weeds in general (Pandey, 1996[a], 1996[b]). Kathiresan (2005) reported that dried powder of the leaves of *Coleus amboinicus* L. at 40 g/l as a water suspension killed water hyacinth within 24 h reducing the fresh weight by 80.72% and the dry weight by 75.63% within one week.

(C) Biological management of weeds using microbes

Microbes as herbicides in weed management

Microherbicides are those which use microorganisms and their secondary metabolites for the management of weeds. In agriculture fields weed management through chemical herbicides, create spray drift hazards and adversely affect the environment. Besides, pesticide residues (herbicides) in food commodities, directly or indirectly affect human health. These lead to the search for an alternate method of weed management, which is eco-friendly. Use of microbes is the cheapest and effective eco-friendly means for addressing the prevalent weed problem in agriculture and other ecosystems. The concept of deliberately using microorganisms or their secondary metabolites to control weeds constitutes the fundamental basis of biological management of weeds. Biological weed management involves two strategies: the classical or inoculative strategy, and the inundative or bioherbicide strategy. In the inoculative approach, an exotic biocontrol agent is introduced in an infested area.

Advantages and limitations of microbial herbicides

The utilization of microherbicides in weed management offers many advantages including the following

1. Good degree of specificity for the target weeds under ideal conditions
2. No effects on non-target organisms / non host plants
3. Remote chances of resistance development by the weeds
4. Ecofriendly, as it forms a part the natural ecosystem. Also no residual toxicity in the environment
5. Self sustaining and self spreading
6. Highly suitable for the control of weeds in no man’s land and ecosystems like forest, grassland, aquatic bodies, and non cropped areas

There have been several successful commercial microherbicide products available in the market in the developed countries. However despite a vast biodiversity available in the midst of ecological and climatic variations in our country, there has been no success in the utilization indigenous microbes for the management of weeds in India.

Limitations of using microbial herbicides

The disadvantages or the problems in the use of microherbicides include

1. Not available for all major weeds of a crop and hence there is no complete weed management in a cropping system.
2. Host specificity is not always perfect except for some rust fungi
3. Greater dependency upon weather factors for the best performance. Some successful pathogens like
4. Slow rate of control and sometimes requires constant monitoring of the population of the pathogens
5. Unavailability in the market at times of need
6. Indiscriminate use of pesticides destroys the natural bioagents
7. Lengthy registration process may be
8. Lack of quality control laws.

Criteria of microbe to be ideal microbial herbicides

1. Should be highly host specific
2. Be easy and cheap to culture and mass produce
3. Should establish with ease in the new environment
4. Should be highly competitive
5. Should not be allergic/toxic to humans or cattles

Types of microbial herbicides

Microbial agents (fungi, bacteria, nematodes etc.) or products (microbial toxins etc.) derived from them can be used as microherbicides for the management of the weeds. *Puccinia snaveolens*, a rust fungus was the first pathogen to have been used for the management of *Ciruum argense*. Since then, several micro organisms have been thoroughly evaluated and developed as microbial herbicides

Phytotoxic metabolites

The use of phytotoxins of both pathogenic as well as non-pathogenic fungi have recently attracted the weed biocontrol workers all over the world. Several toxins have been isolated, identified and screened for their herbicidal potential. Some of these microbial products have also been commercialised as potent herbicide. The use of these secondary metabolites have some advantages like longer shelf life, more predictable and uniform results and no danger of destroying non-target organisms and no residual toxicity on land or water. These characters make them more attractable, both commercially and technologically, when compared to the living products other synthetic chemical herbicides. Similarly toxic metabolites from non pathogenic fungi again have two additional advantages over pathogens. Firstly, they are relatively easily cultured as compared to the pathogens. Secondly, they produce a multitude of biotic products, some of them are relatively simple in structure and therefore, might be economically synthesised. The structure of naturally occurring phytotoxins may also serve as the basis for the synthesis and development of new synthetic herbicides. In addition they also serve as a source of new site of action.

Commercial bioherbicides

Commercial bioherbicides first appeared in the market in USA in early 1980s with the release of the products DeviSevral microbes and their metabolites have been successfully patented and commercialized in various well-developed countries like USA, Canada, UK etc.

Successful examples

Commercial Product	Microbial agent	Target weed	Country of origin	Description
DeVine ®	*Phytophthora palmivora*	*Morrenia odorata*	USA	• Ist bioherbicide released commercially in 1981 • Used in citrus gardens • About 96% control within 10-weeks
Collego ®	*Colletotrichum gloiosporioides* f. p. *aeschynomene*	*Aeschynomene virginica* (Northern Jointvetch)	USA	• Released in 1982 • For rice and soybean • 85% >control
LuboaII ®	*C. gloiosporioides* f. sp. *cuscutae*	*Cuscuta* spp.	China	• Being used in flax, lentil, strawberries • 80% > control
BioMal ®	*C. gloiosporioides* f. sp. *malvae*	*Malva pusilla* (Round leave mallow)	USA/ Canada	• In flax, lentil, strawberries • This weed can not be controlled easily by chemical herbicides
ABG5003	*Cercospora rodmani*	*Eichhornia crassipes* (Water hyacinth	U.S.A.	• High (20-90%) deterioration of weed biomass • Needs some technical advancements for effective control
Camperico ®	*Xanthomonas campestris*	*Poa annua* (winter grass)	Japan	• Used in turf and golf greens of *Cynodon dactylon, Zoysia matrella and Poa pratensis.* • Bioagent is applied after moving of lawn (wound inoculation)
Gluphosina	*Streptomyces*	Non	Germe	• For broad

te	*viridochromo genes*	selective	ny	range of weed control in non cropped areas

Biological control of *Parthenium*, waterhyacinth and *Salvinia* using microbial herbicides

Many *Fusarium* spp. have been tried for effective control of several weeds. *Fusarium pallidoroseum* is another important soil borne pathogen reported to be a potential mycoherbicidal agent against *Parthenium. F. solani* is also reported as potential pathogen and responsible for significant damage to the weed *Parthenium*. *Sclerotinia sclerotiorum* appears to be among the most non-specific, omnivorous and successful of soil borne plant pathogen and it is reported to cause severe stem rot in *Parthenium*. *Rhizoctonia solani* is a destructive, versatile, widespread, noxious soil borne pathogen incites severe diseases in many weeds including *Parthenium.* It has high competitive saprophytic ability in soil but required sufficient food base prior to colonization of host plants.

Water hyacinth (*Eichhornia crassipes*) is one of the most predominant, persistent and troublesome aquatic weed. Among different control methods available, biological method using native pathogens is the most viable and environmentally safe method. The success of the host specific fungi *Cercospora rodmanii* in controlling water hyacinth greatly stimulated interest in the management of this weed using fungal pathogens. Abbot laboratory of USA developed an experimental formulation of *C. rodmanii*, named ABG-5003 against *E. crassipes*.

The current paper discusses the isolation of some common fungi naturally occurring on water hyacinth and testing their pathogenic potential, in order to develop an effective biocontrol agent for the management of water hyacinth. Three fungal pathogens, *viz*., *Fusarium oxysporum*, *Curvularia lunata* and *Alternaria alternata* were isolated and found effective in this laboratory at DWSR, Jabalpur. Efficacy studies of the pathogens were done by inoculating water hyacinth plants, either directly or after creating wounds. Results indicated that artificial injury created in the plants by pin pricks before inoculation of the pathogens aided in the entry of the pathogens there by resulting in the better infection of the plants. Among the three pathogens, *Fusarium oxysporum* was found to be the best resulting in the killing of inoculated water hyacinth in about 15 days.

Salvinia molesta is an aquatic fern of origin in south Eastern Brazil. It has spread to many parts of Asia, Africa and Australia. The species name itself indicates the troublesome nature of the weed (‘molest’ means troublesome). Once invaded, salvinia spreads fast in the water bodies and form thick mats impeding navigation, clogging water ways and irrigation canals, restricting biodiversity of aquatic flora and fauna as well as adversely affecting fish farming and rice cultivation. Due to the high cost for clearing the salvinia mats from the fields prior to land preparation, many farmers have stopped rice cultivation and left the land fallow. The weed was first observed in Kerala in 1955 in the Veli Lake in Thiruvananthapuram. It spread fast and assumed a pest status by 1964. It was a problem in the entire state, especially in the coastal regions, till it was brought under control by biological method. There were several attempts to cind out an efficient biocontrol host specific fungi against the Salvinia yielding saprophytic *Alternaria* sp. and a parasitic *Spicariopsis* sp.. Howevere none of these organisms proved effective in largescale testing for their bioefficacy. Thus the original hope for a biological control of *Salvinia auriculata* by means of a parasitic fungus still remains a theoretical possibility.

Future prospects of biological control

Biological control is cheap and sustainable approach of weed management. There is still scope of introduction of more bioagents into India from the native place of the weeds. In Australia, about 7 insect species have been introduced from the Mexicao against Parthenium, out of which some doing good work against Parthenium. Such proven bioagent should also be introduced into India. Likewise, five insects species have been introduced against water hyacienth in Australia. More concentrated efforts are required to introduce more bioagents into India.

Microorganisms are one of the important functional bio-groups of any ecosystem. They incite variety of diseases in the weeds. Some of them are pre and post emergence, seedling mortality, stem, leaf, inflorescence, bud or seed rot etc. They show a wide range of parasitism and responsible for enormous losses in the plant productivity. However, unfortunately there potential have yet not been fully utilized for the welfare of the human beings. Advances of fermentation and formulation technology of plant pathogens used as bioherbicides are needed to improve the cost-effectiveness and industrial production of these biological weed control agents. Experience obtained with the two commercially developed mycoherbicides indicates that opportunities exist for improvements in the capacity of a fungus to yield spores in submerged fermentation or to tolerate adverse drying procedures. Techniques such as genetic engineering may allow changes in the genome of fungal or bacterial plant pathogens to be brought out that could result in an increase of their favourable properties when used as bioherbicides. Isolation of the genetic determinants of virulence, specificity, sporulation capacity, toxin production, and tolerance to climatic stresses as well as their transfer from pathogen to pathogen appear now quite promising. Thus, ample opportunities are exists to exploit the microorganisms for effective, safer and cheaper arrangement of the weeds. Bioherbicides should not be viewed as a total replacement for chemical herbicides but rather as complementary tactics in integrated weed management. Their integration with the routine management strategies may be highly useful in reducing the doses of the chemical herbicides and also improve the effectiveness of the management system.

References

- Aneja KR, Kaur M and Sharma AB. 1994. Leaf-spot disease of *Parthenium hysterophorus,* a new disease record. *National Academy of Science Letters* **17**: 179-180.
- Aneja KR, Srinvas B and Kaur M. 1993. Evaluation of *Fusarium chlamydosporum* as a biocontrol agent of water hyacinth (*Eichhornia crassipes*) (Mart.) Solms. In: *Integrated weed management for sustainable agriculture*. Proceedings of Indian Society of Weed Science International Symposium, Hisar, India, 18-20 November 1993.
- Babu RM, Sajeena A, Seetharaman K, Ebenezar EG, Raja AS, Biji KR and Prakash MS.2003[a]. Isolation and characterization of phytotoxic substance from *Alternaria alternata* - a leaf blight pathogen on *Eichhornia crassipes*. *Journal of Ecobiology*,15(4): 315-318.
- Bhan, VM and Sushilkumar 1996. Eco-friendly approaches in aquatic weed management. 191-201. In : *Proceedings of Workshop on " Aquatic Weeds-problems and management"* held at Bangalore (Karnataka), 5-7 June 1996. (Eds, Varma, C.V..J.) : 191-201.
- Center TD, Dray FA, Jubinsky GP and Grodowitz MJ. 1999. Biological control of water hyacinth under conditions of maintenance management: Can herbicides and insects be integrated? *Environ. Manager*, 23 (2): 241-256.
- Charudattan. R. 2001.Biological control of water hyacinth by using pathogens: opportunities, challenges, and recent developments In: *Biological and integrated control of water hyacienth, Eichhornia crassipes* (Eds. MH Julin, MP Hill, TD Center and Ding Jianqing). ACAR Proceedings 102: 21-28.
- Dhileepan K 2009. Managing *Parthenium hysterophorus* across landscapes: limitations and prospects. In: Management of Invasive Weeds (ed. S Inderjit), 227–260. Invading Nature – Springer Series in Invasion Ecology Vol. 5, Springer Science, Knoxville.
- Evans HC. 1997, *Parthenium hysterophorus*: a review of its weed status and the possibilities for biological control. *Biocontrol News Information*, **18**: 89N,98N
- Gnanavel I and Kathiresan RM. 2007[a]. Integrated biological control of *Eichhornia crassipes* (Mart.) Solms at different growth stages. *Indian Journal of Weed Science*,; 39(1/2): 85-91
- Gnanavel I and Kathiresan RM. 2008 Effect of integrated biological control on *Eichhornia crassipes* (Mart.) Solms and its impact on insect histology. *Crop Research* (Hisar): 35(3): 273-276
- Gopal B and Sharma, KP. 1981. Water hyacinth (*Eichhornia crassipes*) the most troublesome weeds of the world. Hindasia Publisher, New Delhi, 129pp.
- Gupta OP. 2008. *Weedy aquatic plants: their utility, menace and management.* Agrobios, Jaipur: 286.
- Gupta PM, Rao P and Pawar, AD. 1993. Suppression of water hyacinth by *Neochetina* spp. in Hyderabad. *Indian Journal of Plant Protection*, 21: 23-25.
- Holm, LG., Plucknett, DL. Pancho, JV. and Herberger, JP. 1991. The world's worst weeds, Distribution and Biology, Krieger Publishing Company, Malabar, Florida, U.S.A.
- Jayanth KP and Visalakshy GPN. 1994· Dispersal of the *Parthenium* beetle *Zygogramma bicolorata* (Chrysomilidae) in India. *Biological Science & Technology,* **4(3):**363-365.
- Jayanth KP. 1987. Introduction and establishment of *Zygogramma bicolorata* on *Parthenium hysterophorus* at Bangalore, India. *Current Science*, **56:** 310-311.
- Jayanth, K. 1988. Biological control of water hyacinth in India by release of the exotic weevil *Neochetina bruchi*. *Current Science*, 57:(17):968-970
- Jayanth, KP. 1996. Biological control of aquatic weeds in Inda: Progress and prospects. In : *Proceedings of Workshop on " Aquatic Weeds-problems and management"* held at Bangalore (Karnataka), 5-7 June 1996. (Eds, Varma, C.V..J.) : 122-129..
- Jayasurya AHM 2005. Parthenium weed – status and management in Sri Lanka. In: *Proceedings of the Second International Conference on Parthenium Management* (eds TV Ramchandra Prasad, *et al*.), 36–43. University of Agricultural Sciences, Bangalore, India.
- Kannan, C., and Kathiresan, RM. 2002. Herbicidal control of water hyacinth and its impact on fish growth and water quality. *Indian Journal of Weed Science*, 34, 9295.
- Kathiresan R and Dhavabharathi J. 2008. Rice allelopathy for weed management in aquatic

ecosystems. *Allelopathy Journal*, 22(2): 413-416.

- Kathiresan RM. 2009. Integrated farm management for linking environment. *Indian Journal of Agronomy*.; 54(1): 9-14
- Kathiresan RM. 2005. Allelopathy for bio-control of water hyacinth. *Proceedings of the 4th World Congress on Allelopathy- Establishing the Scientific Base*:-Wagga-Wagga New-SouthWales, Australia, 21-26-August, 2005; 64-70 (confirm with text)
- Kauraw LP and Bhan VM. 1994[a]. *Annual Report*, National Research Centre for Weed Science, Jabalpur.
- Kauraw LP and Bhan VM. 1994[b]. Efficacy of *Cassytha* powder to water hyacinth and of marigold to Parthenium population. *Weednews*,1(2): 3-6.
- Kauraw LP, Chile A Bhan VM 1997.. Evaluation of *Fusarium pallidoroseum* (Cooke) Sacc. for the biocontrol of *Parthenium hysterophorus* L. 70-74 *In*: *Proceedings of First International Conference on Parthenium Management*, Dharwad, India, 1997. 2
- Mahadevappa M. 1999. *Parthenium and its management.* University of Agricultural Sciences, Dharwad (Karnataka): 132 .
- Mathur SM, Mathur AN and Bhatt YC. 2005. Water hyacinth - threat to environment or boon in disguise. In : *Aquatic weeds: problems ,control and management*.(eds. S M Mathur, A N Mathur, R K Trivedy, Y C Bhatt, Pramod Mohonot) Himanshu Publications, Udaipur, India :127-138
- McFadyen.R.E. 1992. Biological control against *Parthenium* weed in Australia. *Crop Protection*, **11**:400-407.
- Mishra, MP, Pawar AD and Ram N. 1989. Establishment of exotic phytophagous weevils *Neochetina eichhoriae* Warner and *Neochetina bruchi* Hustache (Coleoptera : Curculionidiae) for the biological control of water hyacinth in north India. *Journal of Advanced Zoology*, 10(2): 136-138.)
- Mitra E. 1964. Contribution to our knowledge of Indian fresh water plants.4. on some aspects of the morphology and anatomical studies on turions *of Hydrilla verticillata* (Linn.F.) Royle. *Journal of Asiatic Society of Science*, 6:17-27.
- Naseema A, Praveena R, Balakrishnan S and Peethambaran C.K. 2001.Management of water hyacinth with fungal pathogens. In : *The BCPC Conference:Weeds,2001*,Volume 1 and Volume-2.Proceedings of an international conference held at the Bright on Hilton-Metropole-Hotel,-Brighton,UK,12-15-November-2001: 263-268.
- Pandey AK, Luka BM, Hasija SK and Rajak RC. 1991. Pathogenicity of some fungi to *Parthenium* –an obnoxious weed in Madhya Pradesh,. *Journal of Biological Control*, **5:** 113-115).
- Pandey D.K 1996[b.] Relative toxicity of allelochemicals to aquatic weeds. *Allepothay Journal, 3*, 229-234.
- Pandey, D K Kauraw, L P, Bhan, V M 1993. Inhibitory effect of parthenium (Parthenium hysterophorus L.) residue on growth of water hyacinth (Eichhornia crassipes Mart Solms) .I. effect of leaf residue. *Journal of Chemical Ecology* (1993). 19(11): 2651-2662
- Pandey, D.K. 1996[a] Phytotoxicity of sesquiterpene lactone parthenin on aquatic weeds. *Journal of Chemical Ecology* 22 (1), 151-160 ...
- Shushilkumar and Bhan VM 1997[a]. Natural *Parthenium* replacement by *Cassia tora* at Jabalpur and adjoining areas of Madhya Pradesh in India, 41-43. In : *Proceedings of First International Confrence on Parthenium Management*, held at Dharwad (Karnataka), 6-8-October 1997 (Eds., M. Mahadevappa and V.C. Patil), **2**
- Singh GB. 1997. Key note address. *In: First International Conference on Parthenium Management* held at Dharwad (Karnataka), 1997, (Eds. M. Mahadevappa and VC Patil), **1**.
- Singh, NP. 1983. Potential biological control of Parthenium hysterophorus L. *Current Science*, 52: 644.
- Singh, S.P. 1997. Perspectives in biological control of *Parthenium* in India.22-32 In: 1-12. *In : Proceedings of First International Conference on Parthenium* sheld at Dharwad (Karnataka), 6-8 October 1997, (Eds. M. Mahadevappa and V.C. Patil), Volume I.
- Singh, SP. 1989. *Biological suppression of weeds*. NCIPM, Faridabad: *Technical Bulletin No*.1. 15-16.
- Sushilkumar and Bhan, VM. 1997[b]. Establishment and dispersal of introduced exotic *Parthenium* controlling bioagent *Zygogramma bicolorata* in relation to ecological factors at Vindhyanagar (Madhya Pradesh, India). *Indian Journal of Ecology*, **25(1):**8-
- Sushilkumar and. Bhan, VM 1998. Role of exotic weevils *Neochetina* spp. in aggravation of alligator weed *Alternanthra philoxeroides* in the pond at Jabalpur, Madhya Pradesh. Paper presented in " *Microbial Biotechnology for sustainable development and Productivity*,"

November, 14-16, 1998, Jabalpur (Madhya Pradesh): Abstract No. AB-36

- Sushilkumar 1997. Biological control of terrestrial weeds in India. 345-374, In: *Eco-friendly Pest Suppression* (Eds. R.D. Gautam and D. Prasad). Westvill Publishing House, New Delhi.
- Sushilkumar 2005. Biological control of Parthenium through Mexican beetle (*Zygogramma bicolorata*). NRCWS, Jabalpur, 85 pp.
- Sushilkumar 2006. Economic benefits in biological control of parthenium by Mexican beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) in India. *Annals of Entomology*, 24(1&2): 75-78.
- Sushilkumar 2010 Biological control of Parthenium in India: status and prospects. *Indian Journal of Weed Science* 41(1&2) : 1-18, 2009.
- Sushilkumar and Bhan VM. 1995.. Parthenium control by insects in India : retrospecs and prospects. *Journal of Applied Zoological Research***, 6 :** 109-112.
- Sushilkumar and Bhan VM. 1996. Development and damage potential of *Zygogrammma bicolorata*, introduced for *Parthenium* control on another weed *Xanthium strumarium*. *Journal of Applied Zoological Research*, (**2):**120-121
- Sushilkumar and Jay G. Varshney.2007[a]. *Gajarghas ka Jaivik Niyantrana: Vartman Stathi avamn Sambhavnain (in hindi)*, [Biological control of Partheniu: Present status and future]. National Research Centre for Weed Science, Jabalpur: 157pp.
- Sushilkumar and Kamlesh Viswakarma.2006. Biological and chemical integration for water hyacinth management- a case study. International symposium on " Biology, ecology and management of world's worst plant invasive species, December, 10-14, 2006, 146-147.
- Sushilkumar and Ray,P. 2007. Biology of *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) on some of its major weed hosts. *Entomon*, 32(4): 287-290.
- Sushilkumar and Ray. Puja 2010. Activity enhancement of *Zygogramma bicolorata*, a biocontrol agent of *Parthenium hysterophorus*, by temperdture regulated diapause Biocontrol *Science and Technology,* Vol. 20, No. 9.
- Sushilkumar and Ray. Puja 2011 Evaluation of augmentative release of *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) for biological control of Parthenium hysterophorus L. *Crop Protection* 30 (2011) 587e591
- Sushilkumar and Varsheny, Jay G. 2007[b]. Successful biological control of water hyacinth (E*ichhornia crassipes*) through weevil N*eochetina* spp. in ponds of Jabalpur, Madhya Pradesh, India - a case study. Abstract published in the Proceedings of 12th World Lake Conference, Jiapur, 28 October to 2 November 2007,
- Sushilkumar and Varsheny, Jay G. 2010. Current practices and future strategies for mangment of Parthenium problemin India. In: Proceedings of 3rd International Conference on Parthenium, December 8-10, 2010. 74-84.
- Sushilkumar and Varshney, Jay G. 2010. Parthenium infestation and its estimated cost management in India. *Indian Journal of Weed Science* 42(1&2) : 73-77.
- Sushilkumar, 1993. Biological (insect) control of problematic weeds of forests and waste lands in India. *Annals of Entomology,* 11(2):79-97
- Sushilkumar, 1998. Survey of insect and non-insect fauna of weeds in Jabalpur and adjoining area. 37. In : *Annual report* (1997-98) (Eds., M.S. Raghuvanshi), National Research Centre for Weed Science, Jabalpur, India.
- Sushilkumar, 2005[a] Current status of parthenium and mexican beetle (*Zygogramma bicolorata*) in central India, 114-119. In : *Proceedings of Second International Conference on Parthenium Management* held at Bangalore (Karnataka), 5-7 December 2005, (Eds.Prasad *et al.*).
- Sushilkumar, Kamlesh Vishwakarma and Ray. Puja 2008. Non-target effect of herbicide on *Neochetina* spp., a biological contol agent of water hyacinth . *Indian Journal of Weed Science.* 40 (3&4):200-202
- Sushilkumar.2005[b].- Biological control of water hyacinth). NRCWS Extension leaflet, No. 32
- Varshney, Jay G. Sushilkumar and Mishra JS. 2008..Current status of aquatic weeds and their management in India. Sengupta M. and Dalwani, R. (editors) *Proceedings of Tal: The 12th World Lake Conference, Jiapur,* 28 October - 2 November 2007: 1039-1045.
- Vislakshi, GPN. and Sushilkumar 2008. Biological control of terrestrial and aquatic weeds in India. In the Proceedings of ISWS Biennial Conference on "Weed Management in Modern Agriculture : Emerging Challenges and Opportunities" February 27-28, 2008 held at Bihar Veterinary College, Patna (RAU, Pusa, Bihar. pp. 57-62.
- Yaduraju NT, Sushilkumar, Prasad Babu, MBB and Gogoi AK. 2005. *Parthenium hysterophorus-* - Distribution, problem and management strategies in India, 6-10. *In* :

Proceedings of Second International Conference on Parthenium Management held at Bangalore (Karnataka), 2005.

Herbicide residues in the environment and their management strategies for sustainable agriculture

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Introduction

Herbicides are the chemicals which are employed to kill or control vegetation. Herbicides are the fastest growing class. Several herbicide molecules are introduced since the discovery of herbicidal activity of 2,4-D (2,4-dichlorophenoxyacetic acid) in 1941, to cater the need of the farmers. Recent herbicide development marked by the introduction of selective post-emergence herbicides in major crops such as sulfonylureas, imidazolinones and aryloxy phenoxy propionate etc. These herbicides provide excellent selectivity at extremely low dosage (few grams/ha). Herbicides help farmers in increasing crop yield, with efficient weed control.

Fate and Persistence of Herbicides in the soil

As soon as a herbicide is applied a number of processes immediately begin to remove the compound from the original site of application. For the herbicide which is intercepted by plants, the chemicals may be taken up by the plant itself may be washed off by precipitation onto the soil, may undergo photodegradation on plant surface or may volatile back into the air. Herbicides persistence in the soil is expressed as half life or time required to degradates fifty percent of the original molecule (Table 1). However the half life is not absolute because it depends on the soil type, temperature, and concentration of the herbicide applied. Persistence varies with the nature of a chemical, soil properties and climatic conditions. The herbicide should persist long enough to check weeds until the end of critical period of weed competition but should not persist beyond the crop harvest, as it would be injurious to the sensitive crops grown in rotation. Very rapid loss of herbicides from soil will cause insufficient weed control, which is considered as unsatisfactory as their unduly long persistence within soil. Beside herbicides structure, soil conditions prevailing during and after the application of a herbicide as well as herbicide application methods influence the fate of the herbicides in the soil. Heavy rainfall in monsoon will cause greater leaching and runoff. Sandy soil would have a higher leaching potential than a clay soil due to larger pore spaces and lower CEC (Sondhia and Yaduraju 2005). Higher humidity enhances the soil microflora proliferation. Similarly the persistence of herbicides in dry soil is greater as compared in wet soil.

Table 1: Half-lives of some herbicides in soil

Herbicide name	Half live (Days)	Herbicide name	Half live (Days)
Atrazine	13-58	Metribuzin	23-49
Butachlor	5-24	Metolachlor	8-27
Fluazifop-p-ethyl	8-24	Oxyfluorfen	19-29
Fluchloralin	12-13	Pendimethalin	15-77
Imazethapyr	57-71	Sulfosulfuron	3-8
Isoproturon	13-21	2,4-D	7-22

Source: (Sondhia 2007)

A herbicide is said to be persistent when it may be found to exist in soil in its original or a closely related but phytotoxic form longer than one crop season after its original application (Sondhia, 2005). Herbicide residues in crop produce above the safe level can cause health hazards to man and animal (Table 2). Ultimate fate of herbicide in soil depends on number of processes such as volatilization, leaching, runoff and degradation by microbes, chemical processes and photodecomposition

Table 2 Residues of some important herbicides in the soil, food grain and straw

Herbicides	Crop	Dose (g/ha)	Residues*		
			Soil	Grains	Straw
Butachlor	Rice	1000	0.005	0.012	0.029
Sulfosulfuron	wheat	25	BDL	0.010	0.004
Fenoxaprop-p	Wheat	100	0.089	0.0024	0.0013
Metsulfuron-methyl	Rice	4	BDL	BDL	BDL
Isoproturon	Wheat	1000	0.032	0.035	0.065
Oxyfluorfen	Rice	150-250	BDL	BDL	BDL
Imazethapyr	Soybean	100	0.016	0.210	BDL
Imazosulfuron	Rice	30-40	BDL	BDL	BDL
		50-60	BDL	0.006-0.009	0.009-0.039

**Source: (Sondhia, 2007)*

Effect of herbicides on microflora and fauna

Nowadays soil health and microbial diversity have become vital issues for the sustainable agriculture. Loss of microbial biodiversity can affect the functional stability of the soil microbial community and soil health. Generally, negative effects of herbicides on the population level or composition of species are decreased for a while but subsequently improves. Beneficial organism known to be affected negatively by specific herbicides includes nitrogen fixing bacteria (Rhizobium) and some mycorhizal fungi. Actinomycetes are relatively resistant to herbicides and affected at high concentration only. Fungi are probably the more sensitive to the majority of herbicides than are bacteria.

Apart from soil microflora, herbicide may have adverse or stimulatory effects on some beneficial soil fauna. Earthworms are perhaps the most important soil organisms in terms of their influence on organic matter breakdown, soil structural development, and nutrient cycling, especially in productive ecosystems. Isoproturon did not cause lethal effects at 1.4 g/kg soil on mature earthworm (*Lumbricus terrestris* L.) after 60 days.

Effect of herbicides on succeeding crop

Herbicide persistence in soil may injure succeeding crop. For example, injury to pea from sulfosulfuron is noted in field treated with sulfosulfuron in the previous year (Sondhia and Singhai 2006). Several substituted ureas, sulphonylureas, dichlobencil and 2, 3, 6-TBA often pose phytotoxic residues problems on crop land. Even a short residue herbicide like glyphosate has been reported to damage tomato transplants (Cornish, 1992). Sometimes non-phytotoxic residues of previously applied herbicides may damage the rotation crop by interacting with the herbicide applied to the present crop.

Most of the herbicides are absorbed through plant roots and underground absorptive sites besides they undergo number of degradation processes. At the recommended dose of herbicide application the problem may not arise and they selectively kill the weeds. But when the dose is more Than the recommend rates, that happens due to indiscriminative use and improper calibration and method of application, there is possibility of residual hazards in soil particularly in persistent herbicides such as triazines and uracils. Repeated application of the same herbicides in a mono crop sequence may cause accumulation of residues in soil, which in turn will affect the sensitive crops. Leaching of herbicides can cause crop injury due to transport of herbicide into the absorption zone of susceptible crop plants and accumulation of herbicides in toxic level in tolerant crop plants.

In some experiments it was found that pre-emergence herbicides such as thiobencarb, butachlor, pretilachlor and anilofos applied at recommended doses continuously for four seasons in rice crop did not influence germination and yield of urdbean raised subsequently (Balasubramanian *et al*., 1999). Pretilachlor at 0.50 to 1.00 kg /ha, 2, 4-D at 1.50 to 2.50 kg/ha, anilofos 0.40 to 0.60 kg/ha and pendimethalin 1.50 to 2.00 kg/ha applied as pre-emergence to transplanted rice did not affect succeeding wheat and peas crops but cucumber germination was reduced by 28% in 2.5 kg/ha dose but 2, 4-D showed a greater level of persistence in soil (Gupta *et al*., 2000). Sulfosulfuron applied at 25, 50 and 100 g/ha in wheat crop did not show any adverse effect on succeeding maize and sorghum crop however, significantly affected the growth of lentil and pea (Sondhia and Singhai 2007). Toxic and nontoxic effects of some important herbicides are given in Table- 3.

Table 3 Effect of some important herbicides on succeeding crop

Crop	Herbicide	Dose (Kg/ha)	Toxic	Nontoxic	Reference
Wheat	Sulfosulfuron	0.25-100	Pea, lentil	Sorghum, maize	Sondhia (2006)
Wheat	Pendimethalin	1-1.5	-	Sorghum	Kulshrestha and Yaduraju, (1987)
Sorghum	Atrazine	0.25-1.0	-	Fingermillet Cotton	Jayakumar (1987)
Cotton	Fluchloralin Oxadiazon Oxyfluorfen Pendimethalin	1.0 0.5-1.5 0.1-0.2 1.25	Cucumber	Fingermillet Foxtail millet Mungbean	Jayakumar *et al.* (1988)
Sunflower	Fluchloralin Butachlor Alachlor Pendimethalin	1.0 1.0 1.0 1.0	Mungbean	Groundnut Cowpea Cucumber	Basavarajappa and Nanjappa (1994)

Herbicide residues and mitigation strategies

When applied at recommended rates most herbicides breakdown within a few days or weeks after application and impose no restrictions on cropping options to the next year. Some herbicides however do not degrade quickly and can persist in the soil for weeks, months or years following application. The use of residual herbicides can be beneficial as the residues prevent growth of sensitive weed species throughout the season. These residues however can restrict the crops that can be grown in rotation. Various management techniques have been developed which can be adopted to minimize the residue hazards in soil.

Hazards from residues of herbicides can be minimized by the application of chemicals at the lowest dosage by which the desired weed control is achieved. Herbicides such as carbamates, thiocarbamates and dinitroaniline are lost in the environment by surface volatilization. Tillage operations help in bringing deep present herbicide residues to soil surface which would aid in decontamination by volatilization. In case of deep ploughing the herbicide layer is inverted and buried in deeper layers and thereby the residual toxicity reduced. Herbicides are inactivated by plant residues or organic matter incorporated into soil. Farm yard manure application is an effective method to mitigate the residual toxicity of herbicides. The FYM application at 10 t/ha or green manuring with sesbania to the soil found to mitigate the residual toxicity of atrazine, sulfosulfuron and dinitroanilines, pendimethalin, trifluralin fluchloralin and in sandy loam soil. If suspected residues, sensitive crop should be avoided and a tolerant crop can be grown. For example, when carry-over due to imazethapyr (Pursuit) is suspected, crops such as canola and flax should be avoided. Addition of absorbents, antidotes and safeners can also be used to priotect crop from herbicide drift. Activated charcoal (or carbon) can reduce herbicide contamination in specific areas and can also be used as a root dip to protect transplants (tomatoes, peppers, strawberries, ornamentals, etc.) from triazine or substituted urea herbicides. Antidotes or plant protectants are applied to the soil, crop seed or transplants to protect the crop from herbicide injury. The mode of action of antidotes may be due to deactivation or adsorption of the herbicide, preventing its absorption and translocation by the crop. e.g., 1, 3-naphthalic anhydride (NA) and 2, 2-dichloro-N, N-diallyl acetamide can be used to minimize injury from EPTC. Decontamination of herbicide residues by means of controlled irrigation alone, or in combination with tillage, cropping and use of soil amendments has been achieved with success to mitigate residues.

Conclusion

In India use of herbicides is increasing at a faster rate as compared to other pesticides. Newer molecules are added each year. Due to environmental and health concern, the regulatory requirements have been made longer. Herbicides have lower residue concern than other pesticides in view of their lower mammalian toxicity. Further contrary to other pesticides, herbicides are applied at planting or during early stages of crop growth, thus giving more time for degradation of the chemical in the plant and environment. Further the soil and climate conditions prevalent in the country enable faster degradation of the chemical. The fate of herbicides in the soil is a concern of many segments of society. The soil acts as an important buffer governing the persistence and fate of most herbicides in the environment. As long as soil system remains healthy, possible adverse effect from herbicides in the environment probably can be minimized. Herbicides in most instances when applied at recommended doses have not been detected in food chain or in soil at level that should cause concern.

References

- Balasubramanian, R., Veerabadran, V. and Kannathasan, M. (1999). Influence of continuous use of herbicides in rice based system on residue accumulation and on performance of succeeding pulse crop. *Pesticide Research Journal*, 11: 2, 200-203.
- Basavarajappa, D. N. and Nanjappa, H. V. (1994). Residual effect of herbicides applied to sunflower on succeeding crops. *Indian Journal of weed Science*, 26: 97-98.
- Gupta, S., Gajbhiye, V. T. and Gupta, S. (2000). Simple methods for dithiapyr residue analysis in soil, water and plant materials. *Annals of Plant Protection Sciences*, 8: 79-83.
- Jayakumar, R. (1987). Bioassay for detecting certain herbicide residues in soils. *Madras Agricultural Journal*, 74: 267-272.
- Kulshrestha, G. and Yaduraju, N. T. (1987). Persistence of pendimethalin in soil following pre-emergence application to wheat, *Indian journal of Agronomy*, 32: 271-274.
- Sondhia S and Yaduraju N. T. (2005). Evaluation of leaching of atrazine and metribuzin in tropical soil. *Indian Journal of Weed Science* 37: 298-300.
- Sondhia, S. (2005). Phytotoxicity and persistence of metribuzin residues in black soil. *Toxicological and Environmental Chemistry*, 87: 387-389.
- Sondhia S. and Singhai B. (2007). Phytotoxicity and persistence of sulfosulfuron under wheat cropping system *In International conference on Sustainable Agriculture for food, Bio energy and livelihood Security* held at JNKVV, Jabalpur w.e.f 14-16 February, 2007.
- Sondhia S. (2007). Herbicides residues in soil, water and food chain, *Annual Report*, National Research Centre for Weed Science, Jabalpur, pp 17-24.

Weed management in vegetable crops and orchards

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Vegetable crops have high economic and nutritional value. They are grown under input intensive production systems. Frequent irrigations and application of FYM and fertilizers induces heavy infestation of weeds. The degree of weed infestation may vary depending upon climatic, edaphic and biotic factors. It also varies from field to field and season to season.

Weed flora associated with vegetable crops

Major weed flora associated with vegetable crops in *kharif* and *rabi* seasons are:

***Kharif* season**: *Amaranthus viridis, Alternanthera sessilis, Ageratum conyzoides, Brachiaria eruciformis, Cyperus rotundus, Commelina benghalensis, Celosia argentea, Cynodon dactylon, Digitaria ciliaris, Dactyloctenium aegyptium, Digera arvensis, Echinochloa colona, Eleusine indica, Physalis minima, Phyllanthus niruri, Trianthema portulacastrum* etc.

***Rabi* season**: *Asphodelus tenuifolius, Anagallis arvensis, Chenopodium album, C. murale, Convolvulus arvensis Cynodon dactylon, Cyperus rotundus, Coronopus didymus, Euphorbia hirta, Fumaria parviflora, Lathyrus aphaca, Melilotus indica, M. alba, Orobanche* spp. , *Rumex maritimus, Spergula arvensis, Sonchus arvensis, Vicia sativa* etc.

Losses caused by weeds

Weeds if not kept under control can cause huge losses in the yield and quality of produce. Depending upon the type of weed species, severity and duration of infestation, competing ability of crop plants and also climatic conditions which affect weed and crop growth, reduction in economic yield of vegetables has been reported to be 6-82% in potato, 25-35% in peas, 70-80% in carrot, 67% in onion, 42-71% in tomato and 61% in cauliflower.

Weeds as alternate hosts of insect-pests and pathogens

Weeds serve as hosts for many pests and diseases thereby increasing the phyto-sanitary problems and the need for inputs in vegetable crops. Common vetch (*Vicia sativa* L) provides shelter to *Helicoverpa armigera. Solanum nigrum* is a host for brinjal fruit and shoot borer (*Leucinodes orbonalis*), common lambsquarters (*Chenopodium album*) acts as a host for aphids. *Ageratum* spp. and *Lantana* spp. provide shelter to white fly which transmits yellow mosaic virus disease.

Crop-weed competition

Most of the vegetable crops grow slowly during the first few weeks following emergence and are less competitive to weeds. Weeds must be controlled during the first third of the crop cycle or up to the critical stage. Weeds should be kept under control upto first 30-75 days in case of onion/garlic,30-45days in cabbage/cauliflower,15-30 days in okra, 30-45 days in tomato/chilli, 20-60 days in brinjal and 15-20 days in carrot.

Methods of weed control

Preventive weed management

The prevention of a weed problem is usually easier and less costly than control or eradication. The following measures can be suggested to prevent the introduction of weeds into non-inhabited field.

- Use clean crop seed (weed seed-free) for sowing/ planting.
- Use organic manures only after thorough decomposition to prevent weed seed emergence in the field. Undecomposed farm yard manures are a major source of weed seeds
- Clean tillage implements before moving to non-weed infested area.
- Avoid transportation or use of soil from weed infested area.
- Inspect nursery stock or transplant for seed and vegetative propagules of weeds.
- Remove weeds that are near irrigation ditches, fence rows and other non-crop land.
- Prevent reproduction of weeds.
- Use weed seed screens to filter irrigation water.
- Restrict live stock movement in to non-weed infested area.

Weed management through agronomic practices

- Stale seed bed
- Crop rotation
- Hand weeding and inter-row cultivation
- Drip irrigation
- Mulching
- Soil solarization

Chemical methods of control

Herbicides

Several herbicides have been found to control weeds in vegetable crops however; the choice of highly selective herbicides in vegetables is limited. Herbicide recommendations for vegetable crops are as follows :

Herbicide	Dose ($kgha^{-1}$)	Treatment	Crops
Pendimethalin	0.75-1.0	Pre-emergence.	Transplanted pepper, onion,garlic,spinach,brassica crops,umbelliferous crops,legumes,potato
Fluchloralin	1.0-1.5	Pre Plant Incorporation	Transplanted tomatoes, pepper,brinjal,potato,okra,brassica crops,legumes,garlic,umbelliferous crops
Oxyfluorfen	0.20-0.30	Early post	Direct-seeded and transplanted onions, potato
Butachlor	2.0	Pre-emergence	Transplanted tomatoes, cucurbits
Metribuzin	0.2-0.35	Pre or early Post emergence	Direct-seeded and transplanted tomatoes, potato

Integrated weed management

The conventional method of hand weeding has become an expensive input in the cultivation of vegetable crops. Herbicides need to be integrated with mechanical and cultural methods of weed control. In seed beds and tuber/bulb crops mechanical cultivation may damage the seedling and underground parts. In such cases herbicides may be integrated with cultural operations. Solarization alone may not be effective to control *Cyperus rotundus*, therefore some complementary hand weeding will be necessary. Parasitic weed *Orobanche* spp. are difficult to control by herbicides alone. In such fields crop rotation should be followed.

Weed management in Orchards

Several types of weeds invade the row interspaces in orchards. Although annual weeds are predominant, perennial species which are persistent give greater competition to the tree crops. The weeds in addition to competing with the fruit trees also interfere in the fruit picking, pruning, pesticide sprays and other operations. They also serve as host for many harmful insects, diseases and rodents.

In young orchards generally manual weedings and inter-cultivation is employed to check weeds. Mechanical cultivation with bullock or tractor drawn ploughs is normally done to control weeds in orchards of 8-10 years age. For an average type of orchard 3-4 ploughings are sufficient to keep the weeds under check. The other physical methods for controlling weeds may include mulching, mowing, flooding, burning etc. In between rows of trees cover cropping, intercropping of vegetables especially cucurbitaceous crops can also be done with dual advantage of controlling weeds and getting additional economic returns. The mechanical cultivation may damage shallow feeding roots and lower branches hence herbicidal control can be done especially around the base of trees.

At post emergence, paraquat (0.5-1.0 kg/ha) for grasses, 2,4-D(1.0 kg/ha) for broad leaf weeds, glyphosate(1.0 kg/ha) for controlling perennial grasses are widely used.

Importance of weed management in Indian agriculture

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Introduction

Weeds are perceived as unwanted intruders into agro-ecosystems that compete for available resources, reducing crop yields, both in terms of quantity and quality. Plants considered as weeds when they interfere with utilization of land and water resources. The most common and acceptable definition of a weed is: "A plant growing where it is not desired" (Terminology Committee of Weed Science Society of America, 1956). Weed Science Society of America in 1994 again defined weed as "any plant that is objectionable or interferes with the activities or welfare of man". Despite the progress made in weed science over the last 40 years, weeds remain one of the major constraints to agricultural production in developed and developing countries. When improved agricultural technologies (costly inputs) are adopted, efficient weed management becomes all the more important, since weeds could have greater gains than the targeted crops. Weeds compete with crop for nutrients, soil moisture, sunlight and space and reduce the yield quality of produce depending upon the nature and intensity of weeds, agro-ecological situations and management practices. Different methods of weed management in field crops including preventive, cultural, mechanical, chemical biological and biotechnological are being used with varying degree of success. Due to continuous use of single method of weed control (especially herbicide), many weeds have developed resistance and are difficult to control. Ineffective weed control is a major bottleneck in the adoption of conservation tillage systems, especially zero-tillage. Under changing climate scenario, crop-weed competition and efficacy of weed control measures are likely to be affected. Considering the diversity of weed problem and agro-ecosystems, no single method, whether manual, mechanical or chemical could reach the desired level of efficiency under all situations. Various weed management approaches, such as the use of stale seedbed practices, the rotation of tillage systems, and the use of crop residue as mulch, weed-competitive cultivars with high yield potential, appropriate agronomic practices and appropriate herbicide timing, rotation, and combinations, need to be integrated to achieve effective, sustainable, and long-term weed control. Most recently transgenic crops resistant to non-selective herbicide like glyphosate provides farmers the flexibility to control a broad-spectrum of weeds with minimal crop damage.

2. Seed production capacity and dormancy of weed seeds

A sound knowledge of biology of weeds, with particular reference to their reproduction and survival mechanisms is essential for planning their effective management. Majority of weed seeds present on or close to soil surface remain dormant and act as source for future flushes of weeds. Most of the weeds especially annuals produce enormous quantity of seeds. Weed seeds remain viable for longer period without losing their viability. The seed production capacity and length of seed survival in soil of few important weeds are detailed in Table 1.

Table 1. Seed production and length of seed survival of some weeds in soil

Weed species	No. of seeds produced/plant	Length of seed survival in undisturbed soil (years)
Canada thistle (*Cirsium arvense*)	680/stem	21
Common lambsquarters (*Chenopodium album*)	72450	39
Common purslane (*Portulaca oleracea*)	52300	30
Common ragweed (*Ambrosia artemisiifolia*)	3380	39
Common sunflower (*Helianthus annuus*)	7200	1
Curly dock (*Rumex crispus*)	29500	39
Curlycup gumweed (*Grindelia squarrosa*)	29700	10
Devils beggarticks (*Bidens frondosa*)	7000	10
Green foxtail (*Setaria viridis*)	34000	39
Redrot pigweed (*Amaranthus retroflexus*)	117400	10
Wild oat (*Avena fatua*)	250	1
Yellow foxtail (*Setaria glauca*)	6420	30
Large crabgrass (*Digitaria sanguinalis*)	150000	3
Eleusine indica	41200	NA
Commelina benghalensis	2450	NA
Portulaca spp.	193000	NA
Trianthema spp.	52000	NA

NA= Not available

3. Crop-weed competition

Competition is the rivalry between crop and weed causing a demand and supply imbalance. Competition does not occur until the supply falls below the combined demand of both crop and weeds. Weeds compete with the crop for nutrients, moisture, solar radiation and space. Crop-weed competition is largely affected by nature and intensity of weeds, crop species / cultivar, light, moisture, nutrients and management practices.

3.1. Competition for light: Weeds compete with the crops for light due to faster growth, large leaves and climbing devices. The competition for light begins when plants begin to shade each other.

3.2. Competition for water: Competition for water between weeds and crops reduces soil moisture availability and cause water stress. This will be severe in rainfed/dry land agriculture where moisture is a constraint. Weeds are comparatively more tolerant than the crop plants to moisture stress. In general, for producing equal dry matter, weeds transpire more water than most of the field crops.

3.3. Competition for nutrients: Nitrogen, phosphorus and potassium are the primary plant nutrients. In general, weeds absorb mineral nutrients faster than crop plants and thus, remove more nutrients than crops. Uncontrolled weeds in any crop remove more quantity of nitrogen and potassium than the phosphorus. Fertilization usually stimulates weed growth to the crop's detriment. Competition for nutrients will be high under irrigated agriculture where moisture is not a constraint. With low fertility, competition is usually for nutrients, however with high fertility, competition is just as vigorous, and primarily for light. Nutrient removal by weeds and crops is given in Table 2.

Table 2. Nutrients removal (kg/ha) by weeds and crops under unweeded conditions.

Crops	Nitrogen		Phosphorus		Potassium		Reference
	Crop	Weed	Crop	Weed	Crop	Weed	
Wheat	59.3	21.7	12.8	2.9	46.8	28.2	Gupta, 2010
Rice (transplanted)	60	74	5	6	9	108	Gupta, 2010
Maize	46.4	46.7	6.3	7.1	82.5	61.6	Gupta, 2010
Mungbean (rainy season)	12.4	132.2	5.3	17.6	10.3	130.1	Yadav *et al.*,1985
Mungbean (summer season)	55.6	79.1	10.2	19.8	49.1	79.1	Kundra *et al.*, 1991
Chickpea	32.3	54.6	5.0	7.7	47.3	72.4	Dadhich and Mali, 1991
Peas	30.6	71.6	5.8	14.4	33.1	105.0	Ahlawat *et al.*, 1983
Sugarcane	28.3	162.2	17.3	23.8	61.8	202.9	Gupta, 2010

3.4. Critical period of crop-weed competition

Weeds are capable of accumulating dry matter faster than the crop plants. Thus, the duration of weed infestation and time of weed removal has a significant influence on crop growth and economic yield. A fundamental principle of plant competition is that early occupants on a soil tend to exclude the later ones. Removing weeds at any time during growing season may not be beneficial. Stage of weed removal is as important. Therefore, it is necessary to identify the critical period of crop-weed competition to render the weed control practices more effectively. It can be defined, as "the shortest span of time in the ontogeny of crop growth when weeding will result in higher economic returns". Critical period of crop-weed competition and losses due to weeds in different field crops is given in Table 3.

Table 3: Critical period of crop-weed competition and losses due to weeds in different field crops (Mishra (1997)

Crops	Critical period	Average yield reduction (%)
Rice (Direct seeded)	15-45	50-90
Rice (Transplanted)	30-45	15-40
Maize	15-45	40-60
Sorghum	15-45	15-40
Pearlmillet	30-45	15-60
Wheat	30-45	20-40
Pigeonpea	15-60	20-40
Greengram	15-30	30-60
Blackgram	15-30	30-50
Cowpea	15-30	30-50
Chickpea	30-60	15-25
Peas	30-45	20-30
Lentil	30-60	20-30
Soybean	20-45	40-60
Groundnut	40-60	40-50
Sunflower	30-45	30-50
Castor	30-60	30-35
Safflower	15-45	35-60
sesamum	15-45	15-40
Rapeseed-mustard	15-40	15-30
Linseed	20-45	30-40
Commercial Crops		
Sugargane	30-120	20-30
Cotton	15-60	40-50
Jute	30-45	50-80
Vegetables		
Potato	20-40	30-60
Cauliflower	30-45	50-60
Cabbage	30-45	50-60
Okra	15-30	40-50
Tomato	30-45	40-70

Onion	30-75	60-70

4. Losses due to weeds

Weeds are the major agricultural pests that can devastate a crop if not properly managed. Losses caused by weeds in the developing world are still at least 37% annually and in certain regions, losses can be up to 90-95% including total crop failure. In addition to direct effect on crop yield, weeds result in considerable reduction in the efficiency of inputs used. The precious and costly inputs such as fertilizers and irrigation water which are otherwise meant for realizing the potential yield will be usurped by the weeds.

In addition to their direct and indirect effects upon India's economy, invasive weeds are recognised as the biggest threat to India's biodiversity next only to habitat destruction. Estimates on potential and actual losses despite the current crop protection practices are given in Table 4.

Table 4. Estimated loss potential of weeds, animal pests (arthropods, nematodes, rodents, birds, slugs and snails), pathogens (fungi, bacteria) and viruses, and actual losses due to pest groups in six major crops worldwide (Oerke, 2006)

Crop	Attainable production (M t)	Weeds		Animal pests		Pathogens		Viruses		Total	
		Potential (Mt)	Actual (Mt)	Potential (Mt)	Actual (Mt)	Potential (Mt)	Potential (Mt)	Actual (Mt)	Potential (Mt)	Actual (Mt)	Potential (Mt)
Wheat	785.0	23.0	7.7	8.7	7.9	15.6	10.2	2.5	2.4	49.8	28.2
Rice	933.1	37.1	10.2	24.7	15.1	13.5	10.8	1.7	1.4	77.0	37.4
Maize	890.8	40.3	10.5	15.9	9.6	9.4	8.5	2.9	2.7	68.5	31.2
Potato	517.7	30.2	8.3	15.3	10.9	21.2	14.5	8.1	6.6	74.9	40.3
Soybean	244.8	37.0	7.5	10.7	8.8	11.0	8.9	1.4	1.2	60.0	26.3
Cotton	78.5*	35.9	8.6	36.8	12.3	8.5	7.2	0.8	0.7	82.0	28.8

In general, impact of weeds on crop yields varies from high input to low input crop production systems. It has been estimated that weeds caused 5% loss in agricultural production in most developed countries, while it caused 10 % loss in developed countries and 25% loss in least developing countries.

5. Principles of weed management systems

Better understanding of weed biology/life cycle will lead to better crop and weed management. A basic principle of weed management is that control measures should be directed at survival mechanisms of weeds in the soil. For annual weeds, the objective is to prevent seed production and to deplete seed reserves. In case of perennials, destruction of underground vegetative organs is important. Most weed control practices and techniques exploit biological differences between the crop and the weed and are accomplished by manipulations of the shared habitat. Maintenance of the crop in a dominant or superior competitive position in the crop-weed association depend on a differential response of crop and weed to some factor of the habitat which can be modified or manipulated with predictable results. This basic concept underlies effective weed control practice. However, the selection of methods and techniques of agricultural weed control may vary with region, crop, nature of weed infestation and the level of agricultural mechanization.

Every weed management programme is only a part of a total crop production system. The important components in the development of weed management systems are:

- Incorporation of ecological principles
- Use of plant interference and crop-weed competition
- Incorporation of economic and damage thresholds
- Integration of several weed control techniques including selective herbicides
- Frequent supervision of weed management by a professional weed manager employed to develop a program for each crop-weed situation.

Principles in designing integrated weed management systems.

- Crop monocultures seldom use all the environmental resources available for plant growth. The resulting ecological niches, therefore, are susceptible to invasion by weeds and should be protected.
- Weed populations are either active, as photosynthesizing plants, or dormant (seeds). Thus, the seed bank as well as the above-ground vegetation should be considered when determining weed abundance.
- The reproductive capacity and seed survival of weeds determine the composition and abundance of the succeeding weed community in a cropping system. In intensive cropping systems, the type of weed community and its abundance are a direct product of the crop and its management.
- The cropping pattern can be a powerful agent in reducing weed densities.
- Single measurements of weed density are usually not adequate to determine weed impacts. Most crops have thresholds of weed tolerance, expressed as density, amount of biomass, or

period of time before significant economic loss in crop yields results. However, these thresholds vary among cropping systems, weed species, and environmental constraints. The thresholds also may have to be adjusted when criteria other than crop loss are used to determine the economic, ecological, and social effects of weeds.

- Suppressed crop growth cannot always be explained by crop-weed competition. Allelopathy also may be a mechanism through which weeds affect plant growth, and vice versa. In addition, crops and weeds may coexist without crop yields being reduced economically and beneficial effects are possible from some crop-weed associations.
- Weed populations and communities are regulated by a combination of factors (e.g., predation, parasitism, environmental stress, interference, and direct-control methods), and at several stages of the weed's life cycle. Thus, control of weeds can be achieved through direct or indirect means. During direct control the weed plant is physically or chemically removed, while indirect controls rely on biological functions of the crop, the weed, and their associates.

6. Integrated weed management system (IWMS): Concepts and components

Integrated weed management (IWM) is a component of integrated crop management (ICM) which a transient all disciplines. IWM involves three elements;

(a) Multiple tactics (e.g., competitive varieties, cultural practices and herbicide usage)
(b) Weed population maintained at levels below that cause economic damage, and
(c) Conservation of environmental quality.

All crop management practices starting from field preparation to harvesting have implications on weed competition. Judicious use of herbicides, therefore, is given top priority. Lower rates of herbicides integrated with other methods of weed management are invariably more efficient, economical and sustainable than use of higher dose of herbicides alone. IWMS is basically an integration of effective, dependable and workable weed management practices that can be used economically by the producers as a part of sound farm management system. It involves the deliberate selection, integration and implementation of effective weed control measures with due consideration of economic, ecological and sociological consequences. The research approach to the development of an IWMS must take all aspects of the cropping system into consideration. Invariably, each cultural practice influences the competitive ability of both the crop and the weed community leading to a multitude of complex interactions. The effect may be small for individual practice but effect would be substantial if all such practices are combined effectively. In India, at least we are yet to generate information on economic threshold limits (ETL) for different weeds, weed seed dynamics in soil, understanding of eco-physiology of crop-weed competition, weed flora shifts in crops and cropping systems etc. Besides developing effective IWM packages for different crops and cropping systems, it is very important to demonstrate them to farmers on large scale.

6.1. Components of IWMS

The weed management in field crops requires an integrated approach that utilizes effective cultural, mechanical, biological, ecological and chemical methods in a mutually supported manner into the crop production system with due consideration of economic, environmental and sociological consequences. Various methods of weed management have been used with different degree of success in different agro-ecological zones and productions system, which are as follows.

6.1.1. Weed prevention

Prevention involves procedures that inhibit or delay weed establishment in areas that are not already inhabited by them. It encompasses all measures taken to forestall the introduction and spread of weeds. Success of a preventive programme varies with species and the amount of effort devoted to control. The prevention of a weed problem is usually easier and less costly than control or eradication. The following measures can be suggested to prevent the introduction of weeds into non-inhabited field.

- ❖ Use ‘clean’ (weed seed-free) crop seed for planting.
- ❖ Use organic manures only after thorough decomposition to kill weed seeds.
- ❖ Clean harvesters and tillage implements before moving to non-weed infested area.
- ❖ Avoid transportation or use of soil from weed infested area.
- ❖ Inspect nursery stock or transplant for seed and vegetative propagules of weeds.
- ❖ Remove weeds that are near irrigation ditches, fence rows, right-of-way and other non-crop land.
- ❖ Prevent reproduction of weeds.
- ❖ Use weed seed screens to filter irrigation water.
- ❖ Restrict live stock movement in to non-weed infested area.

Other practices used to prevent and avoid potential weed problem at the state, regional or national level are weed laws, seed laws and quarantines.

6.1.2. Cultural methods

Cultural weed management is referred to as the use of any methods that directly enhance crop competitive ability against weeds. Despite the great progress made in agriculture, manual and mechanical methods continue to be important weed management practices in many regions of the world. Cultural methods are used to complement manual and mechanical methods. Cultural practices are manipulated in such a way that they become more favourable for crop growth and less to weeds. They are not only eco-friendly but also reduce the use of costly herbicides.

In *organic agriculture*, the approach to weed management involves the whole cropping system. The aim is not the eradication of weeds but to maintain a balance between crop plants and the weeds, with the grower adjusting the balance in favour of the crops whenever possible. Cultural practices that shift the balance of competition towards the crop usually will disfavour weed occurrence and improve crop yields. Crop rotation is at the heart of the organic system and although the method and timing of soil cultivations and choice of crop are usually linked, both contribute in different ways to manipulation of weed population. Any practice that provide vigorous uniform crop establishment usually will assist in reducing weed prevalence. Factors that improve crop competitiveness are given in Table 5.

Table 5: Classification of cultural practices potentially applicable in an integrated weed management system based on their prevailing effect

Cultural practice	Example	Impact
Crop rotation	Alternation between winter and rainy season crops. Inclusion of weed suppressing crops, Rotation of host crops with non-host crops in case of parasitic weeds.	Reduction in weed emergence, Low input requirement, Improving soil fertility. Effective in managing parasitic and perennial weeds.
Primary tillage	Deep summer ploughing, alternation between ploughing and reduced tillage.	Reduction in weed emergence through placing the weed seeds deep in the soil, destroying the emerged weeds, Farm hygiene.
Seedbed preparation	False/stale seed-bed technique (Allowing weed seeds to germinate and killing them by herbicides/cultivation before sowing).	Reduction in weed emergence, Establishing good crop stand. Cost-effective.
Cultivation	Post-emergence harrowing or hoeing, ridging	Reduction in weed emergence.
Cover crops	Cover crops grown in-between two cash crops and used as green manure or dead mulch such as Sesbania (*Dhaincha*) between summer and rainy season crops	Reduction in weed emergence, Improving soil fertility.
Intercropping	Growing of short duration crops such as cowpea/greengram/blackgram in between rows of maize, pigeonpea, sugarcane, etc.	Reduction in weed emergence, Improvement in crop competitive ability, Cover risk, Improve soil fertility.
Mulching/soil solarization	Use of transparent polyethylene films during summer season (April-May) for a period of 4-6 weeks increases soil temperature by more than 10-12 ^{0}C resulting in death of most of the annual weed seeds. This method is most suitable for weed management in high value crops and organic farming.	Reduction in weed emergence, Improve soil fertility, Conserve soil moisture, Maintain soil temperature.
Crop genotype	Use of cultivars characterized by quick emergence, high growth and soil cover rates in early stage. Examples are, Pea cv 'JP 885'; wheat cv. 'Sujata' and 'C 306', rice cv. 'Vandana', etc.	Improvement in crop competitive ability
Sowing/planting	Puddling and transplanting in rice, higher seeding rates and closer row spacing in wheat and rice. Zero-tillage and bed planting in wheat has been found effective to reduce the problem of *Phalaris minor*.	Improvement in crop competitive ability
Fertilization	Use of slow nutrient releasing organic fertilizers and amendments, fertilizer placement and split application. Avoiding basal dose of nitrogen in direct seeded rice and applying it after first weeding.	Reduction in weed emergence, improvement in crop competitive ability. Higher nutrient-use efficiency.
Irrigation	Drip irrigation in vegetables and fruit crops, sugarcane etc., Furrow irrigation in potato, sugarcane, etc.	Reduction in weed emergence, improvement in crop competitive ability, Higher water use-efficiency

6.1.3. Mechanical method

Physical control of weeds using different tools and implements was the main method of weed control before the advent of herbicides. Still, weed removal in India is largely restricted to mechanical and cultural methods. Mechanical weed control involves removal of weeds with various tools and implements including manual removal by hand weeding. Mechanical method of weed control utilizes manual energy, animal power or fuel to run the implements. Manually operated weeding tools include *khurpi*, sickle, spade or chopping hoes (blade hoe, three tine hoe, fork hoe, plane hoe, etc.) and push-pull type or long handle weeders (grubber, peg type, star weeder, twin wheel hoe, rotary paddy weeder, etc). These weeding tolls are mostly used in upland kharif crops like soybean, greengram, blackgram, groundnut, maize, sorghum, upland rice, etc. Animal drawn weeding tools include three tyne cultivators, sweep cultivator, blade hoe, etc) and mostly used in soybean, sorghum, maize, cotton, groundnut etc. Power operated weeding tools are mostly tractor operated weeding implements used for wide spaced row crops like cotton, sugarcane, orchards, etc. One hand weeding in winter season and two hand weeding in rainy season during critical stage of crop-weed competition provide satisfactory control of weeds in almost all the crops. Use of rotary weeder at 35 days after transplanting has been found most effective and economical for weed management in transplanted rice. Weeding with *Kulpa* at 10 and 25 DAS in soybean, with blade hoe at 25 and 40 DAS in groundnut and sesame are very effective for controlling weeds. Two inter-cultivations with *Kulpa* followed by 2 hand weeding at 30 and 60 DAS has been found effective in cotton. Climate and soil type play an important role in the possibilities for mechanical weed control. Monitoring the early development of weeds is necessary for timing of weed harrowing at the optimum stage. The success of mechanical weeding depends upon the stage of weeds, crop geometry and climatic conditions. Hand weeding may also be used after mechanical inter row weeding to deal with weeds left in crop rows.

6.1.4. Biological control

Biological control of weeds is the deliberate use of natural enemies, primarily insects or fungi, to suppress growth or reduce the population of weed species. The utilization of biological weed control agents in weed management offers many advantages like,

(a) A high degree of specificity for the target weed
(b) No effects on non-target and beneficial plants or man
(c) Absence of weed resistance development
(d) Absence of residue builds up in the environment

The two most common approaches are; the classical or inoculative method and the bioherbicide or inundative strategy.

Classical strategy: It is an ecological approach, which relies on the ability of an organism to multiply and spread following small-scale release. The organism then remains in balance with the target weed, keeping the latter at an acceptably low level. Several weeds have been successfully controlled using different insects and pathogens.

Bioherbicide strategy: It is the second major strategy of biological control of weeds. Here, the strategy is to attack a whole weed population with a single, non-persistent application of inoculum. The inoculum inundates the whole of the area infested by a weed to increase the effectiveness of the agent. Generally, the pathogens considered for this strategy are fungi, hence the commonly used name-*mycoherbicides*.

6.1.5. Chemical method

Weed control through manual/mechanical methods though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, unfavourable environment particularly in rainy season etc. Under such conditions, use of herbicides is advantageous and economical. Herbicides are the chemicals used to kill or suppress unwanted vegetation. The word ‘herbicide’ comes from the Latin *herba*, or plant, and *caedere*, to kill. In general, herbicides account for the largest proportion of crop protection chemicals sold on a world-wide scale. Globally, the herbicides constitute 45% of the total pesticides sale and in some countries like the USA, Germany and Australia; the figure is as high as 60-70 %. In India, however, the herbicides form a meager 16 % of total pesticide consumption. Sharp increase in wages and unavailability of labour due to industrialization, urbanization and Government schemes like Mahathma Gandhi National Rural Employmnet Guarantee Scheme (MNREGS) are bound to make herbicides more acceptable to farmers. Currently about 95 % of the herbicides is consumed in wheat (42%), rice (30%) and tea plantation (23%). The use pattern might change soon with the introduction and indigenization of more chemicals.

In India, the chemical weed control is mostly prevalent in states of Punjab, Haryana, Western UP, Tamil Nadu, Andhra Pradesh, Maharastra and Madhya Pradesh. In Punjab and Haryana, the major use of herbicides is in rice and wheat crop, Tamil Nadu and Andhra Pradesh (in rice), Madhya Pradesh (in soybean, wheat and rice), Maharastra (in cotton) and Gujarat (in groundnut and spices). Nearly 95% of rice and 85% of wheat in Punjab and 60% of rice and 40% of wheat in Haryana is using new technology based on herbicide use for weed management.

Advantages of herbicides

- Herbicides can kill many weeds that survive by mimicry, e.g. *Phalaris mitior* and *Avena* spp. in wheat and *Echinochloa* spp. in rice.
- Herbicides are more effective on perennial and parasitic weeds.
- Herbicides can effectively be used in closely planted crops where manual and mechanical weeding is not possible.
- Herbicides are safe on erodible and sloppy lands where tillage may accelerate soil and water erosion.
- Herbicides enable early and timely planting of crops.
- Herbicides can be used where physical condition of soil is not conducive to manual weeding, e.g., during rainy season
- While one time application of a herbicide is often enough, the manual/mechanical method is repetitive.
- Herbicides kill weeds *insitu* without permitting their dissemination.
- Herbicides can safely be used to control weeds growing in obstructed situations such as right-of-way, under fruit trees and on undulating lands.
- Herbicides provide timely weed control by controlling weeds at the critical period of their competition.
- In dry land agriculture, effective herbicidal control ensures higher water use by the crops and less crop failure due to drought.
- Planning and management of labour for various agricultural operations in big farms are facilitated by use of herbicides.
- Use of herbicides offers gender equality as manual weeding is largely done by female labourers.
- In many parts of the country the cost of weed control through herbicides is lower than that of manual weeding.

Concerns

Despite the above advantages, several concerns have also been made with the indiscriminate use of herbicides. These are as under,

Weed shift

Continuous use of the same herbicide year after year in the same crop in the same area leads to shift in weed flora. For example, due to continuous use of grass killers in rice, particularly in Punjab and Haryana, the weed flora is shifting to sedges like *Cyperus* sp., *Scirpus* sp., *Fimbristylis* sp., *Eleocaris* sp., etc. Similarly with the successful control of grassy weed *Phalaris minor* in wheat, broad-leaved weeds like *Lathyrus sativa*, *Convolvulus arvensis*, *Medicago denticulata*, *Cichorium intybus* and *Cirsium arvense*, are gaining importance. These examples indicate that the existing herbicides though efficient, can't solve all the problems and therefore, new herbicides and their integration with other weed control methods are needed to solve the emerging problems.

Toxicity and residue problem

The indiscriminate use of pesticides leaves behind residues in food and produce. Widespread and increasing use of herbicides is causing concern about potential ecological effects. But still the herbicides are quite safer than the insecticides. In India, around 96% of the herbicides belong to slightly toxic to moderately toxic. Compared to this, more than 70% of the insecticides are highly toxic to extremely toxic. Further, herbicides are never applied directly on grains/fruits which are directly consumed by human beings. A Harvard scientist calculated the risks associated with spraying 2,4,5-T- a relatively toxic herbicide (LD_{50} value 300). If a person worked for applying 2,4,5-T with a backpack sprayer 5 days a week, 4 months a year, for 30 years, the chances of developing a tumor would be 0.4 per million.

Herbicide leaching

Herbicides are liable to leaching to deeper soil layers or surface runoff with irrigation or rainwater to streams, lakes etc., and causing pollution problems. Herbicide leaching may be more in coarse-textured soils than fine-textured soils. Soil moisture status during and after herbicide application can influence the process of leaching.

Herbicide impact on people

In general insecticides are more toxic than herbicides. About 96% of the herbicides are less toxic (blue and green colour coding). Compared to this, more than 70% of the insecticides are more toxic (yellow and red colour coding). Modern herbicides such as glyphosate and sulphonylureas are applied at very low rates and they degrade from environments in few weeks. (Yaduraju and Mishra, 2002)

Soil microorganisms

Because of large populations, short reproductive cycles and great adaptability to environmental change, microorganism populations are very resilient. Butachlor at recommended dose 6 ppm did not change microbial processes remarkably and is safe to use as herbicides for the control of weeds in wet rice fields.

Herbicide resistance

If the same herbicide, herbicides from the same chemical family, or those with the same mechanism of action is used on the same land for several successive years, development of resistance is more likely (e.g., Resistance of *Phalaris minor* to isoproturon, *Echinochloa* spp. to propanil, *Poa annua* to paraquat, *Lolium* spp. to glyphosate, etc). Herbicide resistance is of course a global problem. However, crop and herbicide rotation and herbicide mixtures are important techniques to combat this problem. Integration of many methods of weed management rather than reliance on only herbicides to solve weed problems is an important consideration in the overall management of weeds resistant to herbicides.

With the normal use rate, the quantity of herbicide applied to soil at one time is too small in relation to total soil volume to have any detectable influence on a soil's physical or chemical state. Moreover, the herbicides are applied either before sowing or within one month after sowing of the crop. Results of the experiments conducted under All India Coordinated Research Project on Pesticide Residue and All India Coordinated Research Project on Weed Control indicated that herbicides when applied at recommended doses did not leave any toxic residues either in soil water or in food chain. The high temperature and rain fall conditions in India would result in quick degradation of the chemicals. Most herbicides have half-lives of less than 30-40 days in the soil.

Precautions in herbicides use

- Hand weeding may be given wherever necessary in addition to herbicide treatment.
- Use lower rates in light soils and higher rates in higher soils.
- These recommendations are based on the sole cropping.For herbicide use in inter-cropping system, consult experts.
- Apply herbicide using a sprayer with 500-600 lit/ha water.
- Also spray solutions immediately after preparation. If delay is inevitable, stir the solution or shake the sprayer thoroughly before application to prevent settling down of herbicide in the bottom.
- Flood jet or flat pan nozzle should be used for spraying the herbicide.
- Match the swath correctly. Overlapping of spray may lead to crop phyto-toxicity and gaps may lead to poor control of weeds.
- Separate sprayer need to be used for herbicide and for insecticide spray. If not, then sprayer has to be thoroughly washed with soap water after the herbicide spray before it is used for insecticide spray.
- Avoid spraying on windy days as drifting may damage the neighbouring susceptible crops.
- Do not spray against the wind.
- Avoid smoking or eating during spray application.
- Wash sprayer thoroughly after each spray.
- Handle chemicals carefully. Always keep them away from children and food articles.
- Dispose the empty container by burying in the soil or by burning.
- Use protective clothing (gum boots, gloves, etc.) goggles and mask wherever possible.

The additives which can be used to increase efficacy of herbicides:

***Adjuvants*:** are substances used with herbicide or other pesticide to enhance performance. Adjuvants may be added to the product at the time of formulation, or by the applicator to the spray mix just prior to treatment. Adjuvants are materials that facilitate action of an herbicide or that facilitate or modify characteristics of herbicide formulations or spray solutions. All surfactants and wetting agents are adjuvants but many adjuvants are neither surfactants nor wetting agents. Adjuvants include surfactants, compatability agents, anti-foaming agents and spray colorants, and drift control agents.

Wetter-spreaders: Substances added to spray solutions or suspensions that allows more through contact between spray droplets and a leaf surface.
Stickers: Substances used to increase the amount of spray deposit remaining on a plant surface following application. For example; Several petroleum oils, dupont spreader , stickers, cheveron, citowett.

Emulsifier: Material that aids in the suspension of fine drops of one liquid in another, eg. oil in water, 15-S-3, 15-S-9, tregitol –NPX and solvaid.
Activator: Material used to enhance the activity of a herbicide, often by altering the pH of the spray mixture. E.g. Phytobland oils, Isoparaffinic oils, Ammonium thiocyanate, nitrogen fertilizers.

Additive: Material added to a spray solution or suspension, that is, another term of adjuvant

Dispersing agent: Substance that enhance the dispersal of a powder in a solid-liquid suspension. e.g., Multifilm, biofilm, tryad.

Thickener: Material used to reduce the number of fine droplets produced by nozzles during herbicide application, e.g., Na-alginate, hydroxyl ethyl cellulose

Foliar nutrients: These products may contain plant nutrients such as N, P, K, minor nutrients such as Sulfur and Zinc, and a variety of trace elements. They also contain a relatively small amount of surfactant.

Surfactants: A surfactant is a "surface active agent" and is the active ingredient in most adjuvants. These materials cause a reduction of surface (gas-liquid) and interfacial (liquid-liquid and solid-liquid) tension between substances. Surfactants generally are believed to intensify the activity of herbicides by,

- ✓ Creating uniform spreading or wetting on leaf surface
- ✓ Increasing spray droplet retention
- ✓ Improving spray droplet and leaf surface contact
- ✓ Solubilizing nonpolar plant substances
- ✓ Causing enzymatic denaturation or membrane dysfunction

Based on their ionization properties, surfactants are nonionic (do not ionize, but will have a slight electrostatic charge due to the polarity of dissimilar atoms in the molecule e.g., S-145, tween -20 and surfactant –WK), anionic (ionized, have a strong negative charge e.g., Santomerse, Vat sol-OT, and SDS (Sodium dodecyl sulphate), or cationic (ionized, have a strong positive charge, e.g., Aliquat -4, Quaternary - 0 and CTAB @ 0.5 to 1%).

Herbicide protectants, antidotes and safeners

The recent development in herbicide usage is the use of *protectants* or *antidotes* or *safeners* in order to protect the crop plant from possible damage by herbicide. Safeners are generally most effective when mixed with the herbicide and applied to the soil.

Following are the examples of herbicide protectants:

a) Naphilhopyranone derivatives eg. napthalic anhydride (NA) and phthalic anhydride (PH4).
b) Chloroacetanides eg. allidochlor CDAA and dechlormid DCCA.
c) Oxima ether eg. Cyometrinil, CGA-133205
d) Fluranzole

7. Parasitic weeds

Parasitic weeds are becoming major constraints to many crops in tropical agriculture and the efficacy of available means to control them is minimal. The parasitic mode of existence can be found throughout the kingdoms of life, from bacteria and fungi to insects, arachnids and worms. Parasitism has also evolved in many families of flowering plants. There are around 3000 species of parasitic angiosperm, distributed amongst 17 families. The transfer of host solutes in to a parasitic plant relies on the formation of a bridge between the two organisms. This organ, the *haustorium* (from the Latin, *haurire*, to drink) is thus the defining feature of all parasitic plants. True plant parasites can be *hemi-parasitic* (semi-parasitic) with photosynthetic leaves (such as *Striga* and mistletoe), or *holo-parasitic* and completely dependent on their host (such as dodder and broomrape). They may also be classified as stem parasites (Cuscuta and Loranthus) and root parasites (Striga and Orobanche) depending on their attachment with host plant. Some stem parasites are *endo-parasitic* and live completely within the stems of their host. The only part of pilostyles that emerges from the host is a tiny bud that opens into a minute red flower.

8. Aquatic weeds

Aquatic weeds are those unwanted plants which grow in water and complete at least a part of their life cycle in water. Many aquatic plants are essential as they may play a short-term beneficial role in reducing water pollution and for continuous addition of oxygen to water during photosynthesis for aquatic fauna like fish, prawns, etc. Excessive population of aquatic vegetation deprives us of all facets of efficient use of water. Aquatic weeds constitute a worldwide problem that is becoming more critical because of expanded use lakes, man-made ponds, rivers and irrigation channels. Such weeds invade aquatic habitats used by man for irrigation, transportation, drinking and other public purposes. They clog drainage ditches, obstruct navigation channels, limit fishing and boating in recreational water, interfere with delivery of irrigation water and cause seepage and evaporation, and contribute to breakdown of canals and collection of sediments and many other problems.

Aquatic weeds are a great problem in canal system which has already reduced the designed flow of many of these by 40-50 per cent. The impeded flow of water in canals resulted in forced seepage, water logging and soil salinity. Weeds like *Ipomoea aquatic*, *Typha angustata*, *Eichhornia crassipes, Vallisneria* spp., *Ipomea carnea* are prevalent in canal and irrigartion system of Andhra Pradesh , Rajasthan, Uttar Pradesh, Tamil Nadu and Maharashtra states. In Kerala state, *Salvinia molesta*, an exotic weed introduced in 1967 has widely distributed in irrigation canals. It is so competitive that it has replaced *E. crassipes* and *Pistia stratiotes* weeds . Irrigation supply to paddy is also hindered in about two lakh hectare area due to these weeds in north-eastern states. Aquatic weeds often reduce the effectiveness of water bodies for fish production.

9. Alien invasive weeds

A large number of alien invasive weeds have invaded our ecosystems and are threatening the survival and productivity of the systems. Invasive weeds such as *Parthenium*, *Lantana*, *Chromolaena*, Water hyacinth, *Mikania*, *Ageratum*, etc., are causing a great loss to biodiversity, ecotourism, grassland and pastures and water bodies. A recent assessment calculates the annual losses by alien invasive species in India are around 117 billion US dollar. It have been estimated that around 10 million hectare area (mostly non-cropped area) of the country is invaded by *Parthenium hysterophorus* in almost all the agro-climatic regions. Similarly, *Lantana* in Western Himalayan region, Eastern Himalayan region, Gangetic Plains, Central and Western Plateau and Hill region; *Chromolaena* in Western Plain and Ghat Region and Himalayan region; *Mikania* in Eastern Himalayan Region, East-coast Plain and Hill region, East-coast Plain and Hill region and parts of Western plain and Ghat region and Water hyacinth throughout the country are posing a serious loss to biodiversity. Controlling these weeds would help in increasing grass production and restoring the biodiversity.

The 'Convention on Biological Diversity' (CBD, 1992) recognizes 'Invasive Alien Species' as the biggest threat to biodiversity next only to habitat destruction. The management of the alien weed invasions is a serious challenge as they mostly occur in non-agricultural waste lands which nobody cares for. It calls for the active participation of all stake holders such as the general public, the NGOs, local bodies, government agencies, scientists, and extension agencies etc., many of whom are not well informed and therefore not alarmed. Hence, creating awareness among all the concerned regarding the impact of alien weed invasions on agriculture, environment, human and animal health and urgency to contain them is the need of the hour.

References

- hlawat, I.P.S., Singh, A., Saraf, C.S., 1983. Studies on weed control in field peas. Indian Journal of Weed Science 15, 217-22.
- adhich, S.C., Mali, A.L., 1991. Effect of herbicides and phosphorus on crop weed competition in chickpea (*Cicer arietinum* L.). Indian Journal of Agronomy 36, 283-85.
- Gupta, O.P., 2010. *Modern Weed Management* (3rd Revised Edition).AGROBIOS (India), Jodhpur
- undra, H.C., Gosal, K.S., Brar, H.S., 1991. Effect of weed management practices on nutrient uptake by summer mungbean (*Vigna radiata* L.) and associated weeds. Indian Journal of Weed Science 23, 31-35.
- Mishra, J.S., 1997. Critical period of weed competition and losses due to weeds in major field crops. Farmers and Parliament XXXIII (6), 19-20.
- Oerke, E.C., 2006. Crop losses to pests: Centenary review. Journal of Agricultural Sciences 144, 31-43
- Yadav, S.K., Bhan, V.M., Ashok Kumar, 1985. Nutrient uptake by mung bean and associated weeds in relation to herbicides. Indian Journal of Weed Science 17, 1-5.
- Yaduraju, N.T., Mishra, J. S., 2002. Herbicides-Boon or Bane. Pestology XXVI (5) : 43-46

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Role of emergent weedy plants in bioremediation of low quality water

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Introduction

Due to rapid urbanization and industrial development during the last over two decades in India, large quantity of waste water is generated as sewage from class I and class II cities which is estimated to be about 23000 million litre per day (MLD) while those from industries to be about 13500 MLD (Samra,2007). For disposal of such water, 72 cities in India have no facilities at all for domestic waste water treatment. In Jabalpur around 143 lakh litre of waste water is discharged daily through various open drains which are merged into the river Narmada and Pariyet causes weed infestation. Apart from this the waste water from originating from the human habitation also find its way in surface water bodies such as ponds, lakes. It is estimated that around 7 million ha of surface water bodies are infestated with aquatic weeds. Besides this waste water from the open drains have long been used for irrigating field and vegetable crops during dry season in peri-urban areas of India. The farmers also prefer to use this water because it is extremely valuable source for them as pumping cost from sewage drains is cheaper than a borehole, which makes the practice more accessible to them with fewer financial resources. The municipal waste water in peri-urban areas provides an irrigation source particularly during dry season, which enables farmers to get an increased crop yields due to content of high nutrient load (Hunshal *et al*, 1997). Farmers intend to use waste water to their crop to sell the produce in the market and for the own consumption grow crop separately using good quality tube well water. However, the indiscriminate use of untreated water on the farm lands has created the problems of soil degradation and crop quality.

Soil contamination

Since food chain contamination is one of the major roots for entry of metals into the animal system, bioavailability of these metals in soils is othe major concern. The use of sewge and industrial effluents has been observed to enhance the available metal status of agricultural soils by 2 to 100 times (Samra, 2007). The movements of accumulated heavy metals is however governed by soil properties

like pH, organic matter and calcite content etc. Since most alluvial soils of northern parting India are calcarious in nature , the high capacity to lock up and arrest heavy metals limits their mobility in soils. Thus the accumulation of these metals are observed in surface soils and the contents are negatively related with soil pH and positively with soil organic carbon and clay content. Leaching of contaminats below the root zone may affect the ground water quality in the long run. This depends on the factors including depth of water table, quality of ground water, soil characteristics and quantity of heavy metals being added. It is estimated that there are 100000 sites in the UK, and approximately 1400000 in the EU, that are contaminated. In India Waste water as a source of irrigation is becoming common practice in water scarcity areas and such hidden sites which are yet to be identified at national level. The FAO has set permissible concentration of toxic elements in irrigation water (Table 1).

Estimated clean up costs for remediating contaminated land conventionally are very high which are unaffordable to individuals, local authorities. Therefore, low cost technologies such as phytoremediation are urgently needed for prevention and remediation of soil pollution and environmental risk. Apart from the possible chemical effects of the waste water on the soil and ground water, the waste waster is the means for carrying seeds of the weed species in the fields through drains. Irrigation water was able to carry seeds over long distances without affecting viability (Dastgheib, 2006). *Parthenium hysterophorus* is reported to be spread by seeds in waste water to agricultural fields (Mishra and Bhan, 1995). Besides this the high nitrate loading in waste water greatly increases the incidence of weeds. Investigations were carried out by Khankhane and Varshney (2010) to judge the effect of waste waters on germination and density of weeds in wheat irrigated with drain water at various contaminated sites of Jabalpur and adjoining areas. It was observed higher germination of wild oat under all waste waters in the range of 64-82.5% as compared to lower germination in Petri dishes filled with tube well water (53.6%).

Table 1: Permissible concentration of elements in irrigation water

Element	Concen-tration (mg/l)	Remarks
Manganese	0.20	Toxic to a number of crops at a few tenth to a few mg/l, but usually only in acid soils.
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6-0 in fine textured or organic soils
Cadmium	0.01	Toxic to beans, beets and turnip at concentration as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans
Copper	0.20	Toxic to number of plants at 0.1 to 1.0 mg/l in nutrient solutions
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic to plants in aerated soils , but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipments and buildings.
Aluminum	5.0	Can cause non-productivity in acid soils (pH less than 5.5) but more alkaline soils at pH > 7 will precipitate the ions and eliminate any toxicity.
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than .05 mg/l for rice
Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Lead	5.0	Can inhibit plant cell growth at very high concentrations.
Selenium	0.02	Toxic to plants at high concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium.
Nickel	0.20	Toxic to a number of plants at 0.5 mg/l to 1mg/l : reduced toxicity at neutral or alkaline pH.

Bioremediation

Bioremediation is a system wherein plants in association with soil organisms can remove or transform contaminants into harmless and often valuable forms. Bioremediation can be practiced for both organic and inorganic pollutants present in solid substrate (e.g., soil), liquid substrates (e.g., water) and the air. The different approaches of plant assisted bioremediation (phytoremediation) can be divided into the following areas:

1. Phytoextraction

Phytoextraction is the most commonly recognized of all phytoremediation technologies.

The phytoextraction process involves the use of plants to facilitate the removal of metal contaminants from a soil matrix (Kumar *et al.* 1995a). In practice, metal-accumulating plants are seeded or transplanted into metal-polluted soil and are cultivated using established agricultural practices. The roots of established plants absorb metal elements from the soil and translocate them to the above ground shoots where they accumulate. If metal availability in the soil is not adequate for sufficient plant uptake, chelates or acidifying agents may be used to liberate them into the soil solution. After sufficient plant growth and metal accumulation, the above-ground portions of the plant are harvested and removed, resulting the permanent removal of metals from the site.

This technology is suitable for the remediation of large areas of land that are contaminated at shallow depths with low to moderate levels of metal-contaminants. Many factors determine the effectiveness of phytoextraction in remediating metalpolluted sites. The selection of a site that is conducive to this remediation technology is of primary importance. Phytoextraction is applicable only to sites that contain low to moderate levels of metal pollution, because plant growth is not sustained in heavily polluted soils. Soil metals should also be bio-available, or subject to absorption by plant roots. As a plant-based technology, the success of phytoextraction is inherently dependent upon several plant characteristics. The two most important characters include the ability to accumulate large quantities of biomass rapidly and the ability to accumulate large quantities of environmentally important metals in the shoot tissue. It is the combination of high metal accumulation and high biomass production that results in the most metal removal.

2. Rhizofiltration

Metal pollutants in industrial-process water and in groundwater are most commonly removed by precipitation or flocculation, followed by sedimentation and disposal of the resulting sludge. A promising alternative to this conventional clean-up method is rhizofiltration, a phytoremediative technique designed for the removal of metals in aquatic environments. The process involves raising plants hydroponically and transplanting them into metal-polluted waters where plants absorb and concentrate the metals in their roots and shoots. Root exudates and changes in rhizosphere pH also may cause metals to precipitate onto root surfaces. As they become saturated with the metal contaminants, roots or whole plants are harvested for disposal. Plants should be able to accumulate and tolerate significant amounts of the target metals in conjunction with easy handling, low maintenance cost, and a minimum of secondary waste requiring disposal. It is also desirable plants to produce significant amounts of root biomass or root surface area.

Several aquatic species have the ability to remove heavy metals from water, including water hyacinth *(Eichhornia crassipes.)* and duckweed *(Lemna minor*). However, these plants have limited potential for rhizofiltration, because they are not efficient at metal removal, a result of their small, slow-growing roots. The high water content of aquatic plants complicates their drying, composting, or incineration. Despite limitations, Zhu *ct al*. 1999b indicated that water hyacinth is effective in removing trace elements in waste streams. Terrestrial plants are thought to be more suitable for rhizofiltration because they produce longer, more substantial, often fibrous root systems with large surface areas for metal sorption. Sunflower *(Helianthus annuus* L) and Indian mustard *(Brassica juncea.)* are the most promising terrestrial candidates for metal removal in water. The roots of Indian mustard are effective in the removal of Cd, Cr, Cu, Ni, Pb, and Zn , and sunflower removes Pb, ^{137}Cs, and ^{90}Sr from hydroponic solutions.

3. Phytostabilization

Phytostabilization, also known as phytorestoration, is a plant-based remediation technique that stabilizes wastes and prevents exposure pathways via wind and water erosion; provides hydraulic control, which suppresses the vertical migration of contaminants into groundwater; and physically and chemically immobilizes contaminants by root sorption and by chemical fixation with various soil amendments. This technique is actually a modified version of the in-place inactivation method in which the function of plants is secondary to the role of soil amendments. Unlike other phytoremediative techniques, the goal of phytostabilization is not to remove metal contaminants from a site, but rather to stabilize them and reduce the risk to human health and the environment.

4. Phytovolatilization

Some metal contaminants such as As, Hg, and Se may exist as gaseous species in environment. In recent years, researchers have searched for naturally occurring or genetically modified plants that are capable of absorbing elemental forms of these metals from the soil, biologically converting them to gaseous species within the plant, and releasing them into the atmosphere. Mercury and Se are toxic and there is doubt about whether the volatilization of these elements into the atmosphere is safe. Selenium phytovolatilization has been given the most attention to date, because this element is a serious problem in many parts of the world where there are areas of Se-rich soil. However, there has been a considerable effort in recent years to evaluate weedy plants.

5. Pytodegradation

The use of plants and associated microorganisms to degrade organic pollutants to less toxic forms or rendering them immobilized to prevent their entry into the food chain or environment. Out of these approaches phytoextraction seems to be most attractive due to its versality in usage. For example phytoremediation can be of use only in case of degradable wastes thus of limited use in the case of heavy metal toxicity, rhizofiltration is specific to water treatment and phytovolatilization is limited to certain special methods (e.g., Hg, Se, As) capable of forming volatile compounds. Phytostabilization does not take away the metal from the soil system and emphasizing on rendering it inactive: thus keeping the option of reoccurrence of the problem in future open. Because of the limitations associated with the approaches mentioned above, phytoextraction proves to be more attractive method.

Role of emergent weedy plants in wetland system:

In an investigation of terrestrial plants growing in drains along the roadways of Jabalpur, Khankhane and Varshney (2010) observed that among the weeds, the highest accumulation ratio for lead was observed in *Vetiveria zizinoides* (17.6) followed by *Arundo donax* (12.5), *Calotropis procera* (5.4), *Sphaerantha indicus* (2.7) and *Argimone asteracantha* (2.4). As far as manganese is concerned, the highest metal accumulation ratio was observed in *Vetiveria* *zizinoides* (6.4) followed by *Arundo donax* (6.0), *Ipomea carnia* (5.4), *Sphaerantha indicus(4.7) Hyptis suaveolense* (3.7). Depending on metal accumulation and biomass producing ability, weed species such as *Arundo donax* was selected for further testing in the contentment experiment. The extensive root system of *Arundo* was developed (110-134 cm in length) in hydroponically grown tanks. The average density of plant was 172.3/m². As far as water flow through porous media filled tanks is concerned, no clogging occurs and water is discharged on irrigation plots through gravity flow. As compared with untrated drain water, the concentration of total soluble salts (TSS), nitrate, copper, nickel, zinc and manganese were reduced to the extent of 64.0, 88.4, 69.3, 62.4, 78.0 and 61.7 per cent respectively after 2 days of hydraulic retention time (HRT). In a *Typha* treatment system, iron, and copper was reduced to the extent of 80.19-89.15, 23.7-56.9 in porous media filled tanks (surface and sub-surface) after 2 days of HRT. Higher cadmium (26.32) was reduced by *Typha* grown in hydroponic tank than porous media filled tanks.

Prospects and potential of weed assisted bioremediation

Bioremediation is cost effective and can remediate a site without dramatically disturbing the landscape or causing any type of intrusion. Location specific trials are to be conducted, as certain plants, which were previously identified as hyperaccumulators of certain metals, need not be hyperaccumulators for other metals. Identification of

technology over other approaches of decontamination are: aesthetically pleasing and accepted by the public, relatively low cost, less distruptive of the remediation site, creates a beneficial habitat for wild life, weedy plants can take up heavy metals thus preventing entry of heavy metals in field soil vis-a –vis for maintaining crop quality. The scope of this technology can be extended to in per-urban areas where waste water is the common source for irrigating vegetable crops. Thus it is clear that the utilization of the remarkable potential of weedy plants to accumulate elements and compounds from the environment will serve as the green cure technology for agro-ecosystem in future

References

- Dastgheib F. 2006. Relative importance of crop seed, manure and irrigation water as source of weed infestation. Weed Research 29(2):113-116
- FAO/UNESCO 1973. Irrigation drainage and salinity , An International Society Book.
- Hunshal CS. Salakinkop, SR. and Brock, RM. 1997. Sewage irrigated vegetable production systems around Hubli-Dharwad, Karnataka, India. Kasetsart Jpurnal (Natural Sciences). 32 (5):1-8.
- Khankhane P.J. and Jay G. Varshney (2010) Germination and density of weeds as influenced by waste water irrigation in wheat. Indian Journal of Weed Science 42 (1&2): 107-108
- Mishra, JS and Bhan VM 1995. Khet ka bin bulaya Mehman. Kheti: 30-31
- Pescod MB. 1992. FAO irrigation and drainage paper No. 47. Scientific Publishers, Jodhpur
- Samra J. S. 2007. Heavy metal contaminated waters and their remediation for food safty. Souvenir of 10th Inter-Regional Conference on water and environment organized by Indian Society of Water Management during October 17-20, 2007 at IARI, New Delhi p. 6-11

Molecular biology to the aid of soil management for sustainable agriculture under changing climate

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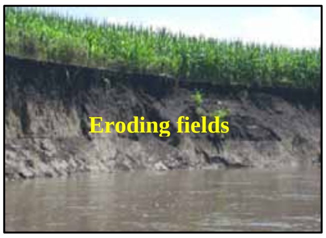
The global atmospheric concentration of carbon dioxide, methane, nitrous oxides and other important GHGs, has increased considerably resulting in warming of the climate system by 0.74°C between 1906 and 2005. IPCC has projected that the global annual temperature is likely to increase in the range of 1.4 to 4.5°C by the end of this century. Overall, the temperature increases are likely to be much higher in winter (*rabi*) than in rainy season (*kharif*). This can cause substantial losses not only in crop production and productivity but also in allied sectors like milk production in livestock, fish abundance, shift in spawning period of some species, etc. Erratic precipitation, more intense tropical cyclones, water logging of arable lands, submergence of crops, salinity and drought are few expected consequences of the changing climate. As a direct consequence, the agricultural resource -land, will be seriously affected.

As such, land or soil is already subject to many stresses that affect its health. As per recent estimates, 120.8 million ha (36.5 % of total geographical area) are degraded due to soil erosion, salinity/alkalinity, soil acidity, water logging, and some other complex problems. Soil erosion due to water and wind is the major cause of soil degradation followed by chemical degradation. Over one-third of total geographical area of the country has soil erosion more than the permissible rate of 10 Mg/ha/yr.

About 87 million tonnes of plant nutrients are also washed away along with eroded sediments. Nutrient mining has increased with intensive cultivation during the post-Green Revolution period and the situation has compounded with low inherent fertility of most of Indian soils. Unfortunately, there is a net negative balance of about 8-10 million tonnes of NPK due to inadequate replenishment through fertilizers and the nutrient limitations are leading to decline in productivity. In addition, the present micro-nutrient deficiencies are to the tune of 49, 33, 13, 12, 5 and 3 % for zinc, boron, molybdenum, iron, manganese and copper, respectively while that for secondary nutrients like S have also become wide spread (41%). These deficiencies are often reflected in poor health of human and livestock. Moreover, the soil organic carbon (SOC) that governs soil productivity is already low in Indian soils and is being negatively influenced by imbalanced use of fertilizers, removal



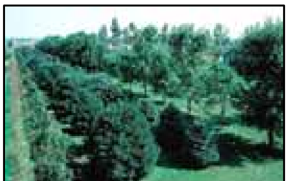
and burning of crop residues, reduced use of FYM and other organics, etc. Also, the soils are getting polluted in some areas with toxic elements from geogenic sources, sewage water, industrial effluents, urban solid wastes, fertilizers etc. For example, nearly 30 million people inhabiting eight districts of West Bengal are exposed to arsenic poisoning through intake of contaminated food. The pollutants thus can enter the food chain and become a potential health hazard to humans and animals.

About 12 M ha area is waterlogged and flood prone, where productivity of arable crops gets severely affected. With 60% of the irrigated farming relying on ground water, India has become the largest ground water based food growing country in the world. However, with over exploitation of ground water resources, water scarcity is one of the major challenges, threatening livelihoods of people and environment. With growing demand for water resources from all sectors, it is projected that by 2050, agricultural sector would require additional 45% water whereas its share is expected to decline by 10%. Unfavourable climatic factors such as erratic rainfall, high evaporative demand, and several droughts, among others, contribute to the increasing water scarcity. Another major uncertainty is the impact of climate change on water availability, and consequently on the agricultural systems. Already coping with water scarcity, reduced nutrient status and degrading structure, soil is also losing its hidden wealth of microbial diversity.

The soil microbial community composition affects the belowground dynamics and fate of photosynthetically-fixed carbon, which can influence fertility (Bradford et al., 2007) and are responsible for decomposing organic matter, regulating nutrient availability and turnover in the soil (Swift et al., 1979). They can also affect the interaction between plants and important aboveground macrofauna. Singh et al. (2011) reviewed the role of soil microorganisms in the development of sustainable agriculture, and showed that plant growth promoting rhizobacteria and cyanobacteria often result in increased crop production and ecosystem health. The soil microbial community is expected to be impacted by various facets of global climate change, such as increased atmospheric CO2, altered temperature and precipitation patterns, and increased frequency of extreme climate events (IPPC, 2007). These microorganisms could also potentially play an important role in contributing to the development of ecosystem resistance to abiotic stresses and increase resiliency in agricultural systems (Pankhurst et al., 1996).

The gist is that climate change will affect soil health. And to manage the soil for sustainable production under the scenario of climate change, what else is better than our indigenous and traditional agricultural practices? Of course, the practices may be augmented with latest technological outputs, which may be then discussed. The major areas where intervention is required include:

Soil erosion: Erosion is a natural process that loosens and sweeps away soil and rock material. The process of erosion happens through natural forces including water, wind, and ice which are caused either by geological or man-made factors. The best method to minimize soil erosion is by enhancing vegetation, especially though plants with a robust root system that can hold on to the soil under severe natural conditions. Emergency cover on bare soil by planting fast growing grasses can also help as they grow very quickly, putting down thick roots. Use of plant mulches and mats will add a layer to the soil and help it retain moisture. They also promote an environment for growing of plants. Planting wind barriers can help avoid wind erosion, similarly use of structural trees can hold the soil together for a long time and also retain the water table. But what is also important is the type of vegetation chosen and its capacity to serve the purpose. Development of genetically modified plants with a stronger, maybe longer root system can help mange soil erosion in better way. Use of structural trees with a faster growing ability will be plants of choice in this context.


Wind breakers

Nutrient depletion: Use of conventional indigenous manures instead of today's fertilizers- urea, DAP, MOP etc. can help replenish the exhausted soil system. Commonly used bio-organic fertilizers for nitrogen fixation, the Blue green algae need to be looked up to. Compost manure produced from waste material such as cereal straws, crop stubble, groundnut husk, farm weeds, grasses, leaves etc have a high carbon nitrogen ratio. Green manuring is a process of enriching the soil by turning down undecomposed plant material (other than crop residues) usually from leguminous plant either *in-situ* or brought in from other places. This can increase humus content of soil as well as supply available nitrogen to the plant. Vermicompost, a nutrient-rich organic fertilizer and soil conditioner, produced using earthworms that breakdown of organic waste matter leaving a higher saturation of nutrients that are highly nutritious for soil health. Farmyard manure is the most commonly used organic manure by farmers. It consists a mixture of cattle dung and the bedding used in stable and plant stalks fed to cattle. Collected cattle urine is added to the dung in the manure pit. Nitrogen in the urine is mainly in the form of urea, which readily changes to ammonium carbonate through bacterial action and acts as a natural fertilizer. Technological intervention is required to identify suitable and more efficient BGA and also relatively active microbes that aid in decomposing of organic material to be used as fertilizer.

Water/moisture levels: Mulch works by preventing evaporation of water from the top soil. Also, most mulch actually absorbs water and releases it slowly into the soil. In addition, mulch adds nutrients to the soil and prevents erosion. But water loss also occurs by transpiration, the evaporation that occurs from leaf surfaces during photosynthesis. This may be minimized or regulated by use of more water use efficient plants that may have been developed by breeding or may have been genetically modified. Or else, we need to simply enhance organic content in soil so that it may retain more moisture. A small amount of organic matter by weight has a big impact on pore space. "Within all textural groups, as organic matter increased from 1 to 3%, the available water capacity approximately doubled. When organic matter content increased to 4%, it then accounted for more than 60% of total AWC (Hudson, 1994). Organic matter increases the bulk of the soil and also improves infiltration, drainage and aeration, not to mention the benefits of improved soil nutrition and soil life. The fastest way to increase levels of soil organic matter is to add mature compost, which has qualities similar to the humus that develops naturally in soil.

Mulching in vineyard

Microbial communities: Microbes are inseparable from soils; be it soil composition or development, nutrient status or carbon sequesteration; microbes play an inevitable role. They are used for decomposition of organic matter, formation of humus, fixing of nutrients, as plant growth promoters, etc. Obviously, an improvement in functioning of these microbes would affect soil development. Microbes with efficient nutrient fixing abilities can nurture the soil while those with enhanced decomposing abilities can help form richer humus in lesser time. Efficient PGPRs can not only aid in better crop growth but also enhance soil quality. Molecular tools not only aid scientists in screening potentially useful microbes, but also permit identification of responsible genes and their utilization to develop better strains for specific uses.

Cropping systems: These are an important factor affecting soil quality. Where sowing of leguminous crops enhances N content in soil, cultivation of vegetables like white cabbage depletes the soil N as it has a higher N demand. It is hence that usually vegetable growers practice vegetable-leguminous crop rotations. Mulch in between during any fallow period can help replenish organic material and moisture to soil benefiting the following crop. Also crops with higher nitrogen use efficiency may demand lesser nitrogen yet yield suitably in comparison to one that has higher nitrogen demand for a comparable yield. Thus, crops modified or bred to have higher NUE or / and higher water use efficiency ought to be incorporated into the cropping system.

Crops tolerant to abiotic stress: Though technologies have been able to address stress, large yield gaps continue to exist. Where there is a need to address constraints in enhancing precision for prediction of events of low precipitation as well as temporal and spatial distribution of rains, there now an urgent need to enhance the inherent tolerance to limited soil moisture stress in crop plants.

Though genetic engineering of crops has enhanced tolerance to abiotic stress by use of individual functional genes at laboratory level, these approaches have not been successful as far as consistency, reliability and visible effects at field levels are concerned, because of multigenic and complex nature of abiotic stress tolerance. The limited knowledge of the stress responsive pathway(s) is one reason for the shortcoming. But, now, the newer technologies of genomics and phenomics have tremendously scaled up our capacity to understand the genetic components of crops and other agricultural commodities. Plenty of information about the genes has been generated and can be accessed through public databases. plant phenomics has evolved as a robust tool with combination of imaging technology and automation to characterize the plant for various morpho-physiological traits without any destructive approaches conventionally used for plant sampling. Some of these technologies can be employed for characterization of plant responses even under field conditions to accelerate our understanding about the mechanisms of tolerance to various abiotic stresses. The method of metagenomic library creation has proven to be an efficient approach for the analysis of uncultivable microbial community. Nanotechnology is a world of sub-micronic particles (1-100nm) which can exhibit pronounced activity in comparison to their original materials. Its impact is visible in engineering, pharmacy, semiconductor and medical devices, domestic goods etc., and recently its interventions are felt necessary in agriculture, aquaculture and environmental remediation. Nano (Bio-) technological innovation can bring a paradigm shift in the conventional technology with more precise and sensitive tools for a sustainable and stress resilient agriculture.

Use of biodiversity: use of locally suited and adapted crop cultivars and contingency crops aid not only the farmer community in terms of yield and revenue, but also helps build up the soil using germplasm suited to the particular agro-ecosystem. Molecular tools may be then used to study, identify and hunt out the gene(s) responsible for performance of crops suited to the prevailing environment. Documentation of biodiversity and conservation of germplasm can also be attended to.

Thus, biotechnology, a science of tools and techniques along with molecular biology, the science helping in understanding mechanisms at the molecular level, both, can very well integrate with agricultural science and aid in its development.

References

- Bradford, M. A., G. M. Tordoff, H. I. J. Black, R. Cook, T. Eggers, M. H. Garnett, S. J. Grayston, K. A. Hutcheson, P. Ineson, J. E. Newington, N. Ostle, D. Sleep, A. Stott, and T. H. Jones. 2007. Carbon dynamics in a model grassland with functionally different soil communities. Functional Ecology 21: 690-697.
- Swift, M. J., O. W. Heal, and J. .M. Anderson. 1979. Decomposition in Terrestrial Ecosystems. University of California Press, Berkeley, CA, USA.
- Singh, J. S., V. C. Pandey, and D. P. Singh. 2011. Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. Agriculture, Ecosystems and Environment 140: 339—353.
- Intergovernmental Panel on Climate Change (IPCC). 2007. *In* B. Metz, O. R. Davidson,,P. R. Bosch, R. Dave, and L. A. Meyers (eds.). Climate change 2007: mitigation.Contribution of Working Group III to the Fourth Assessment Report of the Inter governmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.
- Pankhurst, C. E., K. Ophel-Keller, B. M. Doube, and V. V. S. R. Gupta. 1996. Biodiversity of soil microbial communities in agricultural systems. Biodiversity and Conservation **5**:197—209.
- Hudson, B.D. 1994. Soil organic matter and available water capacity. Journal of Soil and water conservation. 49: 180-194.

Natural resin production under climate change regime

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Natural resins are both of plants and animal origin. They are long chain chemicals and product of commerce, export and an important source of livelihood of resource poor in the world particularly in the rainfed and arid regions in India.

Among the numerous natural resins available, two important natural resins of Madhya Pradesh are Guggul-- an oleoresin of medicinal importance of plant origin and Lac-- a resin of insect origin. These two natural products shall be discussed in context to climate change .

Guggul Gum production

Commiphora wightii is typically an arid plant with thorns and pubescent leaves, found distributed in the arid regions of Gujarat, Rajasthan and Madhya Pradesh in India. It is a RET (Rare, Endangered and Threatened) category of plant in the country. Destructive tapping of the plant for its valuable guggul gum(oleoresin) has lead to rapid decline of it from its natural stand in these three states.

The oleoresin is produced in the phloem tissue and transported by longitudinally running ducts. The plant is tapped in between last week of February and second week of March. The tapping period varies from region to region depending on the local climatic condition.

The gum production also depends on the plant size and region. In Gujarat, the plants are only upto 3feet and yield 25 to 75 g guggul/plant, while in Rajasthan the plants are taller reaching upto five feet and yield 200g guggul/plant. In MP the natural stand of *C wightii* is found only in the Chambal ravines. The height of the plant varies from four to even thirteen feet and the gum yield from 300 to 900g/plant.

C wightii remain leafy from the second week of June to mid October during the year. Thus the plant remains leafless for almost eight months c. This characteristic feature of the plant may be its survival instinct, to reduce trans--evaporation during adverse weather conditions. Thus, the plants remain under stress for eight months during the year produce their food for fours and store for their future. Photosynthesis leads to production of primary metabolites, and these are stored in form of secondary metabolites. Arid plants and those under stress overcome the stress period utilizing the secondary metabolites for survival. There are several forms of storing secondary metabolites by plants. They are stored in stems, tubers, seed, leaves or even in gum form.

C wightii stores the secondary metabolites mostly in the form of gums in its secondary phloem. Gum production and secretion is more when the summer is dry and very hot. During the past three years Chambal ravines experienced wet winters and cool summer. Thus, the soil remained moist while weather cool and wet. This reduced the stress (abiotic), which is essentially required for Gum production and secretion. In the situation-- helped plants to produce leaves-- an abnormal feature and gum production was almost touch the lowest bar. This resulted in loss of livelihood of Gum collectors (landless *Majhi* community) and increased pressure for import of Guggul gum.

Lac production

Lac is a resinous secretion from the three pair of highly specialized lac glands of Lac insect *Kerria lacca*. India is the largest producer and exporter of Lac in the world while MP is the third largest Lac producing Indian State. *K lacca* feeders on the phloem sap of its host trees and secrete Lac to protect its body.

In India over 67 percent share of the lac produced is from *Rangeeni* lac strain, while *Kusmi* lac strain contributes the rest. During the year 2009-2010, *Rangeeni* lac production was severely affected by climatic affect. There was literally no lac production during the year across the country.

In order to understand it must be known that the two cropping season of *Rangeeni* lac are July to October and October to June. Brood lac –the propagation material of lac production is the stage when larvae of lac insect emerge from the mature lac encrustation. It is usually in the 1st week of July and 2nd week of October, broodlac is inoculated on the fresh Lac host tree. In July2009, continuous and heavy rain during the second week washed away the crawling larvae of Lac insect inoculated leaving a few of them to establish on the host trees. Minute and winged form of male lac insect emerge after 40 to 42 days of broodlac inoculation on the host trees. A single male mate with female lac insects before it dies in four days. Mating is important for the female to secrete resin. The season experienced rainfall during male emergence wiped off the male depriving majority of the female lac insects from mating. Thus only few female lac insects produced lac and matured to produce larvae (broodlac) for next season.

In the month of October 2009 there was an acute shortage of broodlac for inoculation for October to June crop cycle. There were only a few fortunate lac growers possessing broodlac inoculated the host trees. Unfortunately, the temperature during March to June 2010 was extremely high that lead to burning of the lac crop across the country. The problem attained a severe status that MP, which produced and sold over 500q of brood lac annually from different sources, was left with just 3q lac in July 2010.

The lesson learnt forced to think on mitigation steps to safe Brood in MP, as a result policy intervention lead to the establishment of broodlac nurseries in the State. Today MP is self again self sufficient for its broodlac and supply to lac growers outside the state.

Time series modelling

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1. Introduction

Time series (TS) data refers to observations on a variable that occur in a time sequence. Mostlythese observations are collected at equally spaced, discrete time intervals. When there is only one variable upon which observations are made then we call them a single time series or more specifically a univariate time series. A basic assumption in any time series analysis/modeling is that some aspects of the past pattern will continue to remain in thefuture. Also under this set up, the time series process is based on past values of the main variable but not en explanatory variables which may affect thevariable system. So the system acts as a black boxand we mayonly beable to know about 'what' will happen rather than 'why' it happen? So if timeseries models are put use, say, for instance, for forecasting purposes, then they are especially applicable in the 'short term'. Here it is tacitly assumed that information about the past isavailable in the form of numerical data. Ideally, at least 50 observations are necessary for performmg TS analysis/ modeling, as propounded by Box and Jenkins who were pioneers in TS modeling.

2. Time series components and decomposition

An important step in analysing TS data is to consider the types of data patterns, so that the models most appropriate to those patterns can be utilized. Four types of time series componentscan be distinguished. They are

(i) Horizontal - when data values fluctuate around a constant value

(ii) Trend - when there is long term increase or decrease in the data

(iii) Seasonal - when a series is influenced by seasonal factor and recurs on a regular ' periodic basis

(iv) Cyclical - when the data exhibit rises and falls that are not of a fixed period

Note: that many data series include combinations of the preceding patterns. After separating out the existing patterns in any time series data, the pattern that remains unidentifiable form the "random' or 'error' component. Time plot (data plotted over time) and seasonal plot (data plotted against individual seasons in which the data were observed) help in visualizing these patterns while exploring the data. A crude yet practical way of decomposing the original data (ignoring cyclical pattern) is to go for a seasonal decomposition either by assuming an additive ormultiplicativemodel viz.

$Y_t = T_t + S_t + E_t$, or $Y_t = T_t . S_t . E_t$

where

Y_t -Original TS data

T_t -Trend component

S_t -Seasonal component

E_t -Error/ Irregular component

If the magnitude of a TS varies with the level of the series then one has to go for a multiplicative model else an additive model. This decomposition may enable one to study the TS components separately or will allow workers to de-trend or to do seasonal adjustments if needed for further analysis.

3. Moving averages and exponential smoothing methods

(i) Simple moving averages

A moving average is simply a numerical average of the last N data points. There are prior MA, centered MA etc. in the TS literature. In general, the moving average at time t, taken over N periods, is given by

$$Mt^{[1]} = \frac{Y_t + Y_{t-1} + \ldots\ldots + Y_{t-N+1}}{N}$$

where Yt is the observed response at time t. Another way of stating the above equation is

$$Mt^{[1]} = Mt\text{-}1^{[1]} + (Y_t - Y_{t-N+1})$$

At each successive time period the most recent observation is included and the farthest observation is excluded for computing the average. Hence the name 'moving' averages.

(ii) Double movingaverages

The simple moving average is intended for data of constant and no trend nature. If the data have a linear or quadratic trend, the simple moving average will be misleading.

In order to correct for the bias and develop an improved forecasting equation, the double moving average can be calculated. To calculate this, simply treat the moving averages Mt [1] over time as individual data points and obtain a moving average of these averages.

(iii) Simple Exponential smoothing (SES)

Let the time series data be denoted by Y_1, Y_2, ...Y_t, Suppose we wish to forecast the next value of our time series Y_{t+1}that is yet to be observed with forecast for $Y_t$denoted by F_t. Then the forecast $F_{t+1}$is based on weighting the most recent observation $Y_t$with a weight value a and weighting the most recent forecast F_t with a weight of (1 -α) where α is a smoothing constant/weight between 0and 1 Thus the forecast for the period t+1 is given by

$$F_{t+1}=F_t+\alpha\ (Y_t - F_t)$$

Note: that the choice of α has considerable impact on the forecast. A large value of α (say 0.9) gives very little smoothing in the forecast, whereas a small value of α (say 0.1) gives considerable smoothing. Alternatively, one can choose a from a grid of values (say α =0.1, 0.2.... 1.9) and choose the value that yields the smallest MSE value.

Ifyou expand the above model recursively then F_{t+1}will come out to be a function of α ,past Y_t values F_1.SO,having known values of α and past values of $Y_t$our point of concern relates to initializing the value of F_1. One method of initialization is to use the first observed value Y_1asthe first forecast ($F_1=Y_1$) and then proceed. Another possibility would be to average the first fouror five values in the data set and use this as the initial forecast. However, because theweight attached to this user-defined F_1 is minimal, its effect on $F_{t+1}$is negligible.

(iv) Double exponential smoothing (Holt)

This is to allow forecasting data with trends. The forecast for Holt's linear exponential smoothing is found by having two more equations to SES model to deal with - one for level and one for trend.The smoothing parameters (weights) α and β can be chosen from a grid of values (say, each combination of α =0.1,0.2, ...,0.9 and β =0.1 ,0.2, ... ,0.9) and then select the combination of α and β which correspond to the lowest MSE.

(v) Triple exponential smoothing (Winters)

This method is recommended when seasonality exists in the time series data. This method is based on three smoothing equations - one for the level, one for trend, and one for seasonality.It is similar toHolt'smethod, with one additional equation to deal with seasonality. In fact there are two different Winter's methods depending on whether seasonality is modeled in an additive or multiplicative way.

4. Stationarity of a TS process

ATS is said to be stationary if its underlying generating process is based on a constant mean and constant variance with its autocorrelation function (ACF) essentially constant through time. Thus, if we consider different subsets of a realization (time series 'sample') the different subsetswill typically have means, variances and autocorrelation functions that do not differ significantly.

A statistical test for stationarity is the most widely used Dickey Fuller test. To Garry out the

testestimate by OLS the regression model $Y'_t= Y_{t-1}+b_1Y'_{t-2}+.......+b_p Y'_{t-p}$

WhereY'_tdenotes the differenced series ($Y_t - Y_{t-1}$). The number of terms in the regression, p, is

usually set to be about 3. Then if is nearly zero the

original series $Y_t$needs differencing. And if <0 then

Y_t is already stationary.

5. Autocorrelation functions

(i) Autocorrelation

Autocorrelation refers to the way the observations in a time series are related to each otherand is measured by the simple correlation between current observation (Y_t) and observation from p periods before the current one (Y_{t-p}). That is for a given series Y_t, autocorrelation at lag p == correlation (Y_t , Y_{t-p}) and is given by

$$r_p = \frac{\sum_{t=1}^{n-p}(Y_t - \bar{Y})(Y_{t-p} - \bar{Y})}{\sum_{t=1}^{n}(Y_t - \bar{Y})^2}$$

It ranges from -1 to + 1. Box and Jenkins has suggested that maximum number of useful r_p are roughly n/4 where n is the number of periods upon which information on Y_t is available.

(i) Partial autocorrelation

Partial autocorrelations are used to measure the degree of association between Y t and Y t-p when the y-effects at other time lags 1, 2, 3... p-1 are removed. Note that usually unto order 2 for p,d, or q is sufficient for developing a good model in practice.

(iii) Autocorrelation function (ACF) and partial autocorrelation function (PACF)

Theoretical ACFs and PACFs (Autocorrelations versus lags) are available for the various models chosen. Thus compare the correlograms (plot of sample ACFs versus lags) with these theoretical ACF/PACFs" to find a reasonably good match and tentatively select one or more ARIMA models. The general characteristics of theoretical ACFs and P ACFs are as follows :-(here "spike' represents the line at various lags in the plot with length equal to magnitude of autocorrelations)

.... Model	ACF	P ACF
AR	spikes decay towards zero	Spikes cutoff to zero
MA	spikes cutoff to zero	Spikes decay to zero
ARMA	spikes decay to zero	Spikes decay to zero

6. Description of ARIMA representation

(i) ARIMA modeling

In general, an ARIMA model is characterized by the notation ARIMA (p.d.q)

where, p,d and q denote orders of auto-regression, integration (differencing) and moving average respectively. In ARIMA parlance, TS is a linear function of past actual values andrandom shocks. For instance, given a time series process $\{Y_t\}$, a first order auto-regressive processis denoted by ARIMA (l,0,0) or simply AR(1) and is given by

$$Y_t = \mu + \phi_1 Y_{t-1} + \varepsilon_t$$

and a first order moving average process is denoted by ARIMA (0,0,1) or simply MA(l) and is given by'

$$Y_t = \mu - \theta_1 \varepsilon_{t-1} + \varepsilon_t$$

Alternatively, the model ultimately derived, may be a mixture of these processes and of higher orders as well. Thus a stationary ARMA (p, q) process is defined by the equation

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} + \ldots - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

where: ε_t's are independently and normally

distributed with zero mean and constant variance

σ^2 for t = 1,2,.,n,Note here that the values ofp and q, in

practice lie between 0 and 3.

(iii) Seasonal ARIMA modeling

Identification of relevant models and inclusion of suitable seasonal variables are necessary for seasonal modeling and their applications, say, forecasting production of crops. Seasonal forecasts of production of principal crops are of greater utility for planners, administrators and researchers alike. Agricultural seasons vary significantly among the states of India. For example, Tamil Nadu has unique three-season cropping pattern for Paddy crop whereas twoseasonpaddy rules elsewhere in the country. Thus seasonal forecasts of crop production can also be made using seasonal ARIMA models.

The Seasonal ARlMA i.e. ARIMA (p,d,q) (P,D,Q)s model is defined by

$$\phi_p(B)\, Ø_P(B^S)\, \nabla^d \nabla_S^D Y_t = \Theta_Q(B^S)\, \theta_q(B)\, \varepsilon_t$$

where

$$\phi_p(B) = 1 - \phi_1 B - \ldots - \phi_p B^p,\quad \theta_q(B) = 1 - \theta_1 B - \ldots - \theta_q B^q$$

$\emptyset p(B^S) = 1- \quad _1 B^S-....- \quad _pB^{sP},_Q(B^S)=1-\theta_1 B^S-...-$

$\theta_Q(B^{sQ})$

B is the backshift operator (i.e. B $Y_t= Y_{t-1}$, $B^2Y_t= Y_{t-2}$ and so on), 's' the seasonal lag and ' $_t$'a sequence of independent normal error variables with mean 0 and variance ^{2}.Ø's and 's are respectively the seasonal and non-seasonal autoregressive parameters. θ's and 'sHis are respectively seasonal and non-seasonal moving average parameters, p and q are orders of non-seasonalautoregression and moving average parameters respectively whereas P and Q are that of the seasonal autoregression and moving average parameters respectively. Also d and D denote non-seasonal and seasonal differences respectively.

7. The art of ARIMA model building

(i) Identification

The foremost step in the process of modeling is to check for the stationarity of the series, as the estimation procedures are available only for stationary series. There are two kinds of stationarity, viz., stationarity in 'mean' and stationarity in 'variance'. A cursory look at the graph of the data and structure of autocorrelation and partial correlation coefficients may provide clues for the presence of stationarity. Another way of checking for stationarity is to fit a first order autoregressive model for the raw data and test whether the coefficient ' $_1$' is less than one. If the model is found to be non-stationary, stationarity could be achieved mostly by differencing the series. Or go for a Dickey Fuller test(see section 4). Stationarity in variance could be achieved by some modes of transformation, say, log transformation. This is applicable for both seasonal and non-seasonal stationarity.

Thus,if 'X_t' denotes the original series, the non-seasonal difference of first order is

$Y_t= X_t- X_{t-1}$

Followedby the seasonal differencing (if needed)

$Z_t= Y_t - Y_{t-s} = (X_t - X_{t-1}) - (X_{t-s} - X_{t-s-1})$

'The next step in the identification process is to find the initial values for the orders of seasonal and non-seasonal parameters, p, q, and P, Q. They could be obtained by looking for significant autocorrelation and partial autocorrelation coefficients (see section 5 (iii)). Say, if second order auto correlation coefficient is significant, then an AR (2), or MA (2) or ARMA (2) model could be tried to start with. This is not a hard and fast rule, as sample autocorrelation coefficients are poor estimates of population autocorrelation coefficients. Still they can be used as initial values while the final models are achieved after going through the stages repeatedly.

(ii) Estimation

At the identification stage one or more models are tentatively chosen that seem to provide statisticallyadequate representations of the available data. Then we attempt to obtained precise estimates of parameters of the model by least squares as advocated by Box and Jenkins. Standard computer packages like SAS, SPSS etc. are available for finding the estimates of relevant parameters using iterative procedures. The methods of estimation are not discussed herebrevity.

(ii) Diagnostics

Different models can be obtained for various combinations of AR and MA individually and collectively. Thebest model is obtained with following diagnostics.

1.Low Akaike Information Criteria (AIC)/ Bayesian Information Criteria (BIC)/ Schwarz-Bayesian Information Criteria (SBC)

AICis given by AIC = (-2 log L + 2 m) where m=p+ q+ P+ Q and L is the likelihood function. Since -2 log L is approximately equal to {n (l+log2) + n log ^{2}} where ^{2}is the modelMSE, AIC can be "written as AIC={n (1+log 2) + n log

^{2}+ 2 m}and because first term in this equation is a

constant, it is usually omitted while comparing between models. As an alternative to AIC, sometimes SBC is also used which is given by SBC

= log ^{2}+ (m log n)/n

2. Non-significance of auto correlations of residuals via Portmonteau tests (Q-tests based on Chisquarestatistics)-Box-Pierce or Ljung-Box texts

After tentative model has been fitted to the data, it is important to perform diagnostic checks to test the adequacy of the model and, if need be, to suggest potential improvements. One Wily to accomplish this is through the analysis of residuals. It has been found that it is effective to measure the overall adequacy of the chosen model by examining a quantity Q known as Box-Pierce statistic (a function of autocorrelations of residuals) whose approximate distribution is chi-square and is computed as follows:

$$Q = n\sum r^2 (j)$$

where summation extends from 1 to k with k as the maximum lag considered, n is the number of observations in the series, r (j) is the estimated autocorrelation at lag j; k can be any positive integer and is usually around 20. Q follows Chi-square with (k-m.) degrees of freedom where m_1 is the number of parameters estimated in the model. A modified Q statistic is the Ljung-box statisticwhich is given by

$$Q = n (n+2) \sum r^2 (j)/ (n-j)$$

The Q Statistic is compared to critical values from chi-square distribution. If model is correctly specified, residuals should be uncorrelated and Q should be small (the probability value should be large). A Significant value indicates that the chosen model does not fit well.

All thesestagesrequire considerable care and work and they themselves are not exhaustive.

Conclusion

The above material is intended to sensitize an avid reader about TS modeling in general. However, the same cannot be claimed to be complete and exhaustive as far as TS modeling is concerned. Many other concepts like stationarity and invertibility conditions, multivariate TS,cross correlation function etc. and methods like regression with ARMA errors, ARIMA modeling with independent variables, transfer function analysis, intervention analysis, state space modeling etc. have not been dealt with. Nevertheless, it is hoped that the preliminaries of TSanalysis have been truthfully covered.

References

- Blank, D.S. (1986). SAS system for forecasting time series, SAS Institute Inc., USA
- Box,G.E.P., Jenkins, G.M.and Reinsel, G.C. (1994). Time series analysis: Forecasting and control. Pearson Education, Delhi.
- Makridakis, S., Wheelwright, s.c. and Hyndman, RJ. (1998). Forecasting: Methods and Applications, John Wiley, New York.
- Pankratz, A. (1983).Forecasting with univariate Box - Jenkins models: concepts and cases, New York:John Wiley &Sins.

Carbon sequestration through agronomic practices

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What is carbon sequestration?

The capture and store carbon produced during human activities and releasing in the atmosphere. It includes increasing carbon pools of both biomass and soil carbon.

Advantage/ benefits of carbon sequestration

- Increase in soil organic carbon increased the productivity of lands.
- Reduced the land degradation
- Increased biodiversity
- Maximize the nutrients and water availability and minimize toxicity & erosion.

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide (CO_2). Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels.

Carbon dioxide is naturally captured from the atmosphere through biological, chemical, or physical processes.

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide (CO_2) and may refer specifically to:

- "The process of removing carbon from the atmosphere and depositing it in a reservoir." When carried out deliberately, this may also be referred to as carbon dioxide removal, which is a form of geo engineering.
- Carbon capture and storage, where carbon dioxide is removed from fuel gases (e.g., at power stations) before being stored in underground reservoirs.
- Natural biogeochemical cycling of carbon between the atmosphere and reservoirs.

Carbon position

- Trees, shrubs and crop plants are natural carbon sinks.
- Soils and plants, rich in organic matter, helps in absorbing atmospheric carbon.
- Agricultural practices promote plant diversification, organic matter in soils, leads to sustainable agriculture and environment.
- About 8 billion tones of carbon are released into atmosphere contributing to global warming and climate change. According to an estimate around one quarter (1/4th) of this, is due to deforestation.
- Globally, soils are estimated to contain approximately 1,500 gigatons of organic carbon to 1 m depth, more than the amount in vegetation and the atmosphere.

Carbon sequestration in Agriculture

Modification of agricultural practices is a recognized method of carbon sequestration as soil can act as an effective carbon sink.

Carbon emission reduction methods in agriculture can be grouped into two categories: reducing or displacing emissions and enhancing carbon removal. Some of these reductions involve increasing the efficiency of farm operations (e.g. more fuel-efficient equipment) while some involve interruptions in the natural carbon cycle. Also, some effective techniques (such as the elimination of stubble burning) can negatively impact other environmental concerns (increased herbicide use to control weeds not destroyed by burning).

Reducing emissions

Increasing yields and efficiency generally reduces emissions of CO_2. Techniques include accurate use of fertilizers, less soil disturbance, better irrigation, and crop strains bred for locally beneficial traits and increased yields.

Replacing more energy intensive farming operations can also reduce emissions. Reduced or no-till farming requires less machine use and less quantity of fuel per unit area. However, no-till usually increases use of chemicals for weed-control and the residue now left on the soil surface is more likely to release its CO_2 to the atmosphere as it decays, reducing the net carbon reduction.

In practice, most farming operations that incorporate post-harvest crop residues, wastes and byproducts back into the soil provide a carbon storage benefit. This is particularly the case for practices such as field burning of stubble - rather than releasing almost all the stored CO_2 to the atmosphere, tillage incorporates the biomass back into the soil.

Enhancing carbon removal

All crops absorb CO_2 during growth and release it after harvest. The goal of agricultural carbon removal is to use the crop and its relation to the carbon cycle to permanently sequester carbon within the soil. This is done by selecting farming methods that return biomass to the soil and enhance the conditions in which the carbon within the plants will be reduced to its elemental nature and stored in a stable state. Methods for accomplishing this include:

- Use cover crops such as grasses and weeds as temporary cover between planting.
- Concentrate livestock in small paddocks for days at a time so they graze lightly but evenly. This encourages roots to grow deeper into the soil. Stock also till the soil with their hooves, grinding old grass and manures into the soil.
- Cover bare paddocks with hay or dead vegetation. This protects soil from the sun and allows the soil to hold more water and be more attractive to carbon-capturing microbes.
- Restore degraded land, which slows carbon release while returning the land to agriculture or other use.

Agricultural sequestration practices may have positive effects on soil, air, and water quality, be beneficial to wildlife, and expand food production. On degraded croplands, an increase of 1 ton of soil carbon pool may increase crop yield by 20 to 40 kilograms per hectare of wheat, 10 to 20 kg/ ha for maize, and 0.5 to 1 kg/ha for cowpeas.

The effects of soil sequestration can be reversed. If the soil is disrupted or tillage practices are abandoned, the soil becomes a net source of greenhouse gases. Typically after 15 to 30 years of sequestration, soil becomes saturated and ceases to absorb carbon. This implies that there is a global limit to the amount of carbon that soil can hold.

Many factors affect the costs of carbon sequestration including soil quality, transaction costs and various externalities such as leakage and unforeseen environmental damage. Because reduction of atmospheric CO_2 is a long-term concern, farmers can be reluctant to adopt more expensive agricultural techniques when there is not a clear crop, soil, or economic benefit. Governments such as Australia and New Zealand are considering allowing farmers to sell carbon credits once they document that they have sufficiently increased soil carbon content.

Intercrop with eucalyptus

Soil organic carbon accumulation was more in land uses having short term crops such as soybean, moong, urd, gram and wheat with perennial tree crops. Research on farming system of mixed intercropping eucalyptus with field crops with addition of organic crop residue management would help to improve further carbon sequestration in agricultural land uses.

Table: Carbon incorporation from residues under different land uses

Land use with eucalyptus	Carbon from crop residues (t/ha)
1st year	1.14
2nd year	2.98
3-5th year	3.82
Paddy	6.70

Means and ways to improve carbon stocks

- Soil carbon could be increased by incorporation of crop/ plant resistance into soil
- Application of manures

Soil organic matter is the main determinant of biological activity. The amount, diversity and activities of soil flora and fauna are directly related to the organic matter. The available organic matter and biological activity that it generates have a major influence on the physical and chemical properties of soils.

Nutrient availability is increased through further decomposition of organic matter and increased cat ion exchange capacity of soils. Water availability is increased by improving soil structure and water holding capacity. Improved soil structure also enhance root penetration, aeration and drainage, reduce toxicity and act as a buffer agent against the acidity/ alkalinity.

Reduced phytotoxicity: the reaction of soil organic matter/ compounds with phytotoxic chemicals is an important beneficial effect of organic matter. Decomposition and transformation of applied pesticides by soil micro organism prevent the accumulation of soil toxicities.

No tillage or Zero tillage

Carbon (air and soil) and other greenhouse gases No-till has carbon sequestration potential through storage of soil organic matter in the soil of crop fields. Whereas, when soil is tilled by machinery, the soil layers invert, air mixes in, and soil microbial activity dramatically increases over baseline levels. Tilling results in soil organic matter being broken down much more rapidly, and carbon is lost from the soil into the atmosphere. In addition to the effect on soil from tilling, emissions from the farm tractors increase carbon dioxide levels in the atmosphere.

Cropland soils are ideal for use as a carbon sink, since they have been depleted of carbon in most areas. It is estimated that 78 billion metric tones of carbon that was trapped in the soil has been released because of tillage. Conventional farming practices that rely on tillage have removed carbon from the soil ecosystem by removing crop residues such as left over corn stalks, and through the addition of chemical fertilizers which have the above-mentioned effects on soil microbes. By eliminating tillage, crop residues decompose where they lie, and by growing winter cover crops, carbon loss can be slowed and eventually reversed.

Nonetheless, a growing body of research is showing that no-till systems lose carbon stocks over time. Regarding a 2014 study of which he was principal investigator, University of Illinois soil scientist Ken Olson said this differing result occurs in part because tested soil samples need to include the full depth of rooting; 1–2 meters deep. He said, “That no-till subsurface layer is often losing more soil organic carbon stock over time than is gained in the surface layer.” Also, there has not been a uniform definition of soil organic carbon sequestration among researchers. The study concludes, "Additional investments in SOC research is needed to better understand the agricultural management practices that are most likely to sequester SOC or at least retain more net SOC stocks.

In addition to keeping carbon in the soil, no-till farming reduces nitrous oxide (N_2O) emissions by 40-70%, depending on rotation. Nitrous oxide is a potent greenhouse gas that stays in the atmosphere for 120 years.

Soil and water

No-till improves soil quality (soil function), carbon, organic matter, aggregates, protecting the soil from erosion, evaporation of water, and structural breakdown. A reduction in tillage passes helps prevent the compaction of soil.

Recently, researchers at the Agricultural Research Service of the United States Department of Agriculture found that no-till farming makes soil much more stable than plowed soil. Their conclusions draw from over 19 years of collaborated tillage studies. No-till stores more carbon in the soil and carbon in the form of organic matter is a key factor in holding soil particles together. The first inch of no-till soil is two to seven times less vulnerable than that of plowed soil. The practice of no-till farming is especially beneficial to Great Plains farmers because of its resistance to erosion.

Crop residues left intact help both natural precipitation and irrigation water infiltrate the soil where it can be used. The crop residue left on the soil surface also limits evaporation, conserving water for plant growth. Soil compaction and no tillage-pan, soil absorbs more water and plants are able to grow their roots deeper into the soil and suck up more water.

Tilling a field reduces the amount of water, via evaporation, around 1/3 to 3/4 inches (0.85 to 1.9 cm) per pass. By no-tilling, this water stays in the soil, available to the plants.

Soil biota, wildlife, etc.

In no-till farming the soil is left intact and crop residue is left on the field. Therefore, soil layers, and in turn soil biota, are conserved in their natural state. No-tilled fields often have more beneficial insects and annelids, a higher microbial content, and a greater amount of soil organic material. Since there is no ploughing there is less airborne dust.

No-till increases the amount and variety of wildlife. This is the result of improved cover, reduced traffic and the reduced chance of destroying ground nesting birds and animals (plowing destroys all of them).

Albedo

Tillage lowers the albedo of croplands. The potential for global cooling as a result of increased Albedo in no till which is a type of the biogeochemical (carbon sequestration) potential.

Management

No-till requires some different skills in order to do it successfully. As with any production system, if no-till isn't done correctly, yields can drop. A combination of technique, equipment, pesticides, crop rotation, fertilization, and irrigation have to be used for local conditions.

Cover crops

Cover crops are used occasionally in no-till to help control weeds and increase nutrients in the soil (by using legumes) or by using plants with long roots to pull mobile nutrients back up to the surface from lower layers of the soil. Farmers experimenting with organic no-till use cover crops instead of tillage for controlling weeds, and are developing various methods to kill the cover crops (rollers, crimper, choppers, etc.) so that the newly planted crops can get enough light, water, nutrients, etc.

Disease, pathogens, insects and the use of crop rotations

With no-till, residue from the previous years crops lie on the surface of the field, cooling it and increasing the moisture. This can cause increased or decreased or variations of diseases that occur. but not necessarily at a higher or lower rate than conventional tillage. In order to help eliminate weed, pest and disease problems, crop rotations are used. By rotating the crops on a multi-year cycle, pests and diseases will decrease since the pests will no longer have a food supply to support their numbers.

Soil temperature

Another problem that growers face is that in the spring the soil will take longer to warm and dry, which may delay planting to a less ideal future date. One reason why the soil is slower to warm is that the field absorbs less solar energy as the residue covering the soil is a much lighter color than the black soil which would be exposed in conventional tillage. This can be managed by using row cleaners on a planter.[40] Since the soil can be cooler, harvest can occur a few days later than a conventionally tilled field. Note: A cooler soil is also a benefit because water doesn't evaporate as fast.

B. Stubble burning

The burning of stubble, contrasted with alternatives such as ploughing the stubble back into the ground has a number of consequences and effects on the environment.

Benefits of Stubble burning

- Quickly clears the field and is cheap.
- Kills weeds, including those resistant to herbicide.
- Kills slugs and other pests.
- Can reduce nitrogen tie-up

However, it has a number of harmful effects on the environment:

- Loss of nutrients.
- Pollution from smoke.
- Damage to electrical and electronic equipment from floating threads of conducting waste.
- Risk of fires spreading out of control

Greenhouse gas emissions from the agriculture sector

Agricultural activities - the cultivation of crops and livestock for food - contribute to emissions in a variety of ways:

- Various management practices for agricultural soils can lead to production and emission of nitrous oxide (N_2O). The large number of different activities that can contribute to N_2O emissions from agricultural lands range from fertilizer application to methods of irrigation and tillage. Management of agricultural soils accounts for over half of the emissions from the Agriculture sector.*
- Livestock, especially cattle, produce methane (CH_4) as part of their digestion. This process is called enteric fermentation, and it represents almost one third of the emissions from the Agriculture sector.
- The way in which manure from livestock is managed also contributes to CH_4 and N_2O emissions. Manure storage methods and the amount of exposure to oxygen and moisture can affect how these greenhouse gases are produced. Manure management accounts for about 12% of the total greenhouse gas emissions from the Agriculture sector in the United States.
- Smaller sources of emissions include rice cultivation, which produces CH_4, and burning crop residues, which produce CH_4 and N_2O.

Importance and scope of medicinal and aromatic plants

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Medicinal and Aromatic Plants (MAPs) is the major resource base for all traditional indigenous health care systems, i.e. Ayurveda, Unani, Siddha and Homeopathy. It is a group of industrially important crops which are of immense social; economic and commercial value. These plants play an important role in Indian agriculture as diversification crops. The potential of these crops can be tapped to benefit the farmers through concerted efforts which include conservation, development of improved geno and chemotypes; good agricultural and post harvest processing practices and value addition. India is among the top ranking countries in the world as far as the medicinal plants phytodiversity is concerned. Enlightened farmers and traders now see prosperity in cultivating, processing and trading of these high value crops. This group of plants enjoys considerable representation as drugs and is used in different systems of medicine either as the active principle or crude drug.

The demand for the products obtained from these plants i.e. biosynthesized metabolites are increasing day by day in national and international markets. The huge demand is mainly on account of (a) consumption by the domestic herbal industries (b) consumption by the rural households for their health care and (c) exports. The non commercial demand of medicinal plants resources by the rural household is more than 25%of the overall consumption of botanical raw drugs in the country .It has been estimated that the world demand for medicinal plant products is growing at the rate of 7% per annum. The planning commission has identified medicinal plants as one of the sectors that can make India a global leader.

Madhya Pradesh is endowed with rich and divers forest resource as well as a reservoir of biodiversity. It is the only state with largest forest area in the country and has a rich resource base of medicinal plants with a tremendous chemotypic and ecotypic variations as well as suitable agroclimate for their cultivation.The loss of biodiversity in our country now been alarming which includes loss of valuable medicinal plants. The efforts are urgently needed both for *insitu* and *exsitu* conversation of medicinal and aromatic plant in different agro-climate zones. Due to over exploitation of naturally available forest wealth of medicinal and aromatic plants, time has come now to domesticate and cultivate them in the farmers field which needs immediate attention towards scientific inputs to identify, adopt, cultivate, process, quality testing and marketing of medicinal and aromatic plants. It is important for commercial cultivation of medicinal and aromatic plants to improve the productivity and quality of raw drug material through genetic, breeding and biotechnological tools and develop improved varieties. The improved varieties are required not only for deriving high biomass yields but also high secondary metabolite production for remunerative economic returns. The state of Madhya Pradesh has different agroecological zones and it is essential to adjudge the best suited medicinal and aromatic plants in all zones. Scientific zoning may helps greatly in derving not only economical levels of productivity but also in the production of higher contents of secondary metabolites. The improvement in production of raw drug material of medicinal and aromatic plants is top priority similarly the production of active bio-molecutes at field level required constant monitoring under different agronomic practices. Significant results have been reported for improvement of herbage production by altering the agronomic practices.

Wealth of Medicinal flora in India

Indian gene centre is extremely rich in plant genetic wealth occupying a unique position with respect to genetic resources of medicinal plants. The country stands 10th among the plant genetic resource rich countries encompassing 15 Agroclimatic zones. India is one of the top mega diversity centres of the world with a unique wealth of 15000 – 20,000 medicinal plant species. It harbors two of the 25 hot spots of the world i.e. Eastern Himalayas and Western ghats.

Habits analysis of enlisted medicinal species found in India indicate that 1/3rd are trees, 1/3rd shrubs, and climbers and the remaining are herbs and grasses. Major plant families contributing to medicinal plant wealth includes Fabaceae Poaceae, Asterceae, Euphorbiaceae, Rubiaceae Acanthaceae, Apocynaceae, Convolvulaceae, Malvaceae, Solanaceae, and Cucurbitaceae.

Medicinal plant sector has traditionally occupied an important position in the socio-economic, cultural and spiritual arena of rural and tribal lives. About 8000 flowering plants 650 lichens, 650 algae, 200 pteridophytes, and 150 bryophytes are attributed with medicinal properties. The Indian coded system encompasses a large number of treaties on recognized systems of medicine viz. Ayurveda, Unani and Siddha. The Ayurvedic system of medicine which cater to the health needs of a major segment of population currently utilize as many as 1000 single drugs and 8000 compound formulations of recognized merit. Other system of medicine viz. Siddha, Unani, and Amchi (Tibeten) systems of medicine together utilized about 1800-1900 medicinal species. Many medicines of plant sourceses used as full prescription drugs in modern system of medicines. The list of Medicinal Plants use for treatment of several disease are given in Table - 1

Table 1 : Therapeutic uses of medicinal plants

Blood purifier *Commiphora wightii* (Guggul) *Curcuma amada* (Aama haldi) *Curcuma longa* (Haldi) *Hedychium coronarium*(Gulabakaoli)	**Cardiac diseases** *Allium sativum (Lahsun)* *Dillenia indica (Chalta champa)* *Terminalia arjuna (Arjun)* *Cymbopogon martini (Rosa Grass)*
Blood disorders *Catharanthus roseus* (Sadabhar) *Celastrus paniculatus* (Malkangani) *Ocimum sanctum* (Tulsi) *Rauwolfia serpentina* (Sarpgandha)	**Piles** *Amorphophallus companulatus* (Suran) *Cissus quadrangularis* (Hadjor) *Gloriosa superba* (Kalihari) *Solanum xanthocarpum* (Bhatkatai)
Asthama *Albizzia lebbak* (Siris) *Amorphophallus companulatus* (Suran) *Nyctanthes arbortristis* (Harsingar) *Solanum xanthocarpum* (Bhatkatai)	**Diabetes** *Emblica officinalis* (Aonla) *Ficus glomerata* (Gular) *Gymnema sylvestre* (Gudmar) *Pterocarpus marsupium* (Bijasar) *Syzygium cumini* (Jamum)
Fever *Abutilon indicum* (Bala) *Argyreia nervosa* (Bidhara) *Gmelina arborea* (Ghamer) *Lagerstroemia speciosa* (Jarul) *Tinospora cordifolia* (Giloe)	**Memory enhancer** *Acorus calamus* (Buch) *Bacopa monnieri* (Brahmi) *Centella asiatica* (Manduk parni) *Nardostachys jatamansi* (Jatamansi)

Medicinal plants as part of culture

It is evident that the Indian people have a tremendous passion for medicinal plants and use them for a wide range of health related applications from a common cold to memory improvement and treatment of poisonous snake bites to a cure for muscular dystrophy and the enhancement of body’s general immunity. In the rural traditions local communities in every ecosystem from the trans Himalayas down to the coastal plains have discovered the medicinal uses of thousands of plants found locally in their ecosystem. India has one of the richest plant medical culture in the world. It is a culture that is of tremendous contemporary relevance because it can on one had ensure health security to millions of people and on the other hand it can provide new and safe herbal drugs to the entire world. There are estimated to be around 25000 effective plant based formulations used in folk medicine and known to rural communities all over India and around 10000 designed formulation are available in the indigenous medical texts.

Distribution of medicinal plants

Macro analysis of the distribution of medicinal plant show that they are distributed across diverse habitats and landscape elements. Around 70% of India’s medicinal plants are found in tropical areas mostly in the various forest types spread across the Western and Eastern ghats, the Vindhyas, Chotta Nagpur plateau, Aravalies and Himalayas. Although less than 30% of the medicinal plants are found in the temperate and alpine areas and higher altitudes they include species of high medicinal value. Marco studies show that a larger percentage of the known medicinal plant occur in the dry and moist deciduous vegetation as compared to the evergreen or temperate habiats.

Analysis of habits of medicinal plants indicate that they are distributed across various habitats. One third are tree and equal portion shrubs and the remaining one third herbs, grasses and climbers. A very small proportion of the medicinal plants are lower plants like lichens ferns algae etc. Majority of the medicinal plant are higher flowering plants. (Table 2, 3 & 4)

Table 2:- Distribution of Medicinal Plants by habits

Habit	Percent distribution
Herbs	32%
Shrubs	20%
Trees	33%
Climbers	12%
Others	03%

Table 3:- Distribution of genera of medicinal importance in various families

Family	No. of genera
Asteraceac	419
Euphurbiaceac	214
Laminaceae	214
Rubiaceae	208
Poaceae	168
Acanthaceae	141
Rosaceae	129
Apiaceae	118

Table 4:- Distribution of medicinal plants by parts used

Medicinally important plant parts	Percentage
Root	26.60
Stem	5.50
Wood	2.80
Leaves	5.80
Flowers	5.20
Fruits	10.30
Seeds	6.60
Rhizome	4.40
Whole plants	16.30

Global trade

The gobal herbal market is a rapidly growing industry. A large number of people use the herbal products. The phytopharmaceuticals also are witnessing higher rate of use. The FDA permits their use as nutraceuticals. The products of natural origin with low concentration and multiple mechanism of action are most preferred. The potential bioenhancers with synergy are in demand.

The Global herbal market of Medicinal and Aromatic Plants can be classified into five strategic areas as follows:-

1. Phyto pharmaceuticals – the plant classified drugs containing isolated pure active compounds used to treat diseases.
2. Medical Botanicals / Botanicals Extracts / Herbal or Dietary supplements: the whole extracts or standardized extracts. Which have been standardized for particular market compound used for maintenance of health by affecting a body structure and its function.
3. Nutraceuticals – the food containing supplement from natural (Botanical) sourceses that deliver a specific health benefit including prevention and treatment of disease.
4. Cosmeceuticals – the cosmetic products which contain biologically active ingredients of botanical origin having an effect on the user.
5. Herbal raw material

An estimate puts the global market for herbal products among US$ 120 billion an year with a share of Ayurveda being almost 50%. USA and Europe are the largest markets for herbal products accounting for nearly two – third of the total demand. There are about 16 best selling herbal drugs is US and Europe of which 8 are produced in India. (Table - 5)

Table 5 : Best selling herbal drugs in USA and Europe exported from India

Common Name	Botanical Name
Isabgol	*Plantago* ovata
St. John's wort	*Hypericum perforatum*
Aloe	*Aloe barbedensis*
Pepper mint	*Mentha pipertta*
Manduk parni	*Centella asiatica*
Milik thistle	*Silybum marianum*
Valerian	Valeriana sp. (Jatamansi)
Ginseng	*Panax pseudoginseng*

India at present exports herbal material and medicines worth Rs. 1210/- crores annually comprising of Rs. 590 crores form saps and extracts Rs. 300 crores from plants and plant parts and Rs. 235/- crores from Ayurveda and Unani medicines.

Domestic market

The domestic market of Indian system of medicine comprising of Ayurveda Unani, Siddha and Homeopathy is estimated to be around Rs.4200/- crores. In the domestic market Ayurveda medicines accounts for a major portion 84% with a growth rate of 15-20% per annum. The crude drugs and extracts are used for the production of over the counter products, ethical formulations as well as traditional and home remedies.

Table 6 : Major herbal extracts exported from India

Herbal extract	
Amla extract	Tusli extract
Hypericum extract	Gurmar extract
Ashwagandha extract	Neem extract
Boswelli extract	Sapand extract of opium
Brahmi extract	Gamboge extract
Gulgule extract	Guduchi extract
Gingko extract	Centella extract

Table 7: Major medicinal plants and plant parts exported from India

Plant parts	
Psyllium husk	Isabgol seed
Senna leaves & pods	Periwinkle leaves & roots
Belladona leaves and roots	Neem seeds
Ginseng roots	Neem leaf powder
Ipecac dried rhizomes and fruits	Gymnema powder
Liquorice roots	Betel leaves
Nux – vomica seed	Ganboge fruits rind
Poppy flower and unripe capsules	Galangol rhizomes
Chirata	Turmeric rhizomes
Ambrette seed	

Commercial cultivation of medicinal and aromatic plants

The systematic cultivation of medicinal plants is quite necessary to meet out the emerging demand of medicinal plants. Cultivation of medicinal plants permits production of uniform quality raw material whose properties are standardized and from which the crude drugs can be obtained unadulterated. Looking to the different utilities of these crop we have to introduce these crop into the cropping system of farming communities, especially based on agroclimatic conditions, where they can easily be grown. In the areas having problem of shortage of water supply, a strong thrust should be given to the need for soil and water conservation by growing adaptive medicinal plants, which may also provide employment opportunities to the youth of the country. However, even after a large number of advantages; the systematic cultivation of these plants is very slow due to the following reasons:

1. Lack of awareness among the farmers regarding commercial cultivation of medicinal and aromatic plants.
2. Lack of high yielding varieties and good quality planting material to obtain high yield and quality product.
3. Less or insufficient processing techniques leading to low yield and poor quality products.
4. Improved cultural practices are not available to obtain high yield from unit area to make cultivation of these plants cost effective compared to wild collection.
5. Lack of product diversification and development of other value added products viz. extracts, concentrates etc. for export market so as to sustain demand of raw materials rather than the dependence on classical formulation alone.
6. Lack of R&D on product and process development.
7. Inadequate infrastructure for quality management processing studies to improve the quality efficiency and effectiveness of the traditional drug.
8. Unstable market condition keeping farmers away from taking up cultivation of medicinal crops.

Advantages in cultivation of medicinal plants in dry areas.

1. Certain complex chemical substances like alkolides; steroids essential oils etc. accumulate in different parts, which are known as secondary metabolites. The concentration of these metabolites was reported to be higher under water stress conditions probably providing drought resistance to certain plant. Some of them are highly tolerant to both biotic as well as abiotic stresses. Hence, rainfed regions offer superior niche for cultivation of such plants. Therefore such plants can be profitably cultivated in dry lands more particularly for economic crop diversification.
2. Longer shelf life of products. If stored properly they retain their quality for long time at room temperature providing ample opportunity to grower to wait for remunerative price.
3. Crops are theft proof as these are not edible and local market virtually absent to dispose of these stolen corps.
4. Crop not eaten by domestic animals or damaged by birds.
5. Low incidences of pest and diseases.
6. Export oriented crops and they earn foreign exchange.

7. By product can be profitably utilized as fuel for distillation unit, mulch for crops manure composting, packing material, cattle feed, manufacture of papers etc.

8. Employment generation through establishment of ancillary industry.

9. Low labour requirement.

Many of these crops can be incorporated in to agri horticultural and agro forestry system and are amenable as intercrops thereby increasing returns from unit area

Though there have been substantial increases in production of food and other crops, the need for diversification of crops / cropping systems have been felt more than any time in agriculture. Diversification laterally through diversified crops / cropping systems and vertically through processing and value addition vastly improves the crop economics. Medicinal and Aromatic Plants fit very well in the current scheme of crop diversification in different agro climatic regions of India.

Table 7: Improved varieties of medicinal and aromatic plants. The following varieties are suitable for this region.

Crop	Varieties
Ashwagandha	Poshita, JA-20, JA134, Ashwagandha
Kalmegh	Anand Kalmegh-1, CIM- Megha, KI-5, IIM(J)-90
Safed musli	MCB 405, JSM 405, MCB 412, MCB 414, ASM
Aloe vera	CIM-Sheetal, IC-111280, IC-111271, RLAV-18
Isabgol	Gujrat isabgol-1, GI-2, Haryana isabgol-5, Niharika, JI-4
Giloy	Giloy,(from IIIM, Jamu)
Satawer	Shatavar
Chandrasur	MLS -5, MLS-6, GA-1
Palmarosa	Trishna, Vaishnavi, Tripta, IW-31245, Jamrosa, PCR-1, PRC-1
Lemon grass	Sugandhi, Cauvery, Krishan pranam, CPK- 25, GRL-1, OD440, OD488
Java citronella	Manjusha, Mendakini, Medini, Manjari

Recent developments in bnf and biofertilizer research for sustainable agriculture

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Introduction

Intensive cropping with use of imbalanced use of high analysis fertilizers coupled with an enormous reduction in recycling of organics or other wastes has led to a continuous decline in the organic carbon levels in Indian soils, impaired soil physical properties, reduced soil biodiversity, aggravated the demand for nutrients not applied etc., all of which are contributing to stagnating yields and reduced factor productivity. World population has now been increasingly relying on nitrogen fertilizers in order to keep up with the demands of food and economic growth rates. As population is increasing, producing enough food in India will require us to increase N consumption by 2.5% per annum. Approximately 2 tons of industrially-fixed nitrogen are needed as fertilizer for crop production to equal the effects of 1 ton of nitrogen biologically-fixed by legume crops. Therefore, biologically-fixed nitrogen influences the global nitrogen cycle substantially less than industrially-fixed nitrogen. So the importance of BNF in a future warmer world is obvious as both the manufacture and use of chemically fixed nitrogen involve emissions of green house gases like carbon dioxide and oxides of nitrogen. For all the above reasons, there is a renewed emphasis now on biological technologies like composting, legume BNF, Biofertilizers, integrated nutrient management, and Biopesticides etc. This is especially important for India where soil organic matter content is low; cost of chemical fertilizers is high and the use efficiency of applied chemical nutrients is poor. This also becomes important in the context of climatic aberrations imposing severe abiotic and biotic stresses on crops. Considering the high import cost of fertilizers, it is imperative to reduce a part of chemical fertilizer inputs by biofertilizers. In India, where ~70% lands are under dry farming, where average pulse yields are only ~700 kg/ha, biofertiliser technologies have to be given a high priority and any neglect would be detrimental.

Biological Nitrogen Fixation

Biological nitrogen fixation (BNF) in natural terrestrial ecosystems contributes globally about 107 million tonnes of nitrogen (Galloway et al 2004) each year. Cultivation induced BNF in agricultural crops and fields adds another 33 m t per year (Smil 1999). Thus

total terrestrial nitrogen fixation is 140 m t N/year. The break-up in agriculture is as follows: symbiotic BNF by *Rhizobium* associated with seed legumes- 10 m t/yr, leguminous cover crops (forages and green manures)- 12 m t/yr., non-*Rhizobium* N fixing species- 4 m t/yr, cyanobacteria in wet rice fields-4-6 m t/yr and endophytic N fixing organisms in sugarcane- 1-3 m t/yr. Relative to cultivation induced BNF, about 3 times as much N is fixed by the Haber-Bosch process, about 100 m t N per year of ammonia. The industrial fixation of nitrogen is increasing each year with the setting up of more plants. We now have a significant repository of information on basic aspects of BNF as well as reliable and cost-effective technologies for enhancing the inputs of nitrogen and phosphorous into cropping systems and a valuable database on nutrient supply through biofertilizers. For most of the cultivated crops and soil types in India, indigenously adapted, efficient strains of rhizobia for legumes, non-symbiotic and associatively symbiotic bacteria for non-legumes, blue green algae for rice and phosphate solubilizing bacteria for all crops have been isolated A recent review highlights the role of biological nitrogen fixation and biofertilizers in agricultural systems (Rao 2014)

Biofertilizers

Biofertilizers are preparations of living microorganisms that are useful for promotion of plant growth through a variety of mechanisms like biological nitrogen fixation, solubilization of insoluble phosphates, oxidation of sulfur, production of growth hormones and some of them also help plants to fight diseases. These include specific strains of bacteria, fungi and blue-green algae. Application of organic manures is required in very high quantities to meet nutrient demand of crops; chemical fertilizers are becoming increasingly expensive. Biofertilisers are thus attractive as they are applied in small quantities, are cheap and when used along with small doses of organic manures and reduced dose of chemical fertilizers, give synergistic benefits on productivity, nutrient use efficiency, crop quality, soil health and disease suppression. By using biofertilizers farmers most commonly report earlier germination, more greenness, greater tillering and healthy crop stand. About 10% higher yield and 25% nutrient savings have been widely observed. In addition, significant improvement in use efficiency of applied nutrients has been observed in hundreds of experiments (Rao, 2014). Biofertilisers also improve produce quality in terms of phyto-chemicals and are contributing to improvement of nutritional security, particularly among those cultivating vegetables. Increased emphasis on organic farming, horticulture and commodity crops will require increased supply of quality biofertilisers.

The biofertilizers that are most widely recommended for crops and produced in significant quantities are:

Rhizobium- Symbiotic nitrogen fixing of legumes which convert atmospheric nitrogen into available forms in the root nodules of legumes, recommended for seed inoculation.

Azotobacter- Non-symbiotic nitrogen fixing bacteria recommended for seed inoculation/ seedling dip of all food, oilseed, vegetable and horticultural crops.

Azospirillum- Associatively symbiotic, nitrogen fixing and plant growth promoting bacteriarecommended for rice, maize, sugarcane, millets and vegetables for seed inoculation/ seedling dip.

Phosphate Solubilising Bacteria (PSB): Various strains of *Bacillus* and *Pseudomonas* are known to solubilize insoluble soil phosphates and are recommended for seed and soil inoculation for all crops.

Plant growth promoting rhizobacteria (PGPR)- They promote plant growth through a variety of mechanisms like fixation of nitrogen, solubilisation of phosphate, production of growthhormones like auxins and gibberellins, antibiotics, siderophores, ammonia and HCN production and some of them also exhibit ACC deaminase activity. Examples include *Bacillus* and *Pseudomonas*, *Azotobacter*, *Azospirillum etc.* listed above. Even *Rhizobium* is known to exert PGPR action on cereal crops.

Blue green algae (BGA)- Non symbiotic nitrogen fixing cyanobacteria, recommended for rice, e.g., *Nostoc, Anabaena, Aulosira, Tolypothrix* etc.

Azolla- Water fern that has nitrogen fixing *Anabaena* as a micro-symbiont, recommended both as a green manure and as inoculant for rice paddies.

VAM (Vesicular-Arbuscular Mycorhiza) are fungi which are associated with the roots of most higher plants and helps the plants in mobilizing macro- and micro-nutrients.

In fact there are a number of other microorganisms that are useful as biofertilizers-for example *Thiobacillus* for S oxidation, *Aspergillus* for P solubilization, Silicon and potassium mobilizers, a number of newly reported PGPR like *Burkholderia*, *Acetobacter* all these are not discussed here as they are yet to become very popular from production point of view, the way others mentioned here have become. In fact most of the microorganisms listed in the previous paragraphs are poly-functional nature. Many of them can solubilize phosphorus as well as act as PGPR. Even BGA are known to solubilize phosphate and produce growth promoting hormones.

Biofertilisers are now included in the Fertliser control order 1985 (amended upto April 2015) which specifies revised standards for ten preparations namely: *Rhizobium*, *Azotobacter*, *Azospirillum*, Phosphate solubilising bacteria, Mycorrhizal biofertilisers, Potassium mobilizing bacteria, Zinc solubilizing bacteria, *Acetobacter*, Carrier based consortia and Liquid Consortia. The global market for biofertilisers in terms of revenue was about 5 billion USD in 2011 and forecasted to double by 2017 (quoted by Malusa and Vassilev, 2014). Biofertiliser production in India is around 50,000 tonnes per year but the potential requirement is much higher. Application of biofertilisers is not a priority for farmers; the main issues are lack of timely availability at sowing time and poor quality in some areas. Other constraints are lack of awareness about biofertilizers due to poor extension efforts and improper application.

Benefits of Biofertilization

The efficacy of various microbial inoculants in increasing the yields and saving nitrogen and phosphorus for pulses, oilseeds, cereals etc., has been convincingly proved in farmers' fields in most agro-eco-zones. Mixed biofertilizers (BIOMIX) containing a consortium of N fixers, P solubilisers and PGPR were found to promote the growth of cereals, legumes and oilseeds better (10-25% increase) and saved 25% NP fertilizers in crops. This was convincingly shown in various field experiments and demonstrations conducted by AICRP on BNF and AINP on Soil Biodiversity-Biofertilizers for both aerobic and lowland rice in Tamilnadu; blackgram, chillis, pigeonpea and cotton in high input usage areas in Vertsols of A,P., for groundnut in Junagarh; for cotton, black gram, soybean and pigeonpea in Vertisols of Maharashtra; pearl millet, wheat and mustard in irrigated lands in Hisar and rain fed conditions in Haryana. Biofertilizer trials were conducted in AP through 22 DAATT centres.

Biofertilizer technology demonstrations in INM package to soybean and wheat farmers was done by IISS, Bhopal. Biofertilizers for minor millets (Kodo millet and Kutki or little millet) and Niger in tribal areas of Dt. Dindori., M.P gave yield increases of 5-11% over farmers practice where no fertilizers are being used (Rawat et al 2008a). IPNS treatment resulted in substantial yield increase ranging from 100-230% over farmer's practice.

In 'Front Line Demonstrations' application of biofertilizers gave additional groundnut pod yields 5-27% in Tamilnadu (Ilamurugu et al 2008) and 15-27% in Maharashtra (Kachhave et al 2008) ; additional soybean seed yields of 5% in Madhya Pradesh and 30% in Maharashtra. In rice in Tamilnadu, 15-20% increase in yield was observed with Azophos. In Haryana 5% increase in grain yield and 6% in fodder yield was observed in pearlmillet besides saving 25% N. In mustard 2.6- 9.0% increase in grain yield was obtained due to inoculation of mixed biofertilizers (increase of 0.5-1.5 q/ha.) The total amount of benefit due to biofertilizers in the inoculated soybean-wheat system in Vertisols in Madhya Pradesh was 124 kg N /ha/yr. The results are summarized in various reports (Rao, 2008, 2014). The response of biofertilizers was better when used along with chemical fertilizers (Kacchave et al 2008).

Recent results on Biofertilizers in Eastern India

In eastern India mycostraw enriched with *Pseudomonas*, *Azospirillum*, Cyanobacteria gave rice yield increase of 10-20% in resource poor and 6-10% increase in resource rich farmers in Bihar. Lentil yields increased by 10-20% due to *Rhizobium* inoculation. Arbuscular mycorrhizal fungi (AMF) inoculum for upland rice in Jharkhand improved rice yields by 7-20%. In Odisha in tribal areas of Kalahandi biofertilizers improved cotton unit yield by 30%. The average benefit was Rs 11,520 ha^{-1}. Cultivation of vegetables (cabbage, cauliflower, broccoli, capsicum) with bioinoculation increased yields by 10-20%. In Jute-rice-green gram system in Odisha, jute yield increased by 19% due to biofertilization over soil test dose, in rice by 8% and in green gram by 12%. NPK recovery increased from 62.0 to 74.0% in STD + BF (extra nutrient uptake of 42 kg/ha). In Jute in Assam, application of biofertilizers decreased the consumption of chemical fertilizers by 50%. Application of microbially enriched compost @2t/ha gave best yields and capsaicin content of hot chilli in NE India. Microbially enriched compost (5t/ha) with biofertilizer or green manure with biofertilizer or *Azolla* @0.5t/ha with biofertilizer gave highest rice grain yield. Application of K along with enriched compost saved 25-50% dose of NP in NE India.In Mandla and Chindwara districts of Madhya Pradesh., inoculation gave additional yield of 10-20% in pulse crops and 15% in soybean and maize. Livelihood improvement of a small farmer owing 1ha land in coastal acid soil of Odisha was demonstrated by cultivation of vegetables, cereals, pulses, oilseeds, resulting in an additional income of Rs 8300/ha. In term of cost inputs B: C ratio of biofertilizers was 14:1 and overall B:C ratio of cultivation increased from 2.1: 1 (without usage) to 2.5:1 due to biofertilizer usage.Use of biofertilizers in field demonstrations in upland crops (rice and pigeon pea) in Jharkhand gave 10-30% yield increase. *Azolla* cultivation was demonstrated to 10KVK's in Assam.

NUE efficiency and quality improvement by Biofertilizers

As mentioned earlier the use efficiency of applied nutrients from chemical fertilizers is very poor. Therefore all efforts must be made to improve fertilizer use efficiency by crops. The use of composts and FYM along with chemical fertilizers has been shown to improve fertilizer nutrient use efficiency by crops. So far, biofertilizers have been seen only as a means of augmenting nutrients through biological nitrogen fixation, phosphorous solubilization, etc. But recent research reveals that they can improve fertilizer use efficiency and thus they can be exploited for this purpose. Bioinoculants for vegetables in tribal areas of Orissa increased the yields by upto 20 % for above ground and upto 50 % for underground crops, saved 20-25% fertilizer cost and improved the nutrient use efficiency by 12-36% for N, 18-28% for P, 9-15% for K and 16-18% for S (Pattanayak and Rao, 2008). The use of biofertilizers also improved the quality of produce- for example anti-oxidants like lycopene increased by 13% and Vitamin C by 27 % in tomato, and curcumin content of turmeric increased by 10% in farmer field produce. So the role of biofertilizers in improving the nutritional security is extremely pertinent.

Organic Amendments improve Biofertilizer Efficacy

Organics have been found to boost the proliferation of *Rhizobium* and enhance nodulation and nitrogen fixation in a number of legumes and oilseeds. *Rhizobium* inoculation increased the pod yield of groundnut by 391 kg ha^{-1} while application of FYM alone @ 5 Mg ha^{-1} increased the yield by 151 kg ha^{-1}. Combined application of FYM and *Rhizobium* increased the yield by 729 kg ha^{-1}. These and similar results in other legumes led to the recommendation released by from AICRP on BNF at Parbhani `Apply *Rhizobium* inoculants alongwith FYM @ 5 t/ha'. Addition of farm yard manure is known to boost microbial activity and rhizobial proliferation which results in improvement of BNF in legumes. Other studies also showed beneficial influence of organics on legumes. FYM @4t/ha +VAM+ *Rhizobium* had best effect on clusterbean yield and soil microbial properties in an arid soil (Tarafdar and Rao 2001).

Regular Inoculation

Surveys on rhizobial populations in the AICRP on BNF for the major grain legumes have shown populations to be well below the threshold in all areas and below 100 cells/g. (Raverkar et al 2005) due to the extremely high soil temperature and drying of surface soil layers in summer. Recent studies on diversity of rhizobial populations in the AINP on Biofertilizers have also thrown up challenging issues for rhizobial strain selection strategies for major pulse growing regions in the country. In a five year survey of the entire state of Madhya Pradesh, it was found that wherever rhizobial inoculation was practiced by farmers along with FYM and fertilizer application (IPNS) there was best nodulation and grain yield (Rawat *et al* 2008). This underscored the need to promote awareness for adoption of integrated approach in nutrient management along with use of good quality rhizobial inoculants to promote soybean yield and BNF .

Production and Use of Biofertilizers

Adequate precautions need to be taken in the use of biofertilizers. Since biofertilizers contain live cells, care should be taken during their transportation and storage. They should be kept in a cold place and not exposed to sunlight. Legume cultures are crop-specific and they must be used for the crop for which they are meant. If they are to be used under adverse soil conditions, appropriate remedial measures like liming and use of gypsum should accompany their application to soil. At present about 50,000 tonnes of biofertilizers are produced in India. In majority the carrier is a solid support like lignite or charcoal. Strictly sterile conditions are required to be maintained in its production at all stages to obtain a good quality product alongwith proper storage conditions to ensure acceptable cell count (> 5 x 10^7 cells/g) at the end of six months expiry period. Liquid biofertilizers with added cell protectants to improve survival of bacteria have been shown to have higher shelf life upto one year. The use of microbial inoculants is now finding increasing acceptance in many areas and farming situations, particularly in organic farming pockets. But there are serious concerns about the poor quality of inoculants from many production units who employ unsterile carriers and unhygienic production methods resulting in high level of contaminants. The Bureau of Indian Standards has produced quality standards for most inoculants. The Govt. of India has included biofertilizers in the Fertilizer Control Order making it mandatory for manufacturers to register themselves with state governments. A quality control mechanism has been put in place and responsibility entrusted to the National Centre on Organic Farming of the Government of India.

Adoption of biofertilizers by farmers

With proper usage, farmers have reported more vigorous crops (greenness), bolder grains and better yields. Soil application is preferred for rice by most farmers. Adoption is easy in vegetable growing as it involves only dipping of seedlings and success is better since FYM is invariably applied and good irrigation regimes are maintained. This invariably led to improvement of the quality of the produce and better nutrient use efficiency. The B/C ratio of Biofertilizers is on the average ~15 and can even as high as 80. Adoption has been good when there is good investment by state in Microbiology teaching and Research as for example in Tamilnadu. Crucial role of TV/ Radio, sale of BF packets through seed depots, advertisement through posters etc needs to be recognized. Adoption has been good wherever the manufacturer is doing "niche marketing". Success has also been obtained in areas where organic residues are available for recycling through horticultural shrubs, trees etc. Adoption of biofertilizers has been better in Southern and Western India. Success stories include widespread usage of *Azospirillum* for rice in Tamilnadu, *Rhizobium* for soybean in Madhya Pradesh, and *Pseudomonas* and *Bacillus* (referred as PSB-phosphate solubilizing bacteria-although the action is more akin to a PGPR effect) in many areas.

There are some constraints in adoption of biofertilizers which has led to their being adopted on a scale that is desired**.** Application of biofertilizers is not a priority for most farmers. In a survey by AICRP-BNF (Rao 2000, detailed report in Ilamurugu et al 2008), problems cited by farmers in Tamilnadu are : Lack of timely availability of inoculants at sowing time and supply of expired packets. Bottlenecks in wide spread adoption of inoculants by farmers include poor quality due to low count, contaminants etc., lack of awareness about BF's due to poor extension efforts and improper application methods (simply mixing powder with seeds) among others. Insufficient extension efforts have contributed to poor diffusion of BF technology. Mushroom growth of production units set up by low and medium investors solely with profit motives, not employing qualified microbiologists, using unsterile carriers with hardly any quality control have mainly contributed to the poor quality. The very low cost of inoculants adds to the problem of maintaining high quality. Quality control is thus largely voluntary. On the other hand the main constraints expressed by manufacturers are: unattractive carrier material, low shelf-life, lack of proper storage facilities, loss of quality on transportation, poor marketing, high risk and less profit discourages dealers, market captured by unwanted companies, mushroom growth of profiteers.

Successful Solutions and Way forward

There are many success stories of biofertiliser usage all over India e.g., *Azospirillum* for rice in Tamilnadu, *Rhizobium* for soybean and phosphate solubilizing bacteria (PSB) all over the country. Biofertiliser adoption is easy in vegetable growing and very successful since farm yard manure is invariably applied and good irrigation regimes are maintained. This leads to improvement of the quality and shelf life of the produce, and improved nutrient use efficiency. These success stories need to be replicated more widely. The production of biofertilisers and usage is more in southern and western India but is now also picking up in eastern India. The main issues pertain to selecting the best suited and most efficient microbial strains for a crop/soil/region; use of certified mother cultures supplied by R& D laboratories for industrial production, using only sterile methods of production and maintaining high quality at all stages - production, storage and till its supply to the farmer. It should be mandatory for the industry to disclose details of strain used and its source in the registration certificates and inoculant literature.

Rhizobia rapidly die off in surface soil layers due to heat and desiccation. Improving the pulses production thus requires inoculation each year and greater production of quality rhizobial inoculants. The share of rhizobia in biofertiliser production is only 15%. To cover the entire legume acreage (including soybean and groundnut) the production of rhizobia needs to be increased 3-4 fold to at least 20-25,000 tonnes. To cover all crops, including horticultural and plantation crops with reasonable rate of application, total biofertilizer production in India needs to be increased 8-10 fold from the current 50,000 tonnes to about 0.4-0.5 million tonnes each year. This requires major policy directives to boost infrastructure and encourage the private sector. Allowing market force mechanisms for maintaining quality through creation of brand equity by reputed players will give a fillip to the industry.

Liquid biofertilizers with added cell protectants to enhance the shelf life have shown good agronomic performance (Trimurtulu and Rao 2014). Addition of small amounts of humic acid has been shown to promote survival of bacteria in solid carriers. Microencapsulation through immobilization of microbial cells or their consortia in biodegradable polymers to protect them against dryness and other environmental stresses during storage needs more research. Viability of custom coating of seeds with nutrients, fungicides and biofertilisers is uncertain due to infrastructure problems of cold storage and other logistical difficulties. An ecological approach based on bio-films are showing promising effects and research is underway on natural clay based nano-biofertilisers. Production of mycorrhiza needs to be stepped including production in synthetic or semi-synthetic media. The use of microbial consortia having two or more beneficial organisms is showing promising results. Extensive field experiments conducted in farmer fields under the ICAR-All India Network Project on Soil Biodiversity-Biofertilizers in eastern India have demonstrated the benefits of microbial consortia. For example in Bihar for rice, use of *Azospirillum*, blue green algae and *Pseudomonas* has been shown to confer differential benefits at different plant growth stages. The use of carrier based biofertiliser inoculants pre-incubated in FYM or microbially enriched compost have both shown excellent responses in all crops, particularly vegetables in Odisha and Assam respectively. Other inoculants used though in lesser quantities are blue green algae and *Azolla;* there is a great potential to step up their production through de-centralized units using local strains - many Krishi Vigyan Kendras of ICAR are already producing them and need to be supported vigorously. Research is under-way on newer plant growth promoting inoculants like Actinomycetes and *Arthrobacter* which are showing promise on a wide variety of crops. *Methylobacterium* has shown promise in imparting stress resistance to rice under drought conditions. In diversification of usage, improvement in yield of fibre crops like jute and cotton, particularly on quality aspects; floriculture-size and shelf life of flowers; high value crops like hot chillis etc., are recent results that need to be further exploited widely by scaling-up.

Epilogue

The constraints to fuller implementation of biofertiliser technologies in Indian agriculture are not scientific, but largely organizational and logistical. There is a need to develop an integrated strategy to replicate the success stories and raise the general awareness about the benefits of biofertiliser usage to a level where it is implemented as a normal package of practice by the farming community to improve yields and benefit soil health.

References

- Kachhave, K.G., Adsul, P.B., Raut, R.S. and Kide D.S. (2008) Front line demonstrations on biofertilizers for oilseeds. All India Network Project on Biofertilizers, Technical bulletin, MAU.DEE NO. 30/2008, MAU, Parbhani, pp 20
- Ilamurugu, K., Natarajan, T., Balchander, D. and Rao, D.L.N. (2008) Research-Adoption-Impact Analysis of Biofertilizers in Tamilnadu. All India Network Project on Biofertilizers Bulletin, TNAU, Coimbatore, pp 62
- Pattanayak, S.K. and Rao, D.L.N. (Eds) (2008) Biofertilizers for tropical vegetables. All India Network Project on Biofertilizers Bulletin, OUAT, Bhubaneswer, pp 20
- Rao, D.L.N. (2003) BNF and Biofertilisers Research in India: Current status and new initiatives in ICAR network. *Biofertiliser Newsletter* 11 (2): 3-10
- Rao, D.L.N. (2007) Biological Nitrogen Fixation and Biofertilizers: Status and Prospects. In “Agricultural Nitrogen used and its Environmental Implications” Eds. Y.P. Abrol, N. Raghuram and M.S. Sachdev. I.K. International Publishing House Pvt. Ltd., New Delhi, pp. 395-414
- Rao, D.L.N. (2008) Biofertilizer Research Progress (2004-07). All India Network Project on Biofertilizers, IISS, Bhopal, pp 105
- Rao D.L.N. (2014) Recent Advances in Biological Nitrogen Fixation in Agricultural Systems. *Proc. Ind. Natnl. Sci. Acad* **80** Spl. Sec: 359-378.
- Raverkar, K.P., Ajay, Gupta, S.B. and Rao, D.L.N. (2005) Survival of soybean rhizobia in summer and proliferation during monsoon in vertisols of central India. J. Indian. Soc. Soil Science 53: 591-597.
- Rawat, A.K., Dwivedi, B.S. and Rao, D.L.N (2008a) Biofertilizer based nutrient management for tribal areas of Madhya Pradesh. All India Network Project on Biofertilizers Folder, JNKVV, Jabalpur, pp 6
- Rawat, A.K., Khatik, S.K., Rao, D.L.N. and Saxena, A. K. (2008b) Soybean rhizobial inoculants survey in Madhya Pradesh. All India Network Project on Biofertilizers Bulletin, JNKVV, Jabalpur, pp 33
- Rao DLN (2014) Soil Biodiversity-Biofertilizers Research Progress (2012-14). All India Network Project on Soil Biodiversity-Biofertilizers, IISS, Bhopal, pp 81.
- Trimurtulu N. and Rao DLN (2014) Liquid Microbial Inoculants and their Efficacy on Field Crops. AINP on Soil Biodiversity and Biofertilizers Bulletin, ANGRAU, Agricultural Research Station, Amaravathi, Andhra Pradesh, pp 54.

Climate Change Impact on Soils: Adaptation and Mitigation

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The dependency of Indian agriculture on climate is indicated by the fact that cultivation in 60% rainfed area of the total cropped area is dependent on uncertainties of monsoon. Climate change can impact directly on food security through food system stability. Agriculture is important for food security in two ways: it produces the food people eat; and it provides the primary source of livelihood for 36% of the world's total workforce. In the thickly populated countries of Asia and the Pacific, this share ranges from 40-50% and in sub-Saharan Africa, 67% of the working population still make their living from agriculture. Agriculture is considered both as a contributor to climate change and a victim as well. Agriculture is a contributor because it emits significant amount of greenhouse gases, and victim because climate change have considerable impacts on agricultural production. The fourth assessment report of Intergovernmental Panel on Climate Change (IPCC) made it clear that the global average temperature has increased by 0.740C over the last 100 years and projected increase is about 1.8 to 4.0^{o}C by 2100. Climate change and agriculture are interrelated processes and global warming is projected to have significant impacts on agriculture by influencing through direct and indirect effects on crops, soils, livestock and pests. Apart from the probable decline in food production, nutritional quality of food may also be reduced raising a concern for nutritional security. Alarmed by the possible impact of the global climate change on the quality of life of human beings efforts are being made to develop strategies to mitigate its negative impacts. In light of these concerns, the impact of climate change on soils and its mitigation and adaptive strategies have been discussed.

Climate change impacts on Soils

Climate change is global phenomena and occurring continuously since the earth came into existence. Climate change has become a major scientific and political issue during the last decade. There are well marked cold and hot cycles in the history of earth's climate, however, these changes have been observed relatively rapid in the last 150-200 years around the world (Fauchereau *et al*., 2003). Soil seems to be more important for modern human societies than ever before to meet the global demands for food and fiber for increasing population from limited soil resources. Climate change is threatening food security globally. Countries like India are more vulnerable in view of the tropical climate and poor coping capacity of the small and marginal farmers. Climate change is projected to have significant impacts on agriculture through direct and indirect effects on crops, soils, livestock and pests. Though, climate change is a slow process involving relatively small changes in temperature and precipitation over long period of time, nevertheless these slow changes in climate influence the various soil processes particularly those related to soil fertility. The effects of climate change on soils are expected mainly through alteration in soil moisture conditions and increase in soil temperature and CO_2 levels as a result of climate change. The global climate change is projected to have variable effects on soil processes and properties important for restoring soil fertility and productivity. The major effect of climate change is expected through elevation in CO_2 and increase in temperature.

Soil formation

Soil formation is controlled by numerous factors including climatic factors such as temperature and precipitation. These parameters of climate influence the soil formation directly by providing biomass and conditions for weathering. Main parameters of climate that directly influence on soil formation are sum of active temperatures and precipitation-evaporation ratio. They determine values of energy consumption for soil formation and water balances in soil, mechanism of organic-mineral interactions, transformation of organic and mineral substances and flows of soil solutions. Stable progressive climate warming lead to irreversible changes in mineral matrix of soils. Changes in external factors of soil formation (temperatures and precipitation) will lead to transformation of internal factors (energy, hydrological, biological). The climate change will increase energy of destruction of soil minerals resulting in simplification of mineral matrix due to accumulation of minerals tolerant to weathering. It will lead loss of soil function for fertility maintenance and greater dependence of on mineral fertilizers.

Soil development

Soil development is broadly controlled by three main factors i.e. climate, parent material and vegetation type. The effects of climate change on soil development are expected mainly through alteration in soil moisture conditions and increase in soil temperature and CO_2 levels. Climate change will influence soil moisture levels by direct climatic effects (precipitation, temperature effects on evaporation), climate induced changes in vegetation, plant growth rates, rates of soil water extraction by plants and the effect of enhanced CO_2 levels on plant transpiration. Changes in soil water fluxes may also feed back to the climate itself and even may contribute to drought conditions by decreasing available moisture, altering circulation patterns and increasing air temperatures. Among various factors controlling the process of soil development, climate plays a major role in weathering of rocks and minerals. The variables of climate change particularly temperature and rainfall dictates various stages of weathering of rocks and minerals (parent material) resulting in chemical and mineralogical changes in soil forming rocks. Water is very essential for chemical weathering to take place and hence, an increase in rainfall accelerates weathering. The same types of primary minerals give rise to different secondary minerals when the conditions of weathering differ. Thus similar rock types undergoing weathering in different climatic conditions could give rise to distinct soil profiles.

Soil fertility and productivity

The drivers of climate change such as moisture, temperature and CO_2 are expected to have variable effects on various soil processes and properties having relevance in soil fertility and productivity. However, these effects of the climate change factors cannot be viewed separately, being one factor influence the other and resultant effect would be complex. Further, all these effects will be highly region specific, depending on the magnitude of the climate change, soil properties and climatic conditions. India is bestowed with 9 of the 12 soil orders that exist in world and 15 agro-climatic zones, with diverse seasons, crops and farming systems. Since climate change is a reality, it will have direct and indirect impacts on soil development processes and properties related to crop production influencing the livelihoods of millions of peoples in the country. The impact of climate change factors, specifically temperature, CO_2 and rainfall on various soil properties is being discussed below to understand the relationship between climate change variables and various soil properties in order to evolve appropriate mitigation strategies (Table 1).

Table 1. Summary of expected effects of individual climate change variables on soil processes

Increasing temperature	Loss of soil organic matter Reduction in labile pool of SOM Reduction in moisture content Increase in mineralization rate Loss of soil structure Increase in soil respiration rate
Increasing CO_2 concentration	Increase in soil organic matter Increase in water use efficiency More availability of carbon to soil microorganisms Accelerated nutrient cycling.
Increasing rainfall	Increase in soil moisture or soil wetness Enhanced surface runoff and erosion Increase in soil organic matter Nutrient leaching Increased reduction of Fe and nitrates Increased volatilization loss of nitrogen Increase in productivity in arid regions
Reduction in rainfall	Reduction in soil organic matter Soil salinization Reduction in nutrient availability

Plant nutrient availability and acquisition

Plant availability of nutrients in the soil is a function of soil chemical properties as well as location of the ion relative to the root surface and the length of the pathway the nutrient must travel in the soil to reach the root surface. Increases in air temperature and changes in precipitation have significant impacts on root zone temperature and moisture regimes. It is well known that soil moisture and temperature are primary determinants of nutrient availability and root growth and development and that carbon allocation to roots governs nutrient acquisition, it is reasonable to expect that process outcomes will be reflective of the changed climate. The nature and extent of the change in these two parameters will be site- and soils specific. It has been suggested that climate change impacts on nutrient use efficiency is be primarily affected through direct impacts on root surface area and influx rate (Brouder and Volenec, 2008).

Nutrient transformation in soil

Plants accumulate nutrients from the soil solution pool, and nutrients must be in solution to be mobile in the soil. Biological transformation between organic and inorganic pools is strongly influenced by moisture and temperature, and thus, global climate change may strongly influence solution concentrations of N as well as S. Pendall et al. (2004) suggests that increased CO_2 may not exert a significant direct effect on N mineralization per se but associated warming can cause increased N mineralization, leading to increased solution-phase N. Rates of adsorption/ desorption reactions will accelerate with increased temperature, and changes in soil moisture may further modify reactions by altering the ionic strength of the soil solution.

Soil Carbon dynamics

It is generally accepted that increases in CO_2 concentration quantitatively and qualitatively alter the release of root derived compounds. Plants under elevated CO_2 decrease their allocation of N-rich metabolites and increase the allocation of C rich metabolites to root exudates (Tarnawski and Aragno 2006). It results in an increase in microbial activity and consequently the CO_2 production, which has is a potential negative effect on the accumulation of organic C in soils and thus on potential sequestration of soils. It has been observed that the priming effect as a result of the enhanced microbial activity in soil at elevated atmospheric CO_2 concentration has a significant negative feedback on global change processes and will reduce the sequestration potential of soils. Several studies using C isotope tracers have demonstrated that the production of CO_2 in the rhizosphere by roots and microorganisms is significantly stimulated by elevated CO_2 plant growth conditions. The stimulation of CO_2 respiration in the rhizosphere may be much higher than the enhancement of root biomass. Cheng and Johnson (1998) demonstrated that although plants produced only 15–26% more biomass under elevated CO_2, rhizosphere respired C increased by 56–74% as compared to ambient CO_2 treatments.

Response to Mycorrhizal association

The effects of elevated atmospheric CO_2 concentration on soil microbial community structure are often characterized by an increased mycorrhizal colonization due to the increased plant demand for nutrients, coupled with increased C assimilation rates CO_2 enrichment should increase mycorrhizal biomass because plant demands for N and P will increase concurrently with C assimilation rates, and plants will allocate more hotosynthates belowground to the roots and mycorrhizal fungi to help satisfy this increased nutrient demand. Greater fine root mass and mycorrhizal infection promote enhanced P uptake in mycorrhizal plants grown under elevated CO_2 concentrations. It seems reasonable to expect that at elevated CO_2 levels, mycorrhizal biomass will increase as C becomes relatively less limiting and soil nutrients become more limiting to plant growth (Drigo *et al.,* 2008). However, information available in literature is not always consistent on this point.

Soil biological activities

The response of soil microorganisms to changes in plant production under elevated CO_2 is highly variable due to very different patterns of plant C allocation in different plant–soil systems. Microbial biomass, gross N mineralization, microbial immobilization, and net N mineralization under elevated CO2 show a high degree of variability. However, rates of soil and microbial respiration are generally more rapid under elevated CO_2, indicating that enhanced plant growth under elevated CO_2 increases the amount of C entering the soil, thereby stimulating soil microbial activity. Soil microorganisms are often C-limited and therefore, increased C availability stimulate microbial growth and activity. It is generally assumed that the CO_2induced increases in soil C availability will increase fungal biomass more than bacterial biomass. It is because of increased concentrations of dissolved organic C in the rhizosphere and to increases in soil water dissolved organic N. Given the important roles played by fungi in organic matter degradation, nutrient cycling, plant nutrition, and soil aggregate formation, shifts in fungal communities might have a strong impact on soil functioning. Furthermore, lower N availability at elevated CO_2 may, in part, explain these increases in fungi, as fungi tend to have a higher C/N ratio than bacteria and so have a lower demand for nitrogen than bacteria have (Hu *et al.*, 2001).

Bacteria and fungi, the initial consumers of soil organic matter, are themselves substrates for a multitude of tiny predators and grazers, including protozoa, nematodes, and arthropods, which comprise the soil food web. Therefore, an increase in bacterial growth due to an increasing C allocation at elevated atmospheric CO_2 levels may be followed by an increase in grazing, resulting in a higher turnover of the microbial biomass. Increased grazing thus results in faster recycling of nutrients from the microbial biomass, which would increase the flux of nutrients to the plant.

Adaptation and mitigation strategies

Agriculture can adapt to climate change by adopting farm management practices that minimize the adverse effects of increasing or decreasing rainfall and temperatures or other extreme weather conditions. Many management-level adaptation options are available to attenuate the effects of climate change on crop production, including zero tillage, retaining crop residues, extending fallows, increasing the diversity of production, altering amounts and timing of external inputs (fertilizers, water), as well as broader agronomic management strategies (e.g. altering planting density, row spacing, planting time; introducing new germplasm resistant to heat or drought stress).

Agriculture can contribute to climate change mitigation through farm management practices that reduce greenhouse gas emissions (carbon dioxide, nitrous oxide, methane) and enhance soil carbon sequestration. Emissions of carbon dioxide can be reduced through reduced biomass burning and more efficient energy use. Emissions of methane can be reduced through improved farm management practices that include improved management of livestock waste and water in rice paddies. Nitrous oxide emissions can be reduced through improved management of N fertilizers including appropriate type, rate and method of application and soil management (avoidance of soil compaction).

Various farm management practices can enhance soil carbon stocks and encourage soil functional stability. Conservation agriculture technologies (minimum soil disturbance, cover crops and crop rotations including legumes), soil conservation measures (e.g. contour farming) and nutrient replenishment strategies can restore soil organic matter by providing a protective soil cover and an environment conducive to vigorous plant growth. In some cases, however, a change in the agricultural production system may be required. e.g. continuous cereal cropping being replaced by ley farming or by the introduction of agroforestry systems. The global soil carbon pool exceeds biomass pools by a factor of four or five, without taking into account that recent soil degradation has led to losses of between 30 percent and 75 percent of their antecedent soil organic carbon. Globally, therefore, a soil carbon increase offers great mitigation potential. Carbon sequestration refers to the storage of carbon in a stable solid form. It occurs through direct and indirect fixation of atmospheric CO_2. Direct soil carbon sequestration occurs by inorganic chemical reactions that convert CO_2 into soil inorganic carbon compounds such as calcium and magnesium carbonates. Direct plant carbon sequestration occurs as plants photosynthesize atmospheric CO_2 into plant biomass. Subsequently, some of this plant biomass is indirectly sequestered as soil organic carbon (SOC) during decomposition processes. The amount of carbon sequestered at a site reflects the long-term balance between carbon uptake and release mechanisms. Many agronomic, forestry, and conservation practices, including best management practices, leads to a beneficial net gain in carbon fixation in soil

Agro-ecosystems can play an important role in mitigating CO_2 emissions through biotic C sequestration in soils and vegetation. Because of historic losses of C from soils, estimated to be 41 to

55 Gt, the soils now offer an opportunity for carbon storage. The carbon sequestration potential of a soil depends on climate, the type of vegetation it supports, the nature of parent material, the depth of solum, soil drainage, the edaphic environment, soil organic matter (SOM) content and its decomposability and land management practices. Improved management of agro-ecosystems can significantly enhance C sequestration in soils. Management practices or technologies that increase carbon input to the soil and reduce C loss or both lead to net carbon sequestration in soils (Table 3). Increased C input in agro-ecosystems can be achieved in a number of ways such as selection of high biomass producing crops, residue recycling or residue retention by lessened tillage intensity, application of organic materials (e.g. animal manure, compost, sludge, green manure etc.), adoption of agroforestry systems, intensification of agriculture through improved nutrient and water management practices, reducing summer or winter fallow, changing from monoculture to rotation cropping, and switching from annual crops to perennial vegetation. Soil carbon loss could be decreased by adopting conservation agriculture and minimizing soil disturbance, checking erosion through reduced tillage intensity, and using low quality organic inputs. Technological options that have been found to be efficient for soil C sequestration in Indian agro-ecosystems include integrated nutrient management and manuring, crop residue incorporation, mulch farming and/conservation agriculture, agro-forestry systems, grazing management, choice of cropping system and intensification of agriculture. Integrated nutrient management involving addition of organic manures/composts along with inorganic fertilizers results in improved soil aggregation (Benbi and Senapati, 2010).

References

- Benbi, D. K, and Senapati, N. (2009) Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice-wheat systems in northwest India. *Nutrient Cycling in Agroecosystems* **87**:233–247.
- Brouder, S.M and Volenec, J.J. (2008) Impact of climate change on crop nutrient and water use Efficiencies. *Physiologia Plantarum* **133**: 705–724.
- Cheng, W.X. and Johnson, D.W. (1998) Elevated CO_2, rhizosphere processes, and soil organic matter decomposition. *Plant and Soil* **202**:167– 174
- Drigo, B., Kowalchuk, G.A., and Johannes A. V. (2008) Climate change goes underground: effects of elevated atmospheric CO_2 on microbial community structure and activities in the rhizosphere. *Biol Fertil Soils* **44**: 667–679.
- Fauchereau, N., Trzaska, M., Rouault, M. and Richard, Y. (2003) Rainfall variability and changes in Southern Africa during the 20th century in the global warming context. *Natural Hazards.* 29: 139:154.
- Hu, S., Chapin, F.S., Firestone, M.K., Field, C.B. and Chiariello, N.R. (2001) Nitrogen limitation of microbial decomposition in a grassland under elevated CO_2. *Nature* **409**:188–191.
- Pendall, E., Bridgham, S., Hanson, P.J., Hungate, B., Kicklighter, D.W., Johnson, D.W., Law, B,E., Luo, Y., Megonigal, J.P., Olsrud, M., Ryan, M.G., Wan, S. (2004) Below-ground process responses to elevated CO_2 and temperature: a discussion of observations, measurement methods, and models. *New Phytol.* **162**:311–322.
- Tarnawski, S. and Aragno, M. (2006) The influence of elevated CO_2 on diversity, activity and biogeochemical function of rhizosphere and soil bacterial communities. In: Nösberger, J., Long, S.P., Norby, R.J. *et al* (eds). Managed ecosystems and CO_2 case studies, processes and perspectives. Ecological studies Series, vol 187. Springer, Berlin, pp 393–409.

Climate resilient soil management strategies for sustainable agriculture and green climate with special reference to salt affected soils

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Prologue

Soil health refers to the fitness of soil for specific purpose determined by the factors chosen for soil classification, soil suitability and land capability. It examines spatial and temporal variations induced by land use policy or management. Soil organic carbon (SOC) is the most reliable, versatile and easily assessable indicator, encompassing interactive effect of several factors. While examining spatial variation of soil properties and tree growth parameters in agroforestry under sodic soil condition Dey et al. (1999) observed high variation for soil organic carbon. Plateuing or decreasing trends of crop yield at current level of management indicates declining soil health. Erosion, drought and desertification, irrigation induced salinity and sodicity, paradigm shift in land use, nutrient depletion and adoption of intensive cultivation are the cause of soil health deterioration. Erratic rainfall and exploitation of land, water and vegetation resources by ever increasing human and livestock population further accentuate the problem of soil health. Increasing salinity, residual carbonate, alkalinity and contamination of surface and ground water through heavy metals, nitrates, fluoride and arsenic are the reflection of deteriorating soil health.

Recycling of contaminated or poor quality water through irrigation is further escalating the problem of soil health. Recent estimate indicated that about 32 to 84 % of wells are having poor quality water, dominantly occurring in arid and rain-fed agro ecosystems; covering more than 65 % (92 M ha) of cultivable land in India and spreads over in 18 states and 12 agro-ecological regions. High saline ground water is reported in arid agro ecosystem while alkali waters predominate in semi arid parts of India receiving 500 to 700 mm rainfall. High RSC water with low salinity is common in central and southern part of rain-fed agro-ecosystem (Gupta et al., 1994). Ground water is contaminated with toxic level of boron, fluoride, nitrate, selenium, and arsenic in some parts of the region.

Declining water table as a consequence of high withdrawal for intensive cultivation is another important issue. An alarming rate of decline in ground water, more than 4 meters during 20 years (1981-2000) in some parts of arid and rain-fed ecosystems depict gravity of situation and a sizeable area turns to gray zone. About 60 % blocks of Rajasthan has been reported in gray zone. Water quality deterioration is attributed partly to increased salt concentration and partly to intermixing of poor quality water strata.

Thus the entire arid and rain-fed ecosystem is dominantly affected with poor quality of water. Its continuous use is the major threat to soil health. Organic carbon decomposition, inorganic carbon buildup, secondary salinization and sodification are the immediate impact. Inadequate fertilization, drought and desertification with poor quality water add other dimension. These altogether call for immediate attention for the sustainability of agriculture. The present paper deals with the issues associated to deteriorating soil health in the region of poor water quality; agro-techniques that counter the impact of poor water quality are elaborated. The paper also highlights the strategy for harnessing the optimum benefit of agro-technique for mitigating the impact of poor water quality and for providing cleaner water and fresh environment to the people deriving their livelihood on the earth.

Poor water quality vis-à-vis soil health

The poor quality water enhances salinity and sodicity, which expedites the process of SOC decomposition (Eswaran *et al*. 1999) and affects micro floral composition adversely. Loss of biological productivity ranged from 10 to 25 % and 25 to 50 % in Inceptisols and Alfisols affected with medium to high sodicity, while decrease of productivity has gone up to 25 to 50 in Inceptisols and Alfisols and >50 % in Vertisols affected with same level of sodicity (NBSS&LUP, 1990). The magnitude of biological productivity loss could be imagined from 10.1 million hectare saline and sodic land apart from 2.2 million hectare saline flats (Sehgal & Abrol, 1994).

Biological productivity is also affected severely by the salinity introduced from the discharge of industry. An investigation from arid region of Rajasthan indicated that discharge from textile industry increased ECe, SAR and ESP from 2.5 to 193.6 dS/m, 24 to 485 and 25 to 87, respectively. Chloride and sulphate content has also gone from 14.5 to 28.30 and 3.0 to 107 me/l respectively. The effluents of textile industry also deteriorated the water quality by increasing total dissolve salts, SAR and chlorides.

Effect on inorganic carbon

The soils irrigated with brackish water have appreciable amount of inorganic carbon/ pedogenic carbon, which is the cause of SOC decomposition, soil salinity development and increase of bulk density (Singh *et al.,* 1999). Pedogenic carbonate alone or in combination with other factors restrict root proliferation, immobilize soil plazma and prepare ground for secondary salinization. The increase of inorganic carbon by 64, 44, 14 and 3.1 to 5.5 and 3.2 g/m^2 was reported in Malkosani, Pipar, Bhagasani, Chirai and Bap variant series of Jodhpur, respectively with simultaneous rise of soil pH by 0.2 to 0.4 units in a span of 27 years from 1975 to 2002.

Temporary drought and desertification

A high solute potential because of salinity and sodicity reduces availability of water. The problem is more acute in the year of low rainfall or in drought years. These altogether heighten the influence of drought or create drought like situation which adversely affect the biological productivity and its input in soils.

About three to four months after *Rabi* harvest and before *Kharif* sowing, land fallowing is common in India, which adversely affects the soil health. Doran and Ziss (2000) estimated SOC loss by summer fallowing is 320 to 350 kg in semi arid tropics. Commonly practiced cropping sequence in arid region such as pearl-millet- fallow-pearl-millet rotation might be the cause of declining SOC.

Effect on soil erosion

Salinity and sodicity on account of regular irrigation with poor quality water adversely affects the soil fabric and expedite the process of soil erosion. Erosion is mostly active on surface soils, erode SOC and nutrients. Loss of biological productivity is reported to the tune of 25 to 50 and >50 % in severely and very severely water eroded Inceptisols and Vertisols, respectively. SOC depletion was reported about 50% higher from wind eroded cultivated soils and cultivable wasteland than their non-eroded counterpart (Narain, 2000).

Effect on nutrient depletion

Nutrient depletions from the agriculture field are the severe threat to the soil health. Sub-optimal nutrient application together with poor quality water results in sparse plant cover and low vegetative inputs into the soils. In arid and rain-fed areas removal by crop was far more than the added through fertilizers (Katyal, 1997). Alfisols, Ultisols and Oxisols with low cation exchange capacity were the heaviest looser. Soil organic carbon loss ranged from 0.22 to 6.0 % over the initial in different cropping sequence of India due to inadequate fertilization, whereas depletion of SOC was far less 0.22 to 2.92 % under balanced fertilization (Anonymous, 2002-03). Inadequate fertilization with high RSC (residual sodium carbonate) depleted phosphorus and potassium by 7.7 and 13.4 %, respectively in arid soils of India from 1975 to 2002 (Singh *et al.,* 2007).

The abrupt change in land use by introducing high water requiring crops further heighten the problem of nutrient depletion. Traditional farming system was extensive with low yields which was sustainable in harmony with the carrying capacity set by the nature. Low productivity system has lost relevance in view of increasing demand of food, fiber and wood. Since 1951- 52 there has been an increase of 36, 22 and 54 million hectare irrigated, net sown and double cropped area respectively on the cost of fallow, pastures and grazing lands and tree grooves. High intensity farming system supports high productivity, they appear non sustainable in absence of holistic land management which satisfies needs of stakeholders in an economically favorable way and simultaneously contains curative action for preserving the soil health and prevents soil degradation.

Agro-techniques to improve soil health

Whether soils are naturally high or low in SOC, adding new organic matter every year is perhaps the most important way to improve/ maintain soil health with minimum use of irrigation. Regular additions of organic matter improve soil structure, enhance water and nutrient holding capacity, protect soil from erosion and compaction and support a healthy community of soil organisms. Good soil physical properties also prevent ground water contamination by improving filtering capacity of soils.

Preventive measures for erosion control

Protecting soils at the place is the most important for reducing the risk of SOC depletion. Stubble mulching with the residue of pearl millet, alternate strip of erosion susceptible and erosion resisting crops, sand dune stabilization with vegetative cover, shelterbelts plantation are the effective measures for controlling wind erosion. In an experiment of wind erosion during 1994 to 1999, an increase of SOC from 850 to 1400 kg/hectare was reported beneath the shelterbelts. An increased level of nitrogen, phosphorus and potassium has also been reported. (Solanki *et al.*, 1999).

Moisture conservation

Increased good quality irrigation water enhances SOC by increasing period of vegetative cover and vegetative input to the soils. These altogether increase water stable aggregates that offer protection to SOC against sun beating and erosion. Water management is also important for soil nitrogen mineralization (Dey and Jain, 1996). Rain water storage in tanks, subsurface barrier for ground water recharge and khadin management are some of the techniques that can be helpful for increasing the availability of fresh water for irrigation. *In situ* moisture conservation including on-farm rainwater harvesting (Dey and Sikka, 2010), field bunding, mulching, deep ploughing and other agronomic practices such as drought tolerant cultivars, optimum plant density, and proper sowing time, balance fertilization, use of sprinklers and drips for irrigation on the undulated topography may prove beneficial for moisture storage and soil organic carbon build up.

Correcting water quality

Gypsum application is very important in reducing the adverse impact of high RSC water used for irrigation. Gypsum application @ 50 and 100% of the total requirement effectively reduces the carbonate and bicarbonate salinity in irrigation water and enhanced soil health as evident from reduced soil pH by 0.3 to 0.4 units, increased nutrient availability and depressed SAR by 6.4 to 10.7 (Joshi and Dhir., 1994).

Integrated nutrient management

Integrated nutrient management including chemical fertilizers, manures and bio-fertilizers such as *Azospirillum*, *Rhizobiu*m, blue green algae, phosphate solubilizing micro organisms and VAM fungi enhanced vegetative cover and over all biomass production. These ultimately results in vegetative input to the soils and a higher SOC which in turn improve aggregate stability (Masri et al., 1996), enhance total nitrogen content (Harris et al., 1995), increase mineralization potentials and stabilize SOC (Ryan 1997) and improved crop productivity and quality (Dey et al., 2005). Study of micronutrients in sugarcane agro-ecosystem in subtropical region showed spatial variation (Dey and Yadav, 2003) and hence, a location specific prescription is warranted to counter micronutrient deficiency.

Legumes based cropping system

Legumes fix atmospheric nitrogen and in addition to this legumes also improve soil structure, reduce soil pH and increase the availability of native phosphorus. This could be seen from a long-term trial conducted at CAZRI Jodhpur with Pearl millet-moth bean cropping sequence in a rotation of four years. The sequence maintains initial SOC of 0.22 and 0.14% in surface and subsurface horizons during the period. Another sequence with legume-legume-legume-pearl millet increased SOC. In contrast rice based cropping sequence together with recommended dose of fertilizers produced higher yield on the cost of declining soil health.

Legume based forage production

Growing grasses is well known for improving SOC and binding soil particles. Inclusion of leguminous grasses with traditional forage in arid region is found more beneficial. This type of rotation induces high residue, which increases SOC, aggregate stability, biological diversity, water movement, aeration, porosity and reduces bulk density**.** A study conducted in the arid region indicated that intercropping of *Cenchrus cilliaris* and *Clitoria ternatia and Cenchrus cilliaris* and *Lablab purpures* added higher SOC both at the surface and in the subsurface as compared to the pasture with *Cenchrus cilliaris* alone (Tripathi *et al.*, 2002).

Silvipasture and silviculture based agriculture

Plantations (silviculture) alone or in combination with grasses are another very important practice for improving SOC. Plantations with *Acacia tortelis*, *Colophospermum mopane*, *Hardwickia binata* and *Cenchrus ciliaris* are noted for increasing SOC, available nitrogen, phosphorus and micronutrients in arid region. Silvipasture and plantations have 185 and 141% higher potentiality of SOC sequestration than traditional pearl millet-fallow system. These could sequester 9.6 and 7.4 kg/m^2 higher CO_2 than pearl millet-fallow system approximately in the same period (Singh *et al.*, 2007). Therefore, silvipasture and plantations should be integral part of agriculture particularly for improving the severely eroded areas, community land and wasteland.

Agroforestry

Growing of crops with shrubs, herbs and grasses is the old age practice for providing fodder to the animals, timber to the farmers and shades to the soils. The practice simultaneously could enrich the soils by sequestering 121% higher SOC than the pearl millet-fallow system. Growing of trees with crops could sequester 6.29 kg/m^2 higher atmospheric CO_2 than the cultivation of crops alone (Singh et al., 2007). This could be possible because of higher biomass production and higher soil moisture profile beneath the agro forestry system. Extensive research revealed that agro forestry including moth, cluster bean and local variety of pearl millet as a crop component with *Calligonum polygonoides* and *Lasiurus sindicus* as perennial trees and grass are more successful in areas receiving 100 to 250 mm rainfall, while plantation of *Prosopis* and *Ziziphus species* in the field and *Capparis decidua* on the boundary with pearl millet, moth bean, sesame and cluster bean is beneficial in 250 to 350 mm rainfall areas. However, growing of *Prosopis cineraria* and *Tecomella undulata* with pearl millet, green gram, moth bean and cluster bean is advantageous in the area of 250 to 450 mm rainfall on the desert margin. In the irrigated area of arid region plantation of *Prosopis cineraria* and *Acacia nilotica* with wheat, barley, mustard and gram in winter cotton, sorghum, pearl millet and sesame in summers are expected to improve SOC.

Agriculture diversification

Diversified farm means growing of variety of crops in a rotation together with animals. These are economically sustainable and resilient. Soil organic carbon depletion not only occurs because of growing of annual crops requiring specific and high management but also keeping land out of agriculture. Diversification integrating both crops and livestock in the farming system may be beneficial to each other because latter may supplement manure to the soils for increasing/ maintaining soil organic matter. Pasture and forage crops included in rotation may also contribute significantly in raising soil organic carbon and reducing erosion.

Conservation agriculture

Tillage operations disturb soil structure and redistribute energy rich organic substances in the soils. Researchers have shown that the use of mould board plough reduced SOC by an average of 256 lb/acre/year (Reicosky et al., 1995). Conservation agriculture is an umbrella covering a wide range of diverse tillage practices that have as common characteristics, the potential to reduce soil and water loss relative to conventional tillage. A well accepted definition of conservation agriculture is planting and tillage combination that retain a 30 % or higher crop residue on the soil surface. Conservation agriculture also increases SOC, improves nutrients, water use efficiency and physical properties besides restricting soil erosion.

Gene mining for drought avoidance

It is the other important practice to develop drought hardy plants. There are several species in sub-Saharan Africa and other desert, which have very extensive root system for mining water from large volume of soils, such as Prosopis Juliflora serving in the rainfall zone ranging from of 200 mm in Bhuj to 1000 mm around Ramnathpuram in east coast. Short duration crop of moth bean is another classical example of deep root system. Genetic and molecular characterization of such plants can help to introduce new genotype in the plants through genetic engineering. Thus genetically modified plants can manage a biotic stress of droughts, salinity, heat and cold waves and such attempts may be beneficial for averting the impact of fallowing on SOC depletion.

Strategies for optimizing the influence of agro-techniques

Strategies for optimizing the influence of agro-technique in terms of improving soil health encompasses long term planning with minimum use of irrigation which consists of selection of ideal land use and management. Agro-eco-zoning and segmentation of land based on the land quality class are the effective methods for compartmentalization of land depending upon quality and constraints. A matching exercise between the land use requirement and available resources should be the next step for obtaining the best possible land use. The associated management practices should also be the part of land use optimization programme. A contingency crop planning should also be framed on the event of severe drought and complete failure of monsoon. The entire soil health improvement plan should be monitored on a specific time frame.

Agro-eco-zoning for regional planning

Agro-ecological zoning separates areas into the region at the apex level and agro-eco unit at the bottom. The agro-ecological region identifies the natural resources in terms of problems, potentialities and constraints and their extent with respect to land utilization types and groups them in uniform units. Digital database in GIS and application of logic through decision support system (DSS) further enhance the process and precession of agro-ecological delineation. The sub agro ecological regions are further subdivided into agro-ecological zones based on landforms, soil association and land use. The agro ecological zones have further taken down to sub zones depending on terrain characteristics, parent materials, soil texture, depth, salinity, surface and ground water potentiality and cropping pattern. The latter is considered ideal for management at the regional level (Faroda et al., 1999).

Land quality class for district and farm planning

Foregoing discussion indicated that alternate land use systems including agro forestry, silvipasture, and silviculture are established techniques for improving soil health. Land quality class (LQC) separates the area for alternate land uses from that area capable of producing crops. The proportion alternate and cropland may range from 30 % on the soils of land quality class (LQC) I to 95% with the soils of land quality class of IX (Eswaran et al. 2000). Marginal shallow soils (LQC IV and V), sand dunes, rocky surfaces, saline flats, shallow and miscellaneous (LQC VI, VII, VIII and IX) should be placed under alternate land use systems. Growing of crops on these marginal lands aggravate wind erosion which affects the adjoining agriculture land of LQC I to III. Alternate land use systems on this kind of land not only improves the soil health by controlling soil erosion, adding organic carbon and providing canopy cover to the soils but also provides fodder to the animals. This acts as a bigger agro forestry system without affecting the area presently used for agriculture. Allocation of marginal land under alternate land use systems also acts as cushion for the farmers for raising animals during the drought years.

Right choice of species for agro-eco-zones/ land quality class

Land suitability evaluation depending on the rainfall, temperature, humidity, soil morphology and fertility helps to identify the right type of cultivars, grasses and trees for each land quality class/ each agro-eco sub-zones. Optimum soil organic carbon density which is a total reflection of soil health can also work as a tool for selecting right type of cultivars. For optimizing SOC density, a soil suitability cumulative index for each land use was derived by allocating the numerical value ranging from 20 to 80 to each soil characteristics depending upon the land use requirement (Sys et al., 1991). Numerical value of each soil characteristics was normalized on the scale of 100 before their addition for cumulative soil suitability index. For giving the regional look normalized soil suitability cumulative index was further normalized on the scale of 0.2 to 1.0 with respect to the best soils of the region. The latter was regressed against soil organic carbon density (0-100 cm soil depth) for developing second order polynomials. These were differentiated twice for calculating optimum value of SOC density for different land use. The soils with SOC density of above 3.0 kg/m^2 could be used for growing cowpea, cluster beans and wheat while soils with SOC density of 2.56 kg/m^2 may be utilized for sesame, moth beans and pearl millet. *Lasiurus sindicus* could be grown successfully in the soils,having soil organic carbon density 2.03 kg/m^2 .

Technological support

Right type of land use for an area should have technological support which includes development of agri-silvipastoral system for erosion control using combination of trees, shrubs and grasses as shelter belt. Crop improvement for drought mitigation, integrated nutrient and water management, residue management for enhancing soil fertility are the other technique should come after the selection of ideal land utilization types. The combined effect of all factors may lead to the desired goal of soil organic carbon improvement in arid regions of India.

Contingency planning for drought mitigation

Keeping land without vegetative cover because of low rainfall punctuated with high drought frequency is the major reason for deteriorating soil health in the arid region. Therefore, a sound contingency planning is needed to provide vegetative cover to the soils during the drought and the planning should be job and income oriented. The land use planning may include short duration varieties of pearl millet and legumes. Mixed cropping with pearl millet, moth bean, moong bean, cluster bean, sesame, kachri may be one of the viable options. Cash crops requiring limited water and soils of lower fertility such as isabgol, cumin, spices and condiments may be the part of contingency planning. Shrubs like *Lawsonia alba*, *Capparis deciduas*, *Cassia angustifolia*, *Commiphora wightii* are drought hardy and may be planted in the field and on the field boundary with short duration varieties of crops. The inclusion of medicinal plants in the crop curriculum may be explored in drought prone areas (Kumar *et al*. 2005).

Monitoring

Monitoring of the soil organic carbon dynamics is essential to assess the sustainability of the soil resource in response to human induced pressures such as land use and soil contamination. Monitoring is defined as the repeated inventory of an item to determine trend and status. One method of monitoring soils is benchmark sampling. The basic principle of benchmark sampling is to sample at the same location year after year. Benchmark sites are representative of larger areas and are usually about a quarter acre (0.1 ha) in size. Sampling with this method is less expensive and time consuming than traditional grid sampling and is more consistent because it assumes the benchmark area is less variable than the larger area which it represents.

Epilogue

Severe erosion, force fallowing, inadequate nutrient application, insufficient moisture, lack of soil aggregation, mono-cropping, irrigation induced salinity and sodicity, gradual building of inorganic carbon, excessive tillage and use of marginal land for cropping are some of the factors that threat to the soil health. A holistic approach dealing with agro-eco-zoning, evaluation of land for ideal land utilization types, optimization of land use may improve soil organic carbon and soil health. Treated and untreated wastewater is currently used to grow a number of crops like rice, wheat, mustard, fodder *berseem*, cabbage, cauliflower, potato, sugarcane, soybean, tomato, tobacco, elephant grass, *aonla*, drumstick and a host of other crops. Use of sewage water for aquaculture in Kolkata is well documented and widely referred. Similarly, crop cultivation along the Musi River in Hyderabad has attracted the attention from international organization resulting in several reports on the subject. Since the water is free, mostly, flood method of irrigation is practiced using more than required quantities of water. Hence, poor quality water is a viable option for crop growth provided, these are supported with agro-techniques which includes adequate area allocation for alternate land use, agroforestry, agri-horticulture, integrated nutrient, water and pest management, conservation tillage, moisture conservation, water harvesting and special allowance for drought mitigation.

References

- Anonymous (2003-04). *Annual Reports NATP for Rainfed Agro ecosystem*. Central Institute of Dry land Agriculture, Hyderabad India.
- Dey, P. and Jain, J.M. (1996). Nitrogen mineralization from enriched green manures as influenced by water management practices. *J. Indian Soc. Soil Sci*. 44 (4): 633-638.
- Dey, P., Rai, Mathura, Kumar, S., Nath, Vishal, Das, Bikash and Reddy, N.N. (2005). Effect of biofertiliser on physico-chemical characteristics of guava (*Psidium guajava*) fruit. *Indian J. Agri. Sci*. 75 (2): 95-96.
- Dey, P., Mongia, A.D and Singh, Gurbachan (1999). Spatial variation of soil properties and tree growth parameters in agroforestry under sodic soil condition. *In*: Wasteland Development: Challenges & Opportunities. (Eds. A.K. Singh, K.S. Bhatia and J.P. Yadav), C.S.A University of Agri. Technology, Kanpur and State Land Use Board, Dept. of Planning, Yojana Bhawan, Lucknow, pp. 168-172.
- Dey, P. and Sikka, Alok K. (2010). Water conservation through rainwater harvesting. The *IUP Journal of Soil and Water Sciences*, 3 (1): 61-71.
- Dey, P. and Yadav, D.V. (2003). Spatial variability of micronutrients in sugarcane growing soils of western Uttar Pradesh. *Indian J. Sugarcane Technol.* 109-111.
- Doran, J. W and Zeiss, M. R. (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology* 15:3-11.
- Eswaran, H., Reich, P.F., Kimble, J.M., Beinroth, F.H., Padamnabhan, E and Moncharoen, P. (1999) *In Global Climate Change and Pedogenic Carbonate* Advances in Soil Science (Lal, R., Kimble, J.M., Eswaran, H and Stewart, B.A Eds.) Lewis Publishers Boca Raton, FL, pp15-25.
- Eswaran, H., Reich, P. and Beinroth, F. (2000). Land Resource of South Asia-Stress, quality and population supporting capacity. In: Proceedings of the International Conference on the Managing Natural Resources for Sustainable Agriculture Production in 21st Century, February 14-18, New Delhi pp.551-668.
- Faroda, A.S., Joshi, D.C. and Ram, B (1999). Agro ecological zones of northwestern hot arid region of India. Annals of Arid Zones 38:1-8.
- Gupta, S.K., Singh, N.T and Sethi, M. (1994). *Ground Water Quality for Irrigation in India* (Map1; 6 Million Scale) Bulletin No.19. Central Soil Salinity Research Institute, Karnal, India.
- Harris, H. (1995). Long-term trials on soil and crop management at ICARDA. Advances Soil Science 19:447-469.
- Joshi, D.C. and Dhir, R.P. (1994). Amelioration and management of soils irrigates with sodic water in the arid region of India. Soil Use and Management 10:30-34.
- Katyal, J.C. (2003) Soil fertility management- A key to prevent desertification. *Journal of the Indian Society of Soil Science*, 51,378-387.
- Masri, Z., Rayn, J and Pala, M. (1996). Specific effects of a cereal–legume rotation on soil

physical properties under Mediterranean type of condition. (Abstracts) International Conference on Land Degradation, June 10-14, Adan, Turkey, pp.51.

- Narain, P. (2001) Strategies of carbon sequestration on degraded soils. Journal of the Indian Society of Soil Science 49: 634-644.
- Ryan, J. (1998). Changes in organic carbon in long-term rotation and tillage trials in northern Syria. In: Management of Carbon sequestration in Soils (Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. eds.) CRC Press Boca Raton, New York, pp.285-296.
- Reicosky, D.C., Kemper, W.D., Langdale, G.W., Douglas, C.L.Jr. and Rasmussen (1995). Soil organic matter changes resulting from tillage and biomass production. Journal of Soil and water Conservation 50:253-261.
- Sehgal, J. and Abrol, I.P. 1994. Soil degradation in India, Status and Impact. Indian Council of Agricultural Research, New Delhi.
- Singh, R.K., Singh, S.K., Tarafdar, J.C. (2008). Influence of cropping sequence and nutrient management on soil organic carbon and nutrient status of Typic Rhodustalfs. Journal of the Indian Society of Soil Science, 56(2):174-181.
- Singh, S.K., Mahesh Kumar, Sharma, B.K. and Tarafdar, J.C. (2007) Organic carbon, Phosphorus and Potassium depletion under pearl millet based production system in Arid Rajasthan. *Arid Land Research and Management* 21:119-131.
- Solanki, K. R., Bisaria, A.K and Handa, A.K. (1999). Sustainable Rehabilitation of degraded land through Agroforestry. National Research Center for Agro forestry, Jhansi, India.
- Sys, I. C., Vanranst, B. and Debaveye. J.(1991). Land Evaluation part I, Methods of Land Evaluation. Agricultural publications, General Administration for Development Co-operation, place, de, camp de Mars, 5btc.57-1050, Brussels, Belgium, pp.1-273.
- Tripathi, K. P., Rathore, S.S. and Garg, V. K. (2002). Improving pasture productivity through legume introduction. Indian Journal of Agricultural Sciences 72:147-150.

Effect of climate change on carbon emission and human health hazards

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The carbon is the most important element in the biosphere which is the foundation of the structure of all cells. When plants, animals and microbes death occurs, the metabolic activities of soil microorganisms transform organic carbon in to carbon dioxide (CO_2), microbial biomass and soil organic matter. At present, the major threat to the world is global warming which is changing the whole systems on the earth, especially the earth's atmosphere which comprises of mainly nitrogen, oxygen and traces of methane gases, carbon dioxide and argon. Carbon dioxide and methane are known to be green house gases absorbs the atmospheric heat rising temperature of the planet. The warming caused is due to the fact that fuel consumption has increased worldwide increasing number of automobiles factories consuming coal and petroleum as a fuel emitting lots of green house gases. The change in temperature takes place is decades. It is believed that even if there is small rise in temperature is observed the earth becomes warm because there are no much tree planted which can absorb the gases and mitigate the effect preventing global warming. The activities of microorganisms in soil is essential to the global cycling of carbon, nitrogen, phosphorus, sulphur and other elements became many substances cannot be degraded by organisms other than microbes.

Carbon in the form of carbon dioxide is being emitted unceaselessly and is a great challenge in checking its emission, emphatic steps has to be taken. The problem is accepted globally, it is estimated that by the year 2100 temperature may rise to 3-5^{o}C and the rise in sea level will be about 25 meters. The CO_2 is increasing @ 3 percent each year CO_2 concentration of 450 ppm will be equivalent to 2^{o}C rise in temperature, which will cause catastrophic changes in environment.

Carbon dioxide is the primary greenhouse gas emitted through human activities. It is a colorless, odorless gas vital to life on earth. This naturally occurring chemical compound is composed of a carbon atom covalently double bonded to two oxygen atoms. The frozen solid form of CO_2, known as "dry ice" is used as a refrigerant and as an abrasive in dry-ice blasting. It also exists in the earth's atmosphere as a trace gas at a concentration of about 0.0395 percent (395 ppm) by volume. Burning of carbon-based fuels since the industrial revolution has rapidly increased its concentration in the atmosphere, leading to global warming (The World Bank, 2011). Carbon dioxide is a major cause of ocean acidification since it dissolves in water to form carbonic acid. It is naturally present in the atmosphere as part of the earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are quite responsible for the increase in the atmosphere since the industrial revolution (NRC, 2010).

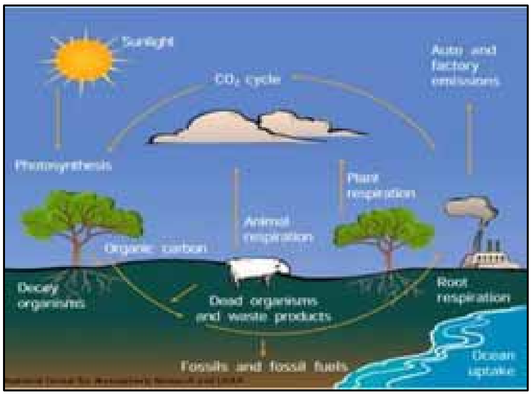

Fig. 1: Carbon Cycle

Biofuel chulha, kerosene oil lamp, burning of crop residues, 65 percent carbon dioxide is contributed in the atmosphere, 14 percent through burning residues and 13 percent emission through diesel vehicles are contributed every year, which is equal to 3800 teragrams carbon dioxide (1 Tg = 1 million metric ton). In India, ten part of green house gases are emitted by transport. Tata Institute of Social

Science (TISS) has developed a carbon budget for industrial and developing countries, Tejal Kanitkar of TISS climate change centre, according to him at the verge of industrial revolution since 1850 to 2100 century, the total emission of carbon is estimated to be 641 Gigaton (1 GT = 1 billion ton) it is evident that the climate change of the world would have not gone beyond control if there would have not been average rise in temperature by 2^{o}C. The total budget of Gigaton carbon (GTC) will be 270 by the year 2100. Till now developed countries have utilized 97 GTC out of total 371 GTC, the remaining balance of 220 GTC with them. On the other hand, it is realized that only 50 percent GTC is remaining with industrial countries for utilization.

In India, 8 million people are poor family fetch fuel wood for cooking meals which is more important than electricity to them and on village level they are producing pollution even after knowing the ill effects of pollutants on women and children causing health hazards. 1.5 million people have died before natural death due to household air pollution contributing 53 percent which causes around 25 lacs diseases. The remains of fuel and ash after cooking is known as asian brown clouds, black particles deposited on ice absorbs heat, leads melting.

Table 1: Rank and role of important countries in carbon emission

Rank	Country	E_nMMT	C emission per person (metric ton)	Share in C emission (%)
1.	China	8715.31	6.52	27
2.	America	5490.63	17.62	5
3.	Russia	1788.14	12.55	5
4.	India	1725.76	1.45	5
5.	Japan	1180.62	9.26	4
6.	Germany	748.49	9.19	2
7.	Iran	624.86	8.02	2
8.	South Korea	610.95	12.53	2
9.	Canada	552.56	16.24	2
10.	South Arab	513.53	19.65	2
11.	UK (Britain)	496.80	7.92	2
12.	Brazil	475.41	2.41	2
13.	Mexico	426.29	4.07	1
14.	South Africa	401.57	9.42	1
15.	Indonesia	426.79	1.73	1
16.	Italy	400.94	6.57	1
17.	Australia	329.29	18.02	1
18.	France	374.33	5.73	1
19.	Spain	318.64	6.82	1
20.	Poland	307.91	8.01	1

*Other countries have percent share in carbon emission is 20 percent.

Source: www. patrika, September, 2015

Sources of Carbon Dioxide Emissions

The emission of carbon dioxide occurs mainly from two sources i. e. natural and human sources. Natural sources include decomposition, ocean release and respiration while human sources includes activities like cement production, deforestation as well as the burning of fossil fuels like coal, oil and natural gases. The atmospheric concentration of carbon dioxide has been rising extensively since the industrial revolution and has now reached dangerous levels not seen in the last 3 million years (Van *et al.*, 2011). Human sources of carbon dioxide emissions are much smaller than natural emissions but they have upset the natural balance that existed for many thousands of years before the influence of humans. Natural sinks remove around the same quantity of carbon dioxide from the atmosphere than are produced by natural sources. This had kept carbon dioxide levels balanced and in a safe range.

1. Human Sources:

The human sources causing carbon dioxide emissions have been experienced since the industrial revolution, the burning of oil, coal, gas and deforestation. 87 percent of carbon dioxide emissions come from the burning of fossil fuels like coal, natural gas and oil. The remainder results 9% from deforestations and other land use changes as well as 4% some industrial processes such as cement manufacturing (Le Quéré C. *et al.*, 2013).

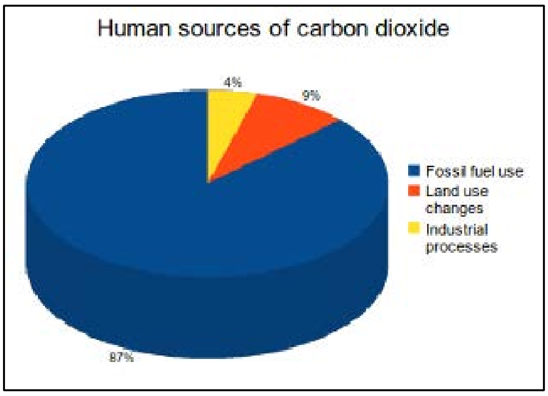

Fig. 2: Global carbon budget from1959-2011

Combustion of fossil fuels

87% of human source of carbon dioxide emissions is due to combustion of fossil fuels. Burning these fuels releases energy which commonly turned into heat, electricity or power for transportation. The three main economic sectors that use fossil fuels are: electricity / heat, transportation and industry. The electricity / heat and transportation, produced nearly two-thirds of global carbon dioxide emissions in 2010. Fossil fuel created 33.2 billion tons of carbon dioxide emissions worldwide in 2011. Coal emits 43% of carbon dioxide emissions from fuel combustion, 36% is produced by oil and 20% from natural gas (International Energy Agency, 2012). Coal is the largest fossil fuel source of carbon dioxide emissions and represents one-third of fossil fuels' share of world total primary energy supply.

Fig. 3: Carbon dioxide emission through fossil fuels combustion

Electricity / Heat sector

Electricity and heat generation is the economic sector that produces the largest amount of man-made carbon dioxide around the world, relies heavily on coal, the most carbon-intensive of fossil fuels. Almost all industrialized nations get the majority of their electricity from the combustion of fossil fuels (around 60-90%). Only Canada and France are the exception.

Table 2: Electrical energy produced by fossil fuel combustion by major industrialized nations

G8 Nation	Fossil Fuel Combustion (Billion Kilowatt hours)	Total	%
Canada	136.31	622.98	21.9%
France	44.65	532.57	8.4%
Germany	340.38	567.33	60.0%
Italy	286.35	201.7	70.4%
Japan	759.93	1031.22	73.7%
Russia	668.26	996.82	67.0%
United Kingdom	244.5	342.48	71.4%
United States	2788.87	4100.14	68.0%

Source: International Energy Statistics Database (2011), Energy Information Administration

Transportation sector

The transportation sector is the second largest source of anthropogenic carbon dioxide emissions. Transporting goods and people around the world produced 22% of fossil fuel related carbon dioxide emissions in 2010. This sector is very energy intensive and uses petroleum based fuels (gasoline, diesel, kerosene, etc.) almost exclusively to meet those needs. Since 1990s, transport related emissions have grown rapidly, increasing by 45% in less than 2 decades. (International Transport Forum, 2010). Global aviation accounts for 11% of all transport carbon dioxide emissions. International flights create about 62% of these emissions with domestic flights representing the remaining 38% (ICAO, 2010). Over the last 10 years, aviation has been one of the fastest growing sources of carbon dioxide emissions (Smale *et al.*, 2012).

Industrial sector

The industrial sector is the third largest source of man-made carbon dioxide emissions. This sector produced approximately 20 percent of fossil fuel related carbon dioxide emissions. This sector consists of manufacturing, construction, mining, and agriculture. Manufacturing is the largest of the 4 and can be broken down into 5 main categories: paper, food, petroleum refineries, chemicals, and metal/mineral products. Manufacturing and industrial processes all combine to produce large amounts of each type of greenhouse gas but specifically large amounts of CO_2. This is because many manufacturing firms directly use fossil fuels to create heat and steam needed at various stages of production. For example factories in the cement industry, have to heat up limestone to 1450°C to turn it into cement, which is done by burning fossil fuels to create the required heat.

Land use changes

Land use changes are a substantial source of carbon dioxide emissions globally, accounting for 9% of human carbon dioxide emissions and contributed 3.3 billion tons of carbon dioxide emissions in 2011 (Le Quéré *et al.*, 2012). Land use changes when the natural environment is converted into areas for human use like agricultural land or settlements. From year 1850 to 2000, land use and land use change released an estimated 396-690 billion tons of carbon dioxide to the atmosphere, or about 28-40% of total anthropogenic carbon dioxide emissions (Houghton, 2010). Deforestation has been responsible for the great majority of these emissions. It is the permanent removal of standing forests and is the most important type of land uses change, because its impact on greenhouse gas emissions. Forests in many areas have been cleared for timber or burned for conversion to farms and pastures. Deforestation is causes serious changes in how carbon is stored in the soil. It also affects regional carbon reuptake, which can result in increased concentrations of CO_2 (IPCC, 2007). When forested land is cleared, soil is disturbed and increased rates of decomposition in converted soils both create carbon dioxide emissions. This also increases soil erosion and nutrient leaching which further reduces the area's ability to act as a carbon sink.

Fig. 4: Carbon dioxide emission through deforestation

Industrial processes

There are many industrial processes that produce significant amounts of carbon dioxide emissions as a byproduct of chemical reactions needed in their production process. Industrial processes account for 4% of human carbon dioxide emissions and contributed 1.7 billion tons of carbon dioxide emissions. Many industrial processes emit carbon dioxide directly through fossil fuel combustion as well as indirectly through the use of electricity, generated using fossil fuels. But there are four main types of industrial process that are a significant source of carbon dioxide emissions: the production and consumption of mineral products such as cement, the production of metals such as iron and steel, as well as the production of chemicals and petrochemical products. Fossil fuels are used to create chemicals and petrochemical products which lead to carbon dioxide emissions. The industrial productions of ammonia and hydrogen most often use natural gas or other fossil fuels as a starting base, creating carbon dioxide in the process. Petrochemical products like plastics, solvents, and lubricants are created using petroleum. These products evaporate, dissolve, or wear out over time releasing even more carbon dioxide during the product's life.

2. Natural Sources

The emission of carbon dioxide from natural sources is much higher than human sources. Natural sources from carbon dioxide emissions include earths, oceans, soils, plants, animals and volcanoes. Among the natural sources of carbon dioxide emissions, 42.84 percent from ocean-atmosphere exchange, 28.56% from plant and animal respiration as well as 28.56% respiration and decomposition (Doe, 2008).

Plant and animal respiration

Plant and animal respiration are important natural source of carbon dioxide, which accounts for 28.56% of natural emissions. Carbon dioxide is a byproduct of the chemical reaction that plants and animals use to produce the energy they need. Annually this process creates about 220 billion tons of carbon dioxide emissions. Plants and animals respiration produce energy, which is used to fuel basic activities like movement and growth. The process uses oxygen to break down nutrients like sugars, proteins and fats. This releases energy that can be used by the organism but also creates water and carbon dioxide as byproducts.

Soil respiration and decomposition

Carbon dioxide is an important natural source of soil respiration and decomposition. Many organisms that live in the earth's soil use oxygen and CO_2 for respiration to produce energy. Most of them are decomposers helps in break down dead organic materials, which release carbon dioxide as a byproduct. Annually these soil organisms create about 220 billion tons of carbon dioxide emissions. Plant roots, bacteria, fungi and soil animals respire to create the energy to survive which also produces carbon dioxide during decomposition.

Ocean-atmosphere exchange

The largest natural source of carbon dioxide emissions is from ocean-atmosphere exchange. The oceans contain dissolved carbon dioxide, which is released into the air at the sea surface. Annually this process creates about 330 billion tons of carbon dioxide emissions.

Volcanic eruptions

A minor amount of carbon dioxide is released by volcanic eruptions, which accounts for 0.03% of natural emissions. Volcanic eruptions release magma, ash, dust and gases from deep below the Earth's surface. One of the gases released is carbon dioxide. Annually about 0.15 to 0.26 billion tons of carbon dioxide emissions is recorded (Volcanic Gases and Climate Change Overview, 2014). The most common volcanic gases are water vapor, carbon dioxide, and sulfur dioxide. Volcanic activity will cause magma to absorb these gases, while passing through the Earth's mantle and crust. During eruptions, the gases are then released into the atmosphere.

Reformations

There are three primary ways for reducing the amount of carbon dioxide in the atmosphere; employing energy efficiency and conservation practices; using carbon-free or reduced-carbon energy resources and capturing and storing carbon either from fossil fuels or from the atmosphere. Many strategies for reducing CO_2 emissions from energy are cross-cutting and apply to homes, businesses, industry and transportation. Solving climate change is a biggest international challenge. Only a concerted global effort, involving the governments of all nations, will be enough to avert dangerous consequences. But the individual actions of everyday people are still crucial. Large and complex issues, like climate change, are usually best tackled by breaking down the problem into manageable bits.

Efficiency and conservation

There are many energy efficiency and conservation practices that reduce the consumption of carbon-based fuels (e.g., natural gas, oil, coal, or gasoline), decreasing carbon dioxide emissions. Improving the insulation of buildings, traveling in more fuel-efficient vehicles, and using more efficient electrical appliances are all ways to reduce energy consumption, and thus CO_2 emissions. Reducing personal energy use by turning off lights and electronic gadgets when not in use reduces electricity demand. Reducing distance traveled in vehicles reduces petroleum consumption. Both are ways to reduce energy CO_2 emissions through conservation. Producing more energy from renewable sources and using fuels with lower carbon contents are ways to reduce carbon emissions.

Carbon capture and sequestration

A third option for reducing carbon dioxide in the atmosphere is carbon sequestration. Carbon dioxide capture and sequestration is a set of technologies that can potentially greatly reduce CO_2 emissions from new and existing coal- and gas-fired power plants, industrial processes, and other stationary sources of CO_2. It involves the capture and storage of carbon dioxide that would otherwise be present in the atmosphere, contributing to the greenhouse effect. As described on the Carbon Sequestration Approaches and Technologies, carbon dioxide can be removed from the atmosphere and retained within plants and soil. Alternatively, carbon dioxide can be captured (either before or after fossil fuel is burned) and then be stored (sequestered) within the earth. Increase in soil organic carbon pool through soil carbon sequestration improves soil quality and set-in-motion land restorative processes, and advances food security (Lal, 2006). Higher rate of soil organic carbon sequestration in soil, it requires additional amount of N, P & S. Richardson *et al.*, (2014) estimated that increasing soil organic carbon by 1 Mg C ha^{-1} into humus requires 73, 17 and 11 kg ha^{-1} of N, P and S, respectively. Suitable management practices to build up soil organic carbon are those that increase the input of organic matter to the soil and decrease the rate of soil organic matter decomposition (FAO, 2011).

Carbon free and reduced carbon energy sources

Another way to reduce carbon dioxide emissions is to use carbon-free or reduced-carbon sources of energy. Carbon-free sources of energy have their own associated impacts, but in general, these technologies generate energy without producing and emitting carbon dioxide to the atmosphere. Carbon-free energy sources include solar power, wind power, geothermal energy, low-head hydropower, hydrokinetics (e.g., wave and tidal power), and nuclear power. Alternatively, switching from high-carbon fuels like coal and oil, to reduced-carbon fuels such as natural gas, will also result in reduced carbon dioxide emissions. The extent to which biomass energy is considered to be carbon-free or a reduced-carbon fuel depends on the type of biomass used and the processes by which it is converted to energy.

Make your home and household energy efficient

Most of the people leave lights on when nobody is present in the room, or switch off the TV by the remote instead of at the wall, fire up the heater on when we could put on an extra layer of clothing, or turn on the air conditioner when we could open the window and turn on a fan. It's force of habit – a bad habit we can break, with just a little thought. Behavior change lies at the heart of most individual actions on reducing our individual carbon footprint. By being sensible about your use household energy use, and making sure your house is well insulated, you can make a huge dent in your CO_2 emissions. On and it will save you plenty money that you no longer spend on wasted energy, year in, year out.

Purchase energy efficient appliances

Aside from behavioral change, invest in more sensible technologies that help in day to day lives. Buying new electronic appliances, air conditioners or washing machines, focus at energy consumption. The more energy efficient will save more power in the long run and will lower CO_2 impact. In most cases the 'payback period' - the difference between the initial costs of a high versus low efficiency appliance have the long-term savings.

Use of green electricity

The future of energy clearly lies in renewable sources such as solar, wind and wave power and 'hot rocks'. Even without climate change, there are limits to available oil, natural gas and coal. 'Green power' is electricity that comes from these technologies, but is delivered in the same way as 'dirty power' from fossil-fuel burning. That is, down the power lines. One can buy enough to replace entire energy usage, or some fraction (I recommend going for 100%; the cost is a few more cents per kilowatt hour of electricity). Most energy suppliers now offer this service and will purchase energy from green sources that is equivalent to what you use. As more people take up this scheme, it will drive ever greater investment in these technologies, reduce cost of delivery, and so further hasten the pace of update.

Recycling of energy

Huge amount of waste is accumulated daily but recycling is very little. Local recycling service can be done for daily use materials. Avoid the temptation of buying useless trinkets and knick-knacks, just because it feels good to accumulate them, make them usable by recycling.

Telecommute and teleconference

Telecommuting can also be an effective way working at home, at office and more official employers are realizing its benefits are accepting the concept. The need to really fight through traffic every day, just to sit at office desk and work on your computer and make best use of the benefits of the Internet. Teleconferences mean less wasted trips by air or road create a huge CO_2 burden. It can't always be done, but fewer trips can make a big difference.

Walk, cycle or take public transport

People using trains, buses, bikes and go on foot is much more greenhouse friendly, and often considerably cheaper. The main problem with public transport is that mass of people does not use it; there is no enough investment by government to improve the quality of service and capacity to support large volumes of commuters. It is just like one cannot get job without experience and one cannot get experience without job, but some cities have solved the dilemma and most of their people move about on public transport. So start patronizing your public transport network, and push governments at all levels for some decent bicycle and walking trails instead of building more and more roads for cars and worrying incessantly about fuel costs.

Eat less red meat

Traditional red meat comes from ruminant livestock such as cattle and sheep. These animals produce large amounts of methane, which is a greenhouse gas that packs 72 times the punch of CO_2 over a 20 year period. Other types of meat, such as chicken, pork, produce far less emissions. At average levels of consumption, a family's emissions from beef would easily outweigh the construction and running costs of a large 4WD vehicle, in less than 5 years. There is no need to cut out red meat entirely, but fewer steaks and snags mean far less CO_2.

Purchase local produce

Food mile new carbon language a way of expressing how far a food material has travelled distance before it reaches your dinner table, and therefore how much CO_2 has been emitted during freighting. A better concept is probably 'embodied energy', which takes account of all the carbon, water and energy that goes into producing any food or manufactured item. Either way, a good rule of thumb is that if you buy something that has been produced locally, it will usually have a lower CO_2 tag attached to it. Your local fresh food market is a good place to start for your food shopping which will make a difference to your climate change impact, and help the local economy.

Effects of Carbon Dioxide Emissions on Human Health:

The attention put on human health and carbon emissions has significantly increased in the last 100 years, causing detrimental effect on the population, though normal levels of CO_2 are considered harmless, under the optimum conditions. High concentrations of CO_2 in confined areas can be potentially too dangerous. It may act as an oxygen displacer in confined spaces may cause a number of reactions. These reactions include, dizziness, disorientation, suffocation, and under certain circumstances death. Depression of the central nervous system with prolonged exposure to high levels of CO_2 death occurs when the body's compensatory mechanisms are fail. (Farrar *et al*., 1999; Nelson, 2000).

Level of carbon dioxide inhaled daily is almost harmless to human health but when the body is exposed too much to CO_2, internal respiration is affected and the victim may experience symptoms of asphyxiation, frostbite, kidney damage or coma.

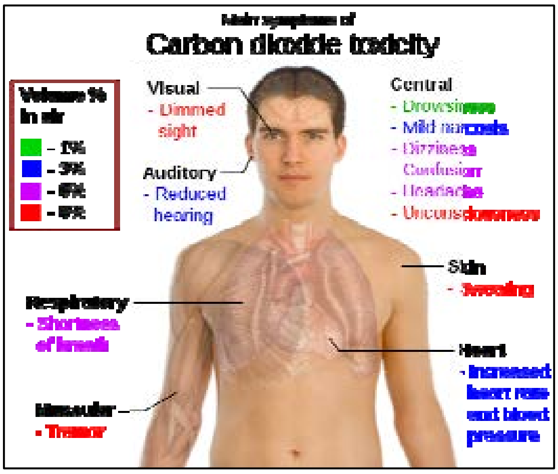

Fig. 5 Effect of carbon dioxide toxicity on human health

Toxicity of CO_2 is considered to be a potential inhalation toxicant and a simple asphyxiate (Aerias, 2005). It enters the body from the atmosphere through the lungs, is distributed to the blood, and may cause an acid-base imbalance, or acidosis, with subsequent central nervous system depression (Priestly, 2003). Acidosis is caused by an overabundance of CO_2 in the blood. Under normal physiological circumstances, there is a higher concentration of CO_2 in the blood than in the lungs, forming a concentration gradient, where blood CO_2 diffuses into the lungs and then is exhaled.

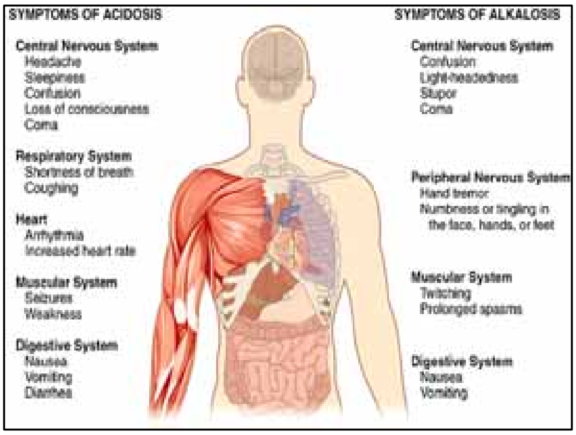

Fig. 6 Carbon dioxide toxicity caused acidosis and alkalosis

Increase in inhaled CO_2 and subsequent reaction with water in the blood forms carbonic acid (H_2CO_3), which then dissociates into hydrogen ions (H^+) and bicarbonate (HCO_3^-). The excess CO_2 shifts the equilibrium toward the creation of more hydrogen ions, thus creating an acidic environment. During respiratory acidosis, the pH of the blood becomes less than 7.35.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Electrolyte imbalance occurs due to decreased blood plasma chloride, potassium, and calcium and increased blood plasma sodium. Furthermore, the oxygen depleted environment does not allow for cells in the body to obtain the oxygen they need to survive. Fortunately, the body compensates for the excess in H^+ ions by binding of the protons to hemoglobin. In addition, the lungs attempt to compensate by removing the excess CO_2, which is the reason rapid breathing is apparent during acute CO_2 exposure. After prolonged exposure, the kidney begins to balance blood pH by retaining bicarbonate and excreting hydrogen ions to correct acidosis (Priestly, 2003).

Symptoms related to acute CO_2 exposure are shown in Table 2 (Aerias, 2005; IVHHN, 2005). Treatment to high exposures of this compound involves removing the victim from the confined space or oxygen inadequate environment, and increasing the oxygen supply to the exposed individual (Nelson, 2000). The condition of acidosis is reversible upon removal from a high CO_2 environment.

Table 3: Symptoms from low to high concentrations of CO_2

CO_2 (%)	Symptoms
2 to 3	Shortness of breath, deep breathing
5	Breathing becomes heavy, sweating, pulse quickens
7.5	Headaches, dizziness, restlessness, breathlessness, increased heart rate and blood pressure, visual distortion
10	Impaired hearing, nausea, vomiting, loss of consciousness
30	Coma, convulsions, death

According to another study on Stanford University was found for each 1^0C increase in temperature caused by carbon dioxide emissions, the resulting air pollution could lead to more than 20,000 deaths a year worldwide and many more cases of respiratory illness and asthma. Mark Jacobson, a professor of civil and environmental engineering at Stanford, the study is the first specifically to isolate carbon dioxide's effect from that of other global-warming agents. It is also the first to find quantitatively that "chemical and meteorological changes due to carbon dioxide itself increase mortality due to increased ozone, particles and carcinogens in the air".

References

- Aeries (2005). Carbon dioxide: A Common Indoor Air Pollutant. www.Aeries.com
- DOE, U. S. (2008). *Carbon Cycling and Biosequestration: Integrating Biology and Climate Through Systems Science; Report from the March 2008 Workshop, DOE/SC-108*. U. S. Department of Energy Office of Science.
- Electricity Generation Year (2011). U.S. Energy Information Administration: International Energy Statistics Database.
- FAO (2011). The State of The World's Land and Water Resources for Food and Agriculture (SOLAW) - Managing Systems at Risk. Food and Agricultural Organization of the United Nations and Earthscan, Rome.
- Farrar, C., Neil, J. and Howle, J. (1999). Magmatic Carbon Dioxide Emissions at Mammoth Mountain, California. USGS Water Resources Investigation Report 98-4217.
- Houghton, R. A. (2010). How well do we know the flux of CO_2 from land-use change?. *Tellus B* **62, 5:** 337-351.
- ICAO (2010). *ICAO Environment Report 2010: Aviation and Climate Chnage*. Montréal: International Civil Aviation Organization.
- International Energy Agency (2012). *CO_2 Emissions from Fuel Combustion 2012*. Paris: Organisation for Economic Co-operation and Development.
- International Transport Forum (2012). *Reducing Transport Greenhouse Gas Emissions: Trends & Data*. Paris: Organisation for Economic Co-operation and Development.
- International Volcano Health Hazard News: IVHHN (2005). Gas and Aerosol Guidelines: Carbon Dioxide. http://seis/bris.ac.uk/~glcjh/ivhnn/guidelines/gas/co $_2$.html Discussion of known CO_2 poisoning events associated with vulcanology.
- IPCC (2007). Technical Summary retrieved June 25, 2007.
- Lal, R. (2006). Enhancing crop yields in developing countries through restoration of soil organic carbon pool in agricultural lands. *Land Degrad. Dev*. **17:** 197-206.
- Le Quéré, C., Jain, A. K., Raupach, M. R., Schwinger, J., Sitch, S., Stocker, B. D., Viovy, N., Zaehle, S., Huntingford, C., Friedlingstein, P., Andres, R. J., Boden, T., Jourdain, C., Conway, T., Houghton, R. A., House, J. I., Marland, G., Peters, G. P., Van Der Werf, G., Ahlström, A., Andrew, R. M., Bopp, L., Canadell, J. G., Kato, E., Ciais, P., Doney, S. C., Enright, C., Zeng, N., Keeling, R. F., Klein Goldewijk, K., Levis, S., Levy, P., Lomas, M. and Poulter, B. (2012). "The global carbon budget 1959–2011". Earth System Science Data Discussions 5, 2: 1107-1157.
- Nelson, L. (2000). Carbon Dioxide Poisoning. Emerg. Medicine **32 (5):** 36-38. Summary of physiological effects and toxicology of CO_2 on humans.
- NRC (2010). *Advancing the Science of Climate Change*. National Research Council. The National Academies Press, Washington, DC, USA.
- Priestly, M. A. (2003). Medicine:Respiratory Acidosis. January, 21, 2003.
- Richardson, A. E., Kirby, C. A., Banerjee, S. and Kirkegaard, J. A. (2014). The inorganic nutrient cost of building soil carbon. Carbon Management. In Press.
- Smale Robin, Max Krahe and Tim Johnson (2012). *Aviation report market based mechanisms to curb greenhouse gas emissions from international aviation*. Gland, Switzerland: WWF International.
- The World Bank. *World Development Report (2011). Development and climate change*. Washington, DC: World Bank and Oxford University Press.
- Van, R. S. W., De Wal, B., De Boer, L. J., Lourens, Köhler, P. and Bintanja, R. (2011). Reconstruction

of a continuous high-resolution CO_2 record over the past 20 million years. *Climate of the Past* **7, 4:** 1459-1469.

- Volcanic Gases and Climate Change Overview (2014). U. S. Geological Survey. http://volcanoes.usgs.gov/hazards/gas/climate.php (accessed August 2, 2014).

Green manuring : A tool for sustainable agriculture

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Indian agriculture has gone through major changes during the last century. It has developed from a more or less subsistence farming to a highly intensive agricultural production particularly after green revolution. It relies heavily on the inputs of energy and other resources and production has become dependent on chemical pesticides and commercial fertilizers. With an increase pressure on farmland country wide, farmers are facing global problem such as soil erosion, wide spread deficiencies of macro and micro plant nutrients, salanisation, increasing pest problems. Besides these, damages to human beings, animals and nature from synthetic chemical pesticides have become more apparent in the different states particularly in Punjab and Haryana. Therefore, a change from high-input and chemically intensive agriculture to a more sustainable form of agriculture like organic farming and integrated farming which are not only desirable but urgently needed to rectify the ill effects of chemically intensive agricultural production (Tandon, 1995; Stockdale *et al.*, 2000)

In organic farming and integrated farming, the nutritional demands of crops are meet out mainly through on farm organic wastes, biofertilizers and green manure crops. In the present article an endeavor has been made to compile the available literature on important green manures crops of India, their potential in terms of biomass and nutrients, techniques for harnessing the maximum benefits from green manuring and their complementary effects on crops yields, physico-chemical properties of soil and quality of agricultural produce.(Kumar et al, 2014)

What is green manuring ?

Green manuring is the practice of growing lush plants on the site into which you want to incorporate organic matter, then turning (tilling, ploughing and soading) into the soil while it is still fresh. The plant material used in this way is called a green manure (GM). Generally the practice of green manuring is adopted in two ways:

(a) ***In-situ* green manuring:** In this system the short duration legume crops are grown and buried in the same site when they attain the age of 60-80 days after sowing. This system of on-site nutrient resource generation is most prevalent in northern and southern parts of India where rice is the major crop in the existing cropping systems. The most common green manure crops which are grown for *in-situ* green manuring are listed in Table 1

Table 1. Common legume crops for in-situ green manuring

S.No.	Common Name	Botanical Name	Growing season
1	Dhaincha	*Sesbania aculeta*	Zaid / Kharif
		Sesbania rostreta	Zaid / Kharif
2	Sunhemp	*Crotolaria juncia*	Zaid / Kharif
3	Mung	*Vigna radiata*	Zaid / Kharif
4	Cowpea	*Vigna unguiculata*	Kharif
5	Guar	*Cyamopsis tetragonoloba*	Kharif
6	Senji	*Melilotus alba*	Rabi
7	Berseem	*Trifolium alexandrium*	Rabi
8	Khesari	*Lathyrus sativus*	Rabi

(Singh *et al.*, 1992)

Besides these, some weeds growing in the fields can be buried in the soil while they are still fresh at the time of field preparation. The weeds which can be used for green manuring along with the common legumes to cater the nutritional requirement of crops under organic farming are presented in Table 2.

Table 2 . Mineral composition of certain weeds on dry weight basis

S.No.	Weed	Nutrient content (%)		
		N	P_2O_5	K_2O
1	*Amaranthus viridis*	3.16	0.06	4.51
2	*Cassia occidentalis*	3.08	1.56	2.31
3	*Chenopodium album*	2.59	0.37	4.34
4	*Cleome viscosa*	1.96	1.53	5.81
5	*Dactyloctenium aegyptium*	2.78	0.24	1.65
6	*Digitaria sanguinallis*	2.00	3.36	3.48
7	*Echinochloa crusgalli*	2.98	0.40	2.96
8	*Portulaca quadrifida*	2.40	0.09	5.57
9	*Solanum xanthocarpum*	2.56	1.63	2.12
10	*Trianthema partulacastrum*	2.34	0.30	1.15
11	*Eupatorium spp.*	2.93	0.49	1.47
12	*Parthenium hysterophorus*	2.66	0.88	1.29
13	*Eichhornia crassipes*	2.83	0.90	1.79

(Gupta, 2000)

(b) **Green leaf manuring:** Green leaves and tender plant parts of the plants are collected from shrubs and tress growing on bunds, degraded lands or nearby forest and they are turned down or mixed into the soil 15-30 days before sowing of the crops depending on the tenderness of the foliage or plant parts. The most common shrubs/trees used for green leaf mauring are given below :

S.No.	Common Name	Botanical Name
1	Subabool	*Leucaena Leucocephala*
2	Gliricidia	*Gliricidia maculata*
3	Wild daincha	*Sesbania speciosa*
4	Kranj	*Pongamia pinnata*

Status of GM crops in India

At present only 6.7 million hectares area is green manured which accounts for 4.5 per cent of net sown area (142 million ha) of the country (Agril Ststistics, 2013). The practice of green manuring is most common in rice growing states like A.P., U.P., Karnataka, Punjab and Orissa which contribute 41, 16,11,6 and 5 per cent to the total area under green manuring in India respectively. Whereas, the share of Gujrat (3%), M.P. (3%), Himanchal Pradesh (2%) and Haryana (1.7%) is not very encouraging and concentrated effects are to be made out at all levels to bring more area under green manuring that too in irrigated areas if nutritional need of organic farming is to be made.

Biomass potential of GM crops

The benefits deriving from green manure crops are directly related to the amount of biomass and nutrients added in soil. Biomass production of green manure crops varies widely according to the species of the legumes, environmental conditions, soil fertility and crop management practices and age of green manure crops (Palaniappan, 1992).

According to the estimates of Sigh *et al.* (1992), the *Sesbania aculeta* and *Crotolaria juncia* have higher rate of biomass production and both can produce dry matter to the tune of 16.0 to 19.0 t/ha within a short period of 45-60 days and on an average about 5.0t/ha dry matter can easily be produced which is sufficient for meeting out the nutritional demand of a crop grown either in *Kharif* or *rabi* season. Beside these, some weeds particularly *Eichhronia crassipes* have maximum rate of biomass production and one can get about 70 q/ha dry matter with in a period of 46-60 days and could be used for *ex-situ* green manuring. Weeds like *Trianthema portulacastrum* and *Parthinum hysterophorus* are also found abundantly in different habitat with better nutrient content and dry matter production to cater the need of the organic agriculture (Table 3 and 4).

Table 3. Nutrient compositions of common green manure crops and weeds on dry basis

S.No.	Crop/weed	Nutrient content						
		Major nutrients (%)*			Total micro nutrients (mg/kg)**			
		N	P_2O_5	K_2O	Zn	Fe	Cu	Mn
1	*Sesbania rostrata*	2.62	0.37	1.25	40	1968	36	210
2	*Sesbania speciosa*	3.98	0.24	1.30	50	480	44	110
3	*Crotolaria juncia*	2.86	0.34	1.27	30	1190	24	110
4	*Eichhornia crassipes*	2.83	0.90	1.79	50	470	19	420
5	*Trianthema spp.*	2.34	0.30	1.15	30	1992	19	200
6	*Parthenium hysterophorus*	2.66	0.8	1.29	70	470	19	160
7	*Gliricidia maculata*	3.49	0.22	1.30	30	550	19	150
8	*Cowpea residue*	1.70	0.28	1.25	-	-	-	-
9	*Mungbean residue*	2.21	0.26	1.26	-	-	-	-

* Singh *et al* (1992) and ** Gupta (2000), Savitri *et al* (1999)

Table 4. Biomass and nutrient potentials of different green manures and weeds

S.No.	Crop	Dry matter in 45-60 DAS (q/ha)	Nutrient accumulation						
			Major nutrients (kg)			Total micro nutrients (g)			
			N	P_2O_5	K_2O	Zn	Fe	Cu	Mn
1	*Sesbania rostrata*	50.0	131.0	18.5	62.5	200	9840	180	1050
2	*Sesbania speciosa*	30.0	119.4	07.2	39.0	150	1440	132	330
3	*Crotolaria juncia*	52.5	150.2	47.3	93.9	262	2467	100	2205
4	*Eichhornia crassipes*	70.0	198.1	63.0	125.3	350	3290	133	2940
5	*Trianthema spp.*	25.0	58.5	07.5	28.7	75	4980	47	500
6	*P. hysterophorus*	40.0	106.4	35.2	51.6	280	1880	76	640
7	*Gliricidia maculata*	36.0	125.6	7.9	46.8	108	1980	68	540

Palaniappan (1992) ; Singh *et al.* (1992)

Nutrient potential of GM crops

Almost all GM crops which are used for *in-situ* or *ex-situ* green manuring contains all the plant nutrients which are essential for completing the life cycle of any palnt grown in community. Among the different GM crops, dhainch (*Sesbania aculeta*) and Sunhemp (*Crotolaria juncia*) have higher accumulation of major and micro nutrients on account of more biomass production and better nutrient composition compared to food legumes which are inferior due to low contents of nutrients coupled with less dry matter production (Table 3&4). Water hyacinth has great nutrient potentials and it could contribute 198 kg N, 63.0 kg P_2O_5, 125.3 kg K_2O and 350 g Zn, 3290 g Fe, 133 g Cu and 2940 g Mn when about 70 q/ha dry matter is added in the soil and could serve as better source of plant nutrients through *ex-situ* green manuring.

Techniques for harvesting the benefits of green manuring

The maximum benefit from green manuring can be obtained through better knowledge of suitable sowing time of GM crops, age or stage of GM crop for burial and time interval between burial and sowing of next crop.

(a) Sowing time of GM crops: Sowing time of GM crops for in-situ green manuring varies according to local conditions and farming situations. The green manures can be grown as catch crop during summer season particularly in irrigated agro-ecosystem. The quick growing crops like sunhemp and dhaincha etc. are sown in month of April-May and buries in the field in the month of June and July before the planting of main *kharif* crop. In rainfed areas as well as in intensive farming areas, the dhaincha is intercropped with paddy in 4:1 row proportion, whereas sunhemp and cowpea are intercropped in between the rows of widely spaced crops like cotton, maize and sugarcane and buried in the soil when these crops attain the age of 30-45 days with the help of hoes or mould board plough. In *kharif* fallow areas sunhemp, guar, cowpea and dhaincha are sown in June, July and buried in the soil during Ausgut-Spetember. This practice is most common in Punjab, U.P., Rajasthan, Bihar and M.P.

(b) Stage of GM crop at burial: Knowledge of time of burial of GM crops is of utmost importance for deriving maximum benefit from green manuring. The chemical composition of most plants changes identically during growing season. During early period of crop growth its content of N, protein and water soluble constituents are maximum, while the amount of fiber, cellulose, hemicelluloses, lignin and the C:N ratio are also less. Therefore, tissues of immature plants usually decompose more rapidly as compared to those of matured plants. Singh et al (1992) reported while reviewing the nutrient transformations in soils amended with green manures that the green manure crops are to be buried in the soil when they are 2 months old and two weeks delay in the incorporation reduced their N content and increased the C:N ratio, cellulose, hemicelluloses and lignin contents.

(c) Time interval between burial of GM and sowing of next crop: Knowledge of time interval between burial of GM crops and sowing of next food crop for just to facilitate the complete decomposition of the turned in green matter is essential. Ghose *et al.* (1960) reported from their studies conducted at CRRI, that the time interval was not so important when succulent green manure crop of eight weeks age was buried because transplanting of paddy immediately after burying of green manure crop was as good as any other treatment. But it was necessary to give the time interval of 4-8 weeks before planting paddy when the GM was 12 weeks of age.

Effect of green manuring on crop yields

In most of the studies conducted in different parts of the world, the crop yields under organic management are somewhat lower than conventional systems. In developing countries, organic farming methods provided similar outputs and income per labour day to that of high-input systems using inorganic fertilizers (Andrew and Hidka, 1998) In Sambalpur district of Orissa, the studies of Patra *et al.* (2000) revealed that there was reduction in the yield of rice to the tune of 15-23 per cent due to alone green manuring as compared to 100% recommended dose of NPK through fertilizers which produced the maximum yield (42.97 q/ha) of rice. In Samastipur (Bihar), Thakur *et al.* (1999) assessed the impact of green manuring on yield of rice-wheat system and reported that green manuring with dhaincha significantly improved the productivity of rice over other sources, whereas residual effect of green manuirng on succeeding wheat was marginal. Nair and Gupta (1999) also recorded 25% more yield of rice over no-green manuring which produced only 34.94q/ha of rice at Pantnagar, Uttranchal. Similar views were also endorsed by Hemalatha *et al.* (2000) at Madurai in Tamil Nadu

Effect of green manuring on soil productivity

The physico-chemical properties of soils are affected significantly due to addition of organic matter in the form of green manures particularly in plots receiving green manuring through *Sesbania rostrata* and *Crotolaria juncia*. Consequently, marked improvement in soil structures, infiltration rate, bulk density and water holding capacity of soil. It is evident from the results of studies of Badanur *et al.* (1990) that incorporation of subabool, sunhemp and crop residues was equally effective in increasing infiltration rate of soil while the water use efficiency of sorghum was increased significantly with the green leaf manuring of sunhemp, subabool and fertilizer application over crop residues. Aggregate stability and porosity increased identically with the addition of organic inputs particularly green manures and consequently it improves the soil aeration and water holding capacity of the soils under organic management (Droogers *et al.*, 1996). Lower rates of runoff and soil erosion have also been reported under organic systems (Logsdon *et al.*, 1993; Reganold *et al.*,1987). On the contrary in several studies no change in the physical properties of soil have been observed when managed organically or conventionally (Niggli *et al.*, 1995)

The changes in chemical properties of soil could be predicted well through the nutrient budget. The results of several studies showed that nitrogen, phosphorus and potassium, organic carbon etc. ranged from deficit to surplus in organic farming systems (Fagerberg *et al.*, 1996; Nguyen *et al.*, 1995, Hemalatha *et al.*, 2000, and Selvi and Kalpana, 2009). Green manuring under submerged conditions markedly increased Fe and Mn concentration and partial pressure of CO_2 and decreased pH, Eh and Zn in soil solution. The increase in Fe and Mn concentration attributed to the formation of complexes of Fe^{2+} and Mn^{2+} with organic acids produced during anaerobic decomposition of green manure and also due to sharp decrease in Eh and pH and increase in partial pressure of CO_2 (Sadana and Chahal, 1995; Sadana and Nayyar, 2000).

Effect of green manuring on product quality

There is no clear-cut scientific evidence with some studies showing increases in vitamin C, minerals and proteins (Lampkin, 1990) because these are controlled by a complex of interaction in added manures and fertilizers. Therefore, it is difficult to distinguish the effects of the environment and farming systems on quality of crop products. Studies of Starling and Richards (1993) showed that organic wheat had lower protein levels compared to conventionally grown crops. Results of studies conducted at Madhurai in Tamil Nadu have also indicated that incorporation of Sesbania 12t/ha increased the optimum cooking time, total amylose content, crude protein in rice and reduced the gruel loss (%) of grain Hemalatha *et al*., 2000.

References:

- Agricultural Statistics (2013). Agricultural statistics at a glance. Ministry of Agricultural, New Delhi.
- Andew, D.A. and Hidaka, K. (1998). Yield loss in conventional and natural rice farming system. *Agric Ecosystem Environ*. 70 : 151-158
- Badanur, V.P., Poleshi, C.M. and Naik, B.K. (1990). Effect of organic matter on crop yield and physical and chemical properties of vertisol. *J. Indian Soc. Soil Sci*., 38 (3) : 426-429
- Droogerss, P., Fermont, A. and Bouma, J. (1996). Effects of ecological soil management on workabiltiy and trafficiability of a loamy soil in Netherlands. *Geoderma* 73 :131-145.
- Fagerberg, B., Salomon, E. and Jonsson, S. (1996). Comparisons between conventional and ecological farming systems at Ojebyn : nutrient flows and balances. *Swedish J. Agric. Res.,* 26:169-180.
- Ghosh, R.L.M., Ghate, M.B. and Subrahmanyam, T. (1960) Rice in India. I.C.A.R. New Delhi-12
- Gupta, O.P. (1984). Scientific weed management in tropic and subtropics. *Today and Tomorrow Printers and Publishers*, New Delhi
- Hemalatha, M., Thriumurugan, V. and Balasubramaniam, R. (2000). Effect of organic sources of nitrogen on productivity, quality of rice and soil fertility in single crop wetlands. *Indian J. Agron.*, 45 (3) : 564-567
- Lampkin, N. (1990). Organic farming. Farming Press, *IPSWICH, U.K.*, pp 715
- Logsdon, S.D., Radke, J.K. and Karlen, D.L. (1993). Comparison of alternative farming systems. I. Infiltration techniques *Am. J. Alt. Agric*., 8 : 15-20.
- Nair, A.K. and Gupta, P.C. (1999) Effect of green manuring and nitrogen levels as nutrient uptake by rice and wheat under rice wheat sequence. *Indian J. Agron.*, 44 (4) : 659-663
- Kumar, Ravindra Mahajan, G. Shrivastava, S. and Sinha , Asha (2014). Green manuring: A boon for sustainable and pest management- A review. *Agri. Review,* 35 (3): 196- 206.
- Nguyen, M.L., Haynes, R.J. and Goh, K.M. (1995) Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, Newzealan. *Agric. Ecosystems Environ.*, 52 : 149-162.
- Niggli, U., Alfoldi, T., Mader, P., Pffiffner, L., Speciss, E. and Besson, J.M. (1995). DOK-Versuch Vergleichende Longzeit-Untersuchungen in den drei Anbausystemen biologish- dynamisch, Organish-biologish und Konventionell VI. *Synthese 1und 2 Fruchffloge periode. Schweiz Landw Fo. Snderheft DOK* 4 : 1-34.
- Palaniappan, S.P. (1992) Green manuring : nutrient potential and management. (In) fertilizers, development and recyclable waste and biofertilziers. *Ed*. Tandon, H.L.S. Development and consultation Organization, New Delhi
- Patra, A.K., Nayak, B.C. and Mishra, M.M. (2000). Integrated nutrient management in rice-wheat cropping system. *Indian J. Agron*., 45 (3): 453-457
- Reganold, J.P., Elliot, L.F and Unger, Y.L. (1987). Long term effects of organic and conventional farming on soil erosion. *Nature* 330: 370-372.
- Sadana, U.S. and Nayyar, N.K. (2000). Amelioration of iron deficiency in rice and transformations of sol iorn in course textural soils of Punjab. Indian J. Pl. Nutr. 23 (11-12): 2061 – 2069.
- Sadana, V.S. and Chahal, D.S. (1995). Iron availability, electrochemical changes and nutrient content of rice as influenced by green manuring in a submerged soil (In) : Iron nutrition in soil and plants (Netherlands) *Ed.* J. Abadia pp 105-109.
- Savithri, P., Poongothai, S., Joseph, B and Vennila, R.K. (1999). Non-conventional sources of micronutrients for sustainable soil health and yield of rice-green gram cropping system. *Oryza*, 36 (3) : 219-222.
- Selvi, R.V. and Kalpana, R. (2009). Potentials of green manure in integrated nutrient management for rice – A review. *Agri. Review,* 30 (1):40-47.
- Singh, V., Singh, B. and Khind, C.S. (1992). Nutrient transformations in soil amended with green manures *Adv. Soil. Sci*., 20 : 238-298
- Starling, W. and Richards, M.C. (1993). Quality of commercial samples of organically grown wheat. *Aspects Appl. Boil*., 36 : 205 – 209.
- Stockdale, E.A., Lampkin, N.H., Hovi, M., Keatinge, R., Lennartsson, E.K.M., Macdonald, D.W., Padel, S., Tattersall, F.H., Wolfe, M.S. and Watson, C.A. (2000). Agronomic and environmental implications of organic farming systems. *Adv. Agron*. 70 : 261-327.
- Tandon, H.L.S. (1995) Sustainable agriculture for productivity and resource quality- A model for India. *Fert. News,* 40 (10) ; 39-45
- Thakur, R.B., Choudhary, S.K. and Jha, G. (1999). Effect of combined use of green manure crop and nitrogen on productivity of rice-wheat under lowland rice. I*ndian J. Agron*., 44 (4): 664-668.

Impact of climate change on soil and mitigation strategies

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Abstract

The extreme weather and drought were experienced in past many years and the impacts of global climate change will be even more severe in certain regions. These regions are already prone to declining soil fertility status as well as agronomic yields and increased food insecurity due to the adverse effects of climate change. Natural and anthropogenic activities result in changes in the global environment, sometimes with severe consequences for our future life. Changes in the gaseous composition of the atmosphere partly due to CO2 may lead to a rise in temperature with high spatial and temporal variability.This may lead to alterations in the global circulation processes, and to a serious rearrangement of atmospheric precipitation, increasing aridity in some locations not only in India but also at global level. These modifications are reflected sensitively by ecosystems (natural vegetation and land use pattern) and by considerable alterations in soil formation and degradation processes, in soil properties and soil functions.

Increased concentration of greenhouse gases (GHGs) in the atmosphere was considered responsible for warming of the global climate by 0.74 °C between 1906 and 2005. The trends of rise in temperature, heat waves, droughts and floods and sea level shown by the Indian scientists are in line with those of Inter-Governmental Panel on Climate Change (IPCC) though magnitude of changes could differ. The increasing rate of temperature, deficit in rainfall and occurrence of droughts particularly in non-conventional pockets are evidences of weather aberrations indicating climatic risks. The potential impacts of the forecasted climate change should be studied with special emphasis on soil water management, soil moisture regime and their influences on the main soil degradation processes. The climate change and potential impacts of the climate change are summarized in the present paper with specially with respect to soil and its management strategies.

Keywords: IPCC, Climate Change, Soil, Global warming, Green House Gases (GHGs).

Introduction

India has to produce 300 Mt of food grains by 2020 to feed growing population. The net cultivated land (142.5 M ha) is limited and pressure for production of food grains is increasing, therefore, maintenance of soil fertility is a prime issue for farmers (Anonymous 2012 -13). The present day agriculture is facing a problem of continuous decline in soil nutrients reserve and scientists reported that it may be due to variable change weather and climatic phenomena which is going from bad to worse year after year.

The anthropogenic activities are leading to changes in the global environment at virtually unprecedented rates, with potentially severe consequences to our future life. The study and solution of the problems of the predicted global environmental changes require urgent and efficient actions. This crucial task formulates a challenge for science to describe, understand and control the interactive physical, chemical and biological processes that regulate the total earth system, the unique environment for life (Scharpenseel *et al*., 1990; Lal *et al*., 1994). According to the IPCC 2007, global temperatures are expected to increase between 1.1 and 6.4 °C during the 21st century and precipitation patterns will be altered. These all are largely due to increased emissions from energy, industry and agriculture sectors; widespread deforestation as well as fast changes in land use and land management practices. These anthropogenic activities are resulting in an increased emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), popularly known as the “greenhouse gases” (GHGs) (Table -1)

Table 1: Effect of anthropogenic activities on green house gas emission

Parameters	CO_2	CH_4	N_2O	Chlorofluorocarbons
Average concentration 100 years ago (ppb*V)	290,000	900	270	0
Current concentration (ppb V) (2007)	380,000	1774	319	3-5

Projected concentration in the year 2030 (ppb V)	400,000	2800-3000	400-500	3-6
Atmospheric lifetime (year)	5-200	9-15	114	75
Global warming potential (100 years relative to CO_2)	1	25	298	4750-10900

Source: - IPCC (2007), * Part per billion

Soils are intricately linked to the atmospheric/climate system through the carbon, nitrogen, and hydrologic cycles. Because of this, altered climate will have an effect on soil processes and properties. Recent studies indicate at least some soils may become net sources of atmospheric C, lowering soil organic matter levels. Soil erosion by wind and water is also likely to increase, hence it's very important to study about the change in soil properties occur in a specific area or region due to climate change.

Arable land and the per capita land area

India is endowed with abundant land resources and being the 7th largest country in the world, it has a total area of 328.8 million hectares (Mha) and Agricultural land area has been relatively stable since 1960 at 180 Mha. The arable land area peaked at 163 Mha in 1980 and has since declined by 3% (Table -2), and additional decline may occur because of numerous competing use (*e.g.*,urbanization, infrastructure development, and industrial installation) and losses to degradation by accelerated erosion, and secondary salinization. Whereas the available agricultural and arable land areas are decreasing, the population of India is increasing. Therefore, there is an exponential decline in the per capita land area for agriculture and arable uses. The per capita arable land area has declined from 0.34 ha in 1961 to 0.14 ha in 2010, and is projected to decline to 0.09 ha by 2050.

Table: -2 Agricultural and arable land area in India

Year	Land Area (10^6 ha)	
	Agricultural	Arable
1961	175	156
1970	178	161
1980	180	163
1990	181	163
2000	183	162
2010	180	158

Source: - Adapted from FAOSTAT 2013

Similarly, per capita agricultural land area has declined from 0.38 ha in 1961 to 0.18 ha in 2010 and is projected to 0.10 ha by 2050. Thus, all basic necessities for human well being (*e.g.*, food, fiber and fuel) and other ecosystem services must be met from per capita agricultural land are of <0.1 ha. Therefore, it is very much necessary to keep a watch on the factors which are responsible for affecting all phenomena occur into soil due to climate change.

Climate change and its environmental consequences

A change in climate will result into considerable changes in natural vegetation and also in land use practices adopted by the farmer. As we all know that in the year 2010, when north India received a very good amount of monsoon rain, the eastern part of the country (Bihar, Jharkhand and West Bengal) faced a severe drought. The year 2014 was the hottest year ever since the temperature measurement started. In the last 100-150 years considerable changes have taken place in the gas composition of the atmosphere due to natural processes and human activities, such as increasing energy consumption, industrialization and intensive agriculture. This may lead to a rise in global temperature and high spatial and temporal variability. The changing temperature regime would result in considerable changes in the precipitation pattern (IPCC 2007).

If, temperatures rise, as forecasted, an increasing number of mountain glaciers, the permafrost soil zone and the polar ice caps will melt. This would lead to changes in the water flow dynamics, including flood waves and surface runoff, resulting in a rise of the eustatic *sea* level, threatening low lying, man protected lands, agricultural areas, and extended seashores with low slope. Other consequence would be the further extension of salt affected territories under the direct effect of sea water inundations or due to the rise of the sea level connected water table of saline or brackish groundwater (Scharpenseel *et al.*,1990; Várallyay, 1994).

The alteration in temperature and precipitation pattern would lead to considerably influence or change in the field water cycle and formation/degradation processes soil. So change in atmospheric phenomena may result into change in use pattern of soil by the farmers. This regional disparity in the cause and effect of climate change can be better appreciated by looking at the country wise contribution to global warming and its effect on future agriculture productivity (Table 3)

Country' s name	Per capita CO_2 emission (tones CO_2/capita/year)	% change in agriculture productivity
USA	18.9	+8
Canada	16.9	+13
Russia	10.8	+26
Japan	9.8	+8
Germany	9.6	+12
U.K	8.9	+11
France	6.0	+7
China	4.9	+7
India	1.4	-29
Pakistan	0.9	-20
Sri Lanka	0.6	-8
Bangladesh	0.3	-10
Nepal	0.1	-4

Grain production trend of India

Production of major food grains increased drastically between 1961 and 2010 (Table - 4). The increase was by a factor of about 3 for rice, 9 for wheat, 5 for maize, and 3.4 for total grain production. In accordance with the increase in the

***Source*:** Kumar *et al*., (Febraury, 2011)

production, the net per capita production index has progressively increased between 1965 and 2011.

Table: 3 Per capita CO_2 emission (2007) and estimated impact of global warming (with carbon fertilisation) on agriculture productivity in some selected countries in 2080s

The baseline production for 2004-2006 (2005) as 100, the per capita production increased between 1965 and 2011, from 73 to 122 for agriculture, 75 to 111 for total cereals, 79 to 123 for crops, 73 to 120 for total food and 81 to 144 for non-food production. Whereas the trends in agricultural and food grain production are impressive, there is no scope for complacency because even greater challenges lie ahead.

Thus, there is a strong need to identify and implement appropriate strategies to enhance food production from decreasing soil and water resources, under changing and uncertain climate. Furthermore, production targets must be met while restoring degraded soils, improving quality and quantity of renewable freshwater resources, achieving land degradation neutrality, improving biodiversity and increasing the provisions of numerous other ecosystem services (Lal, 2013).

Table:-4 Growth in food grain production in India between 1961 and 2012

Year	Production (10^6 Mg)									
	Rice	Wheat	Maize	Sorghum	Millet	Barley	Soybean	Lentil	Beans	Total
1961	53.5	11.0	4.3	8.0	7.7	2.8	0.005	0.36	1.7	89.4
1970	57.9	20.1	6.2	7.2	11.1	2.7	0.014	0.38	2.0	131.1
1980	80.3	31.8	7.0	10.4	10.5	1.6	0.4	0.32	2.8	144.0
1990	111.5	49.8	9.0	11.7	7.4	1.5	2.6	0.71	4.1	201.3
2000	127.5	76.4	12.0	7.5	8.7	1.4	5.3	1.08	2.8	244.1
2010	144.0	80.8	21.7	6.7	13.2	1.4	12.7	1.03	4.9	286.5
2012	152.6	94.9	21.1	6.0	10.3	1.6	11.5	1.0	3.6	302.6
*RIF	2.85	8.63	4.90	0.75	1.34	0.57	2300	2.78	2.12	3.38

Source: Adapted from FAOSTAT 2013, *Relative increase Factor

Influence of Climate Change on Soil Properties and Processes

Carbon and nitrogen are major components of soil organic matter. Organic matter is important for many soil properties, including structure formation and maintenance, water holding capacity, cation exchange capacity, and for the supply of nutrients to the soil ecosystem. Soils with an adequate amount of organic matter tend to be more productive than soils that are depleted in organic matter, therefore, one of the biggest questions concerning climate change and its effects on soil processes and properties involve how potential changes in the C and N cycles will influence soils.

Early expectations were that increased atmospheric CO_2 would lead to increased plant productivity coupled with increased carbon (C) sequestration by soil, meaning increased plant growth and the soil plant system would help offset increasing atmospheric CO_2 levels (Coughenour and Chen., 1997; Hattenschwiler *et al.*, 2002).This increase in plant growth is known as the CO_2 fertilization effect. However, recent studies indicate the CO_2 fertilization effect may not be as large as originally thought (Poorter and Navas, 2003). Increasing levels of ozone as the climate changes may actually counteract the CO_2 fertilization effect leading to reduced plant growth under elevated CO_2 and the negative effects of increased temperatures on plant growth may also cancel out any CO_2 fertilization effect that does take place. Nitrogen limitations may negatively affect plant growth, and modeling of C dynamics as influenced by N indicates less C sequestration by soil than originally expected given CO_2 fertilization. The decomposition of plant tissues grown under elevated atmospheric CO_2 also indicate that increased levels of CO_2 are emitted during that decomposition and research by Carney *et al*. (2007) observed soil organic C levels declining under increased atmospheric CO_2 levels due to increased microbial activity. Therefore, elevated CO_2 levels will not necessarily lead to increased soil C sequestration, but may instead result in more C turnover. Increased temperature is likely to have a negative effect on C allocation to the soil, leading to reductions in soil organic C and creating a positive feedback in the global C cycle (increased temperatures lead to increased CO_2 release from soils to the atmosphere, which leads to more increases in temperature) as global temperatures rise (Gorissen *et al*.,2004; Wan *et al*.,2011)

The primary and secondary impacts of climate change on various soil properties

a) Soil Erosion

There are no linear relationships between mean annual precipitation, surface runoff and the rate of denudation/erosion. The rate, type and extension of soil erosion depends on the combined influences of climate quantity and intensity of rainfall, relief, vegetation (type, continuity, density), and soil erodability characteristics. The main influences of potential climate changes on soil erosion are as higher precipitation, especially intensive rainfalls and thunderstorms may result in an increasing rate of erosion (higher runoff), if it is not balanced by the increasing soil conservation. Effect of more dense and permanent vegetation due to better water supply, lower precipitation generally reduces the rate of erosion, but it can be by the poorer vegetation due to moisture limitations; lower precipitation which may intensify wind erosion.

b) Acidification

Decreasing precipitation may reduce downward filtration and leaching. Climate determines the dominant vegetation types, their productivity, the decomposition rate of their litter deposits, and influences soil reaction in this indirect way.

c) Structure destruction, compaction

The most important direct impact is the aggregate-destructing role of raindrops, surface runoff and filtrating water. The indirect influences act through the vegetation pattern and land use practices.

d) Biological degradation

Temperature, precipitation and vegetation changes considerably influence biological soil processes, but only little research is available on these consequences.

e) Salinization

Expected global ‘warming’ may lead to the rise of eustatic sea level, increase of inundated territories (especially in the densely populated delta regions and river valleys), and the areas under the influence of sea water intrusion. Higher precipitation will reduce downward filtration and leaching, lower precipitation and higher temperature will intensify salinization processes higher rate of evapotranspiration increasing capillary transport of water and solutes from the groundwater to the root zone. This salt accumulation, however, can be balanced by the sink of groundwater table in low lying, poorly drained lowlands (evaporative basins, *i.e.* the Carpathian lowlands) where the main salt source is the shallow saline/brackish groundwater

Mitigation strategies of climatic change

a) Soil management

Most of the cultivated soils contain about 0.5 to 5.0% carbon by weight, much of it stored in organic matter, derived from the residues of plants growing on the soil. The goal of soil management, for green house gases (GHGs) mitigation, is to increase the soil organic matter, thus increasing the amount of organic carbon that is retained in soils. Several soil management practices such as conservation agriculture,minimum tillage etc favours the

b) Agroforestry

An attractive and promising option for sequestering carbon on agricultural lands while leaving the bulk of the land for agricultural production, Agro forestry plays vital roles in mitigation of atmospheric accumulation of GHGs, Carbon sequestration rates are very encouraging for complex agroforestry, boundary planting, hedgerow intercropping, and home gardens

c) Manure and nutrient management

Manure is a major source of methane, responsible for some 400 million tons of CO_2 equivalent and poor manure management is a leading source of water pollution. Now a day, organic farming is being promoted as a climate friendly and sustainable farming system. It is thought to contribute to GHGs mitigation based on a number of factors. Organic agriculture has a much reduced consumption of fossil fuels for energy, less vulnerability of soils to erosion, and an increase in carbon sequestration.

d) Forests

The global forests cover 3952 million ha, or 30% of the earth's land area, of which about 95% are natural forests and 5% are plantations Tropical and subtropical forests comprise 56% of the world's forests, while temperate and boreal forests accounts t for 44%. Forests are capable of mitigating large amount of carbon dioxide.

e) Biochar

Biochar is the charcoal produced from carbonaceous source and being used as soil amendment. Biochar is usually produced by pyrolysis of biomass at around temperature range of 300 to 600 degrees centigrade .It is under investigation as an approach to carbon sequestration to produce negative carbon emission.

Climate smart benefits of Biochar

Carbon in biochar can persist in soils over long time scales. Beyond the carbon sequestered in the biochar itself. Biochar incorporated in soils also offers numerous other potential climate benefits (IBI)

I. **Soil fertility**: Biochar can improve soil fertility, stimulating plant growth, which then consumes more CO_2 in a positive feedback effect.
II. **Reduced fertilizer inputs**: Biochar can reduce the need for chemical fertilizers, resulting in reduced emissions of greenhouse gases from fertilizer manufacture.
III. **Reduced N_2O and CH_4 emissions**: Biochar can reduce emissions of nitrous oxide (N_2O) and methane (CH_4), two potent greenhouse gases from agricultural soils.
IV. **Enhanced soil microbial life**: Biochar can increase soil microbial life, resulting in more carbon storage in soil.
V. **Reduced emissions from feed stocks**: Converting agricultural and forestry waste into biochar can avoid CO_2 and CH_4 emissions otherwise generated by the natural decomposition or burning of the waste.
VI. **Energy generation**: The heat energy and also the bio oils and synthesis gases generated during biochar production can be used to displace carbon positive energy from fossil fuels.

References

- Anonymous (2012-13) Agriculture statistics at a glance. Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India, New Delhi.
- Carney, K.M., Hungate, B.A., Drake, B.G., Megonigal, J.P. (2007) Altered soil microbial community at elevated CO_2 leads to loss of soil carbon. *Proc. Natl. Acad. Sci. USA*, (104), 4990-4995.
- Coughenour, M.B. and Chen, D. X. (1997) Assessment of grassland ecosystem responses to atmospheric change using linked plant soil process models. *Ecol. Appl.*, (*7)*: 802-827.
- FAOSTAT (2013) http://www.fao.org/home/en/
- Gorissen, A., Tietema, A., Joosten, N.N., Estiarte, M., Peñuelas, J., Sowerby, A., Emmett, B.A.;,Beier, C. (2004) Climate change affects carbon allocation to the soil in shrublands. *Ecosystems*, (7) : 650-661.
- Hattenschwiler, S., Handa, I.T., Egli, L., Asshoff, R., Ammann, W., Körner, C. (2002) Atmospheric CO_2 enrichment of alpine treeline conifers. *New Phytol.*, (156), 363-375.

- International Biochar Initiative http://www.biochar-international.org/biochar/carbon
- IPCC. (Intergovernmental Panel on Climate Change), Climate Change (2007) The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK, p 996.
- Kumar, M., Patra, A. K. and Swarup, A. (2011) Impact of Climate Change on Fertilizer Demand in Agriculture: Concerns and Imperatives for Food Security in India. Indian Journal fertilizer, 7(2) : 48-62
- Lal, R. (1994) Soil Processes and Greenhouse Effect. CRC Lewis Publishers, Boca Raton. p 440.
- Lal, Rattan (2013) Soil and Sanskriti *Journal of the Indian Society of Soil Science*; 61(4) : 267-274.
- Poorter, H., and Navas, M. L. (2003) Plant growth and competition at elevated CO_2: On winners, losers and functional groups. *New Phytol.*, (157) : 175-198.
- Scharpenseel, H. W., Schomaker, M. and Ayoub, A.(1990) *Soils on a Warmer Earth*. Elsevier, Amsterdam, p 274.
- Varallyay, G. (1994) Climate change, soil salinity and alkalinity. In: Sounsevell, M. D. A. and Loveland, R. J. (eds.) *Soil Responses to Climate Change*. NATO ASI Series. (23), pp. 3-11.
- Wan, Y.; Lin, E.; Xiong, W.; Li, Y.; Guo, L. (2011) Modeling the impact of climate change on soil organic carbon stock in upland soils in the 21st century in China. *Agric. Ecosyst. Environ.*, (141) : 23-31.

Impact of continuous cropping and fertilizer use on productivity of crops and soil health of *typic haplustert*

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With the advent of sustainable agriculture concept the sustainability of soil fertility has now looked into more in areas where dependence on agrochemicals and fertilizers has sharply increased for crop production. So the current concept of soil health monitoring is a subject to vital concern for not only the soil fertility and productivity factors but also other aspects responsible for the soils welfare. Stagnation to productivity has been observed due to long term cultivation and imbalance use of plant nutrient, which deteriorates the fertility of soil. A major component of sustainable land use is to sustain the productivity and improve the soil health. Therefore, soil fertility is one of the key components to determine productivity and proper management of soil fertility demands careful identification of constraints of current nutrient status with monitoring the changes in soil fertility so as to sustain food production at a reasonable level to ensure continued high productivity in the future. Thus, maintenance of optimum soil health vis-à-vis nutrient management at optimum level is one of the key factors in activating high and sustainable productivity. (Dwivedi et al , 2007). With the advent of sustainable agriculture concept the sustainability of soil productivity has now looked into more in areas where dependence on agrochemicals and fertilizers have sharply increased for crop production. So the current concept of soil health monitoring is a subject of vital concern for not only the soil fertility and productivity factors but also other aspects responsible for the soils welfare (Tomar and Dwivedi, 2007). On the other hand, stagnation to productivity has been observed due to long term cultivation and imbalance use of plant nutrients, which deteriorate the quality of soil (Tomar and Dwivedi 2008). A major component of sustainable land use is to sustain the productivity and improve the soil quality.

Assessing the soil health indicators (soil properties) is usually linked to soil factors. Several indicators have been suggested reflecting changes over various spatial and temporal scales. Improved soil quality often is indicated by improvement on physical, chemical and microbiological soil environment (Singh, et al, 2012).

Agricultural production becomes imperative for establishment of the relationships between crop productivity, use of plant nutrients and soil characteristics. What farmers need to know is how much and which plant nutrients they should supply to provide the optimum economic increase in yield without damaging the soil environment (Thakur et al 2011b). The answer depends on the soil test based recommendation for the specific farming system. Increased attention is now being paid to developing such a Plant Nutrition Systems that maintain or enhance soil productivity through a balanced use of mineral fertilizers combined with organic sources of plant nutrients, including biological nitrogen fixation (Singh et al, 2012). Integrated nutrient management is only option to motivate the farming community which may consequently improve both soil productivity and crop yields. The works of AICRP on LTFE is repertory for the parameters concern to soil productivity and crop yields.

The challenges for plant nutrition management are aimed to maintain sustainable crop productivity to enhance the quality of soil and water resources. Crops inevitably removes plant nutrients from the soil. Consequently, if a cropping system is to be sustainable, these nutrients have to be replaced by whatever sources are available. The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, poses a serious threat to soil fertility and agricultural production. Hence,, the use of external sources such as mineral fertilizers and organic manures etc is essential to meet crop requirements and to increase crop production in farming systems (Singh, et al, 2012).

Major constraints in monitoring soil health and crop productivity

After the impact of green revolution, the production and productivity has stagnated on fluctuating but the measuring yield trend is very low. Despite the good research work done there has not been any commensurate growth in production and productivity. Some of the important factors contributing to slow growth rate are:

- **Climatic**: Rainfall (extent & distribution, light duration and intensity, temperature affect the crop productivity and variation in these parameters reflect the productivity potentials.
- Land: Cultivation on marginal and sub marginal lands of low productivity.
- Irrigation: Cultivation mostly under fain fed situation (assured irrigations are limited).
- Crop variety: Low yielding long duration varieties/ lack of selection of suitable varieties to problem areas. Inadequate availability of quality seeds of improved varieties.
- High cost input: Rise in output of agriculture through increased use of fertilizers/pesticide/seeds. The supply of these inputs at lower prizes at a adequate quantities reflects the productivity.

Impact of Nutrient Management on Crop Productivity

Continuous cropping without adequate restorative practices may endanger the sustainability of Agriculture. Nutrient depletion is a major form of soil degradation. A quantitative knowledge on the depletion of plant nutrients from soils helps to understand the state of soil degradation and may be helpful in devising nutrient management strategies. Nutrient-balance exercises may serve as instruments to provide indicators for the sustainability of agricultural systems. Studies have been undertaken suggested that a wide spread occurrence of nutrient mining and soil fertility decline has been reported. Most nutrient-balance studies also provide rapid findings, based on a short time-frame exercise, and necessarily depend on a number of assumptions relating to system dynamics. In this regards the findings on impact of four decades of continuous use of fertilizer on crop productivity and soil fertility of black soil is monitored under AICRP on LTFE at Jabalpur. The lowest crop productivity of Soybean (Fig- 1) and wheat (Fig -2) was recorded in control (T_{10}) and it was found to be increased by around 30% due to use of N alone (T_7) thus application of optimal dose of N alone may not be an economic preposition for obtaining high crop productivity. However, when P was also included in fertilizer schedule (i.e. 100% NP) the crop productivity increased by 127 % over control and 75 % over 100 % N alone. These findings indicated the importance of Pin crop productivity in Soybean-Wheat cropping sequence followed in this region as both the crops are heavy feeder of P. Responses to P application by Soybean and Wheat have also been recorded by Bhatnagar et, al. (2011). Further inclusion of K in the treatment (100 % NPK v/s 100 % NP) caused an increase in crop productivity indicating the importance of K as suggested by Chouhan et al 2011 Thakur et al (2011 a). Increasing levels of NPK application had resulted in increased crop productivity as 12 %, 15 %A and 197% increased was observed over control due to the application of 50% NPK, 100 % NPK and 150 % NPK application respectively. The difference between 100% and 150 % NPK treatment were very marginal which could be due to the fact that higher level of fertilizer application could have resulted in higher demand of other nutrients (micro nutrients) which might have remained un fulfilled causing a constraint on crop productivity. Data shows at the optimal dose of fertilizers is used in conjunction with FYM increases the crop productivity indicating the beneficial effect of organic manure, which not only contribute plant nutrients but also help in creating favorable soil environment for crop growth due to its effect on soil physical properties. Deletion of S in the fertilize schedule had resulted in 11% decrease in crop productivity over its inclusion (T_2) this clearly brings about the importance of S in plant nutrition and also crop productivity similar results have been reported by Dwivedi et al 2002.

Impact of nutrient management on soil fertility

The date on available NPK contents in soil (table-1) clearly indicate that cultivation of crops without addition of fertilizers and manure resulted in marginal increased in available N and P content of soil but had caused substantial lowering of available K and S contents, which indicates deterioration in soil health. Similar findings of fertilizer addition on soil health have been reported by Dwivedi et al, (2005) , Thakur et al, (2010) and Thakur et al, (2011b). However, balanced use of fertilizers either alone or in combination with manure had helped in strengthening the N and P status of soil. Since removal of K by crops was higher resulted in substantial lowering in available status of K. the magnitude of lowering was however low as compared other treatments. These findings indicate that use of balanced fertilizer either alone or in combination with organic manure is conductive for maintaining soil health as reported by Dwivedi and Dixit, 2002 Thakur et al, Thakur et al, 2010, 2011a Thakur et al, 2011 b. The data clearly indicate that there is need for upward revision of the doses of K that is being applied to the crop Sawarker et al (2013). On the other hand lowering in available S status of soil in N P K without S treatment indicates that use of sulphur free fertilizer will have deleterious effect on soil health especially of sulphur fertility (Dwivedi et al, 2009).

Management of soil health

Restoring, maintaining and increasing the fertility of the soil are major agricultural priorities, particularly in the many parts of the country where soils are inherently poor in plant nutrients, and the demand for food production is increasing rapidly. In such areas, there is a need to intensify the crop production to meet demand for food without using former land fallow practices. A fertile soil provides a sound basis for flexible food production systems that, within the constraints of soil and climate, can grow a wide range of crops to meet changing needs. IPNS is used to maintain or adjust soil fertility and plant nutrient supply to achieve a given level of crop production by adopting the following measures:

- Promote the balanced use of fertilizers combined with organic and biological sources of plant nutrients in improving the efficiency of fertilizer, thus limiting losses to the soil environment.
- Identify a better understanding of the role of plant nutrients for maintaining soil productivity in securing the sustainability of agriculture.
- Formulate recommendations for fertilizers based on soil test, production goals and strategies within specific agro ecological management.

References

- Bhatnagar,R.K. Dwivedi,A. K.Schidanand, B. and Pahalwan, D. K. (2011) Impact of integrated application of organic manure and chemical fertilizers on productivity of soybean, wheat and chickpea grown on vertisols of Madhya Pradesh. JNKVV Res. J. 45(2) 190-193
- Dwivedi A. K., Chauhan, S.S., Bhatnagar, R.K. and Vaishya, U.K. (2009 b) Productivity nutrient availability and nutrient uptake in Soybean – Wheat rotation under long term fertilizer in Typic Haplustert. JNKVV Res. J. 42 (1): 38 - 41
- Dwivedi A.K, Bhatnagar, R.K. Chauhan S. S. and Vaishya U.K (2009 a) Long term Influence of Organic & Inorganic manuring on Soil Fertility and Productivity of Soybean - Wheat System in a Vertisol . JNKVV Res. J. 42(1) :33 - 37
- Chauhan S. S., V Kumar, Bhadauria, UPS, and Dwivedi A.K, (2011) Effect of conjoint use of organic and inorganic fertilization on Soil Fertility and Productivity of Soybean - Wheat crop sequence. Ann. Pl. Soil Res. 13(1) : 47-50
- Dwivedi A. K, Chauhan, S.S. and Dikshit, P. R. (2005). Productivity sustenance in soybean wheat cropping system in Typic Haplustert International Conference Sustainable crop production in stress environment: Management and genetic options held at JNKVV, Jabalpur during Feb. 9-12, 2005. Abst No. 1503: 54 pp.
- Dwivedi A.K ,Bhatnagar, R.K. Chauhan S. S. and Vaishya U.K (2009) Long-term Influence of Organic & Inorganic manuring on Soil Fertility and Productivity of Soybean - Wheat System in a Vertisol . JNKVV Res. J. 42:132-35
- Dwivedi, A. K. & Dikshit, P. R. (2002). Influence of long term fertilizer use on productivity and nutrition of soybean (Glycine max) – wheat (Triticum aestimum). 2nd

International Agronomy Congress on Balancing food and Environmental Security – A continuing challenge Nov. 26-30, 2002, Vol. 1: pp 354-56.

- Sawarkar, S.D., Khamparia, N.K., Thakur, Risikesh, Dewda, M.S. and Singh, Muneshwar (2013). Distribution of potassium fractions as influenced by long term continuous application of inorganic fertilizers and organic manure in Vertisol. *Journal of the Indian Society of Soil Science,61 (2) :*
- Singh ,Muneshwar , Wanjare, R H Dwivedi , A K and Ram Dalal (2012) Yield response to applied nutrients and estimates of N2 fixation in 33 years old Soybean – Wheat experiment on a vertisol . Expt Agric. Cambridge University Press .12:: 1–15
- Subba Rao A and Sammi Reddy K.(2005) Integrated nutrient management *vis-à-vis* crop production/productivity, nutrient balance, farmer livelihood and environment: Proc. Regional Workshop on improving plant nutrient management for better farmer livelihoods, food security and environmental sustainability held at Beijing, China during 12-16 December 2005 pp 26-40
- Tembhare, B. R. Dwivedi, A. K. & Tiwari, A. (1998). Effect of continuous cropping and fertilizer use on crop yields and fertility of Typic Haplustert. Proc. Long Term soil fertility management through integrated plant nutrient supply. Edt. Swarup, A. Raddy, D. D. and Prasad, R. N. IISS, Bhopal. pp. 221-228.
- Thakur Risikesh, Kauraw D.L. and Singh Muneshwar (2011 a). Profile Distribution of Micronutrient Cations in a Vertisol as Influenced by Long Term Application of Manure and Fertilizers. *Journal of the Indian Society of Soil Science* 59 (3): 239-244.
- Thakur Risikesh, Sawarkar S.D., Vaishya U.K. and Singh Muneshwar (2011b). Impact of Continuous Use of Inorganic Fertilizers and Organic Manure on Soil Properties and Productivity under Soybean-Wheat Intensive Cropping of a Vertisol. *Journal of the Indian Society of Soil Science*, 59 (1): 74-81.
- Thakur, Risikesh and Sawarkar, S.D. (2009). Influence of Long Term Continuous Application of Nutrients and Spatial Distribution of Sulphur on Soybean-Wheat Cropping Sequence. *Journal of Soils and Crops*, 19 (2): 225 – 228.
- Thakur, Risikesh, Sawarkar, S.D., Kauraw, D.L. and Singh, Muneshwar (2010). Effect of Inorganic and Organic Sources on Nutrients Availability in a Vertisol. *Agropedology*, 20 (1): 53-59.
- Tiwari, K. N. (2002) Nutrient management for sustainable agriculture J. Indian Soc. Soil Sci., 50: 374-397.
- Tomar V.S. and Dwivedi, A.K. (2007) Potassium nutrient and crop health JNKVV, Res J 41 (1) : 2-8.
- Tomar V.S. and Dwivedi, A.K. (2008) Soil Quality as a Measure of sustainable Management Proc. “Soil, Plant and Water Testing for Efficient Use of Input Resources for an Eco-Friendly Production System” CAS Deptt. of Soil Sci. Agri. Chem., JNKVV, Jabalpur.

Role of potassium in sustainable agricultural production

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Abstract

This review intends to focus on the role of potassium in sustainable agricultural production. Moisture deficit created by drought or withholding irrigation results in a significant reduction in plant water potential, osmotic potential, relative water content, photosynthetic rate, respiration, etc. Moreover, a marked reduction in various growth characters like, leaf area, weight or yield has been reported under abiotic and biotic stresses incidence of insect-pest and diseases. The application of potassium in general, mitigates the adverse effect of such stresses, which facilitate the conditions, that favours more or higher growth and yield levels of crop.

Introduction

Potassium is an alkali metal that occurs naturally in most of the soils. The total K content of the earth crust is about 2.3 to 2.5 per cent, but only a very small proportion of it becomes available to plants (Leigh and Jones, 1984). It is one of 18 elements that are essential for both plant and animal life (Brady and Weil, 2002). Plants require K proportionately in large quantities, hence, it is regarded as one of the three major plant food elements (Golakiya and Patel, 1988; Leigh and Jones, 1994; Dev, 1995). Higher yields of better quality depend greatly on the capacity and capability of the crop to resist or tolerate moisture and temperature abnormalities, diseases and other stresses during growing periods (Amtmann *et al*., 2004; Dev, 1995). Potassium is involved in many physiological processes such as photosynthesis (Vyas *et al*., 2001), photosynthetic translocation (Umar, 1997; Tiwari *et al*., 1998), protein and starch synthesis, water and energy relations (Rao and Rao, 2004), translocation of assimilates (Tomar, 1998) and activation of number of enzymes (Vyas *et al*., 2001; Sharma and Agrawal, 2002). Potassium also improves the water use efficiency (Singh et al., 1997; 1998) through its influence on maintenance of turgor potential (William, 1999). As most of the *kharif* and *rabi* crops are grown under rainfed conditions, crops experience water and temperature stresses of varying degrees and duration at various growth stages, thus, relevance of K nutrition under such stress conditions may assume great importance.

Potassium in Plant System

Potassium, an important macronutrient for plants, carries out vital functions in metabolism, growth and stress adaptations (Krauss, 2001; Krauss and Johnston, 2002). These functions can be classified into those that rely on high and relatively stable concentrations of K^+ in certain cellular compartments and those that rely on K^+ movement between different compartments, cells or tissues (Vyas *et al*., 2001). The first class of functions includes enzyme activation, stabilization of protein synthesis and neutralization of negative charges on proteins (Marschner, 1996). The second class, linked to its high mobility, is particularly evident where K^+ movement is the driving force for osmotic changes as, for example, in stomatal movement, light-driven and seismonastic movements of organs, or phloem transport (Amtmann *et al*., 2004). In other cases, K^+ movement provides a charge-balancing counter-flux i.e. essential for sustaining the movement of other ions (Singh and Singh, 1999). Thus, energy production through H+ ATPases relies on overall H+/K+ exchange (Tester and Blatt, 1989). Accumulation of K+ (together with an anion) in plant vacuoles creates the necessary osmotic potential for rapid cell extension (Singh and Singh, 1999; Warwick and Halloran, 1991).

Potassium deficiency leads to (i) growth arrest due to the lack of the major osmoticum (Singh *et al*., 1997 ; Warwick and Halloran,1991) , (ii) impaired nitrogen and sugar balance due to inhibition of protein synthesis, photosynthesis (William,1999) and long-distance transport (Bhaskar, *et al*.,2001) and (iii) increased susceptibility to pathogen probably due to increased levels of low molecular weight nitrogen and sugar compounds (Tiwari *et al*., 2001). In a natural environment, low-K conditions are often transient therefore, plants have developed mechanisms to adapt to short-term shortage of K supply.Potassium is involved in numerous functions in the plant, such as in enzyme activation, cation/anion balance, stomatal movement, phloem loading, assimilate translocation and turgor regulation, etc. (Golakiya and Patel, 1988; Singh *et al*., 1999; Umar, 1997). Stomatal resistance decreases and photosynthesis increases with increasing K content of leaves (Peoples and Koch, 1979). In tobacco plants well supplied with K, 32% of the total N^{15} taken up within 5 hrs was incorporated into protein whereas, by 11% in K deficient plants (Koch and Mengel, 1974). Potassium deficient leaf cells accumulate substantial quantities of low molecular weight organic compounds (Noguchi and Sagawara, 1966; Baruah and Saikia, 1989) because they act as an osmoticum in the absence of sufficient potassium.

Potassium and Stress Tolerance

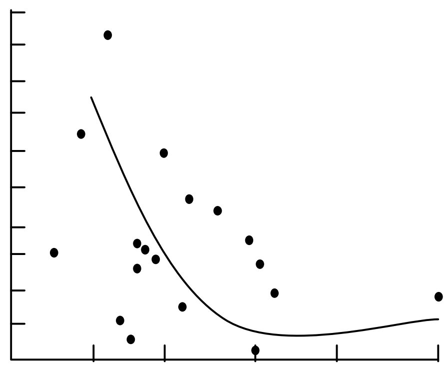
Abiotic and biotic stresses negatively influence survival (Agrawal *et al*., 2006) biomass production and crop yield (Amtmann *et al*., 2004; Dev, 1995; Tomar, 1998). Climatic extremes and unfavorable soil conditions are two major determinants affecting crop production (Singh *et al*., 2004). Potassium supply up to certain extent, can lessen their adverse effects on crop growth. The word abiotic means non-living and the components are those that do not have life, such as soil and climate / weather parameters. The biotic means living and components are those that have life, for example, plants, animals, microorganisms as well as some decomposers.

Abiotic Stresses

Soil moisture

The transport of K ion in soil medium towards plant roots takes place by mass flow and diffusion. On an average 10 per cent of total K^+ requirement of crops is transported by mass flow. In general diffusion is the main process of K^+ transport. According to Nye (1979) the diffusion of K^+ in the soil solution increases with soil moisture. Tortuousity i.e. the soil impedance increases with drying of soil. The diffusion coefficient for K^+ of about $1x10^{-7}$ cm^{-2} sec^{-1} at a soil water content of 23% decreases to $5x10^{-8}$ cm^{-2} sec^{-1} at 10% moisture content which is about $1.5x10^{-5}$ cm^2 sec^{-1} in pure water (Mengel and Kirkby, 1980). As water stress develops, K^+ helps in reducing the extent of crop growth loss through maintaining higher activity of enzyme nitrate reductase, which normally decreases under stress condition (Saxena, 1985). Potassium is also involved in the biosynthesis of proline and crop varieties with higher proline content are reported to have high yield stability as well as high productivity under moisture stress (Krishnasastry, 1985).

With variations in wet and dry conditions, the added K fertilizer may yield large responses in K responsive soils. Barber (1963; 1971) reported that lesser the rainfall for 12 weeks after planting, the greater the per cent yield increase of soybean from K additions (Fig.1). However, with low rainfall the roots tend to function more in the sub-soils and much lower in low K status (Nelson, 1978).



To provide 5 kg K/ha to the roots, the required K concentration in the soil solution in moist and dry soils varied. The drier the soil, the higher is the needed K concentration (Johnston *et al*., 1998). The K flux improves with the soil moisture (Fig. 2). On the other hand, a generous K supply can, to certain extend, compensate less diffusive K flux in drier soils.

With high rainfall and/or in waterlogged conditions the pore spaces in the soil get filled with water and oxygen content declines. This lowers respiration in plant roots and thus decline in nutrient absorption. However, by adding high amounts of K, the K need of the plant can be met even when root respiration is restricted (Skogley, 1976). Working on barley crop the adequate K had a reduced transpiration rate during stress (rate relative to 1.0 under non-stress) 5 minute after exposure to hot windy conditions. On the other hand, under severe K deficiency, the transpiration rate greatly increased. Greater water loss, thus, could limit the crop yield. Hot and dry winds are common occurrence in the plains and may be disastrous to crops.

Potassium fertilization can partially overcome the adverse conditions of poor aeration caused by waterlogging or compaction (Nye, 1979). The uptake of K is a process that requires energy provided by root respiration. If oxygen is lacking, root respiration is impaired and so is K uptake. As early as in 1963, Brown reported that poorly drained soils with low K resulted in poor yield as compared to the well drained soils. However, when K was increased to 150 kg/ha the yield increased even in poorly drained fields (Table 1).

Table 1. Yield of lucerne (ton/ha) under varying pH and drainage conditions

Soil drainage	pH 5.8		pH 6.5	
	37 kg K/ ha	150 kg K/ha	37 kg K/ha	150 kg K/ha
Poorly drained	7.4	10.7	8.10	12.3
Well drained	9.2	10.7	9.8	11.9

Source: Brown, 1963

A number of physiological disorders are related to K levels in poorly aerated paddy soils. In such soils excessive ferrous (Fe^{2}+) or the presence of respiration inhibitors like hydrogen sulphide may inhibit K uptake and cause Fe toxicity, a disorder commonly known as “bronzing” (Dev,1995 ; Hardter,1997).

Soil salinity

Plant adaptations to saline conditions can depend on an increase in specific inorganic and organic solutes within the cell, which may contribute osmoregulation or to the ability to prevent the accumulation of salts within the cytoplasm (Warwick and Halloran, 1991; Singh and Singh, 1999) . The operation of either mechanism is important for tolerance and adaptations to salinity. Analysis of plant tissues for Na and K contents under salt stress condition has been suggested as one of the useful parameter to measure the varietal salt tolerance (Warwick and Halloran, 1991; Singh and Tiwari, 2006). In this regard, Singh and Singh (1999) tested four chickpea varieties including tolerant and susceptible for Na and K contents with increasing salt stress (Singh *et al*., 2004). It was observed that the values of K content in tolerant genotypes were significantly higher than those of susceptible genotypes (Singh *et al*., 2006).

Temperature

Potassium can help plants to tolerate to both very high and very low temperatures (Grewal and Singh, 1980). The relationship between K nutrition and temperature is complicated by the interaction of soil and plant factor (Johnston *et al*., 1998). Frost damage has been reduced by maintaining of good level of K in the tissues of both annual and perennial crops (Grewal and Singh 1980; Shrinivasa Rao and Khera, 1995). The results from the findings of Grewal and Singh (1980) demonstrated that frost damage of the foliage of potato is inversely related to the K content of leaves.

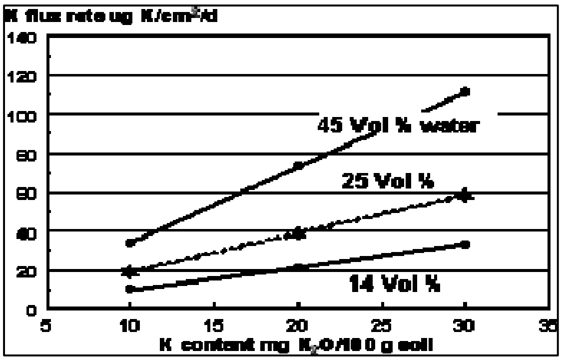


Fig. 2. K diffusive fluxes as affected by soil water content and K status of the soil (Source: Gath, 1992)

Similarly, the pattern of K uptake increases with increasing temperature up to a maximum and very high temperature can be detrimental if the loss of energy through respiration becomes excessive. Alterations in the amount of shade influences the effect of factors, such as temperature and moisture condition on growth and yield and thereby, K requirements (Nelson, 1978; Dev, 1995; Rao, 2004).

Biophysical properties

The biophysical role of potassium, in turgor maintenance and expansive growth, particularly its role in stomatal regulation and its effects on water use and carbon dioxide assimilation processes are affected by K deficiency (Rao, 1999). However, moisture stress undoubtedly is known to reduce the turgidity of cells (Umar, 1997) and thereby, decreases stomatal conductance and photosynthesis (Singh *et al*., 1998). Potassium application helps in drought tolerance and enhanced maturity as well as juice quality in sugarcane. The application of potash @ 80kg K_2O/ha resulted in an increase in leaf area, diffusion resistance of stomata and thereby, reduced transpiration rate over without application (Tiwari *et al*., 1998). This could be due to adequate supply of the potassium. However, the stomata close rapidly under drought and minimize the transpiration rate (Umar, 1997). Role of K in stomatal regulation in *Brassica* under moisture stress had also been reported (Sharma *et al*., 1992).

It has also been observed that most of the tropical legumes experience frequent droughts of varying degree and durations during their growth periods. Potassium influences the water economy and crop growth through its effect on water utilization, by root growth reflecting maintenance of turgor, transpiration and stomatal behavior (Nelson, 1978) and consequently influencing dry matter production to greater extent (Cadisch *et al*., 1993). Singh *et al.* (1997) also observed relatively lower values of leaf osmotic potential under water stress. While, these increased upon watering, indicating the change in osmoregulation. Under stress condition, the decline in osmotic potential is mainly due to the accumulation of solute like K^+, proline and soluble carbohydrates. Moreover, the osmotic adjustment enables plants to deplete the soil water to a lower soil water potential level. Thus, facilitates a greater exploration of available soil moisture by roots (Singh *et al*., 1997; Tiwari *et al*., 1998; Willium, 1999).

Golakiya and Patel (1988) studied the effect of cyclic dry spells and potassium treatments on the yield and leaf diffusive resistance of groundnut. The repeated occurrence of stress conditions caused considerable reduction (up to 75%) in pod yield and the shortfall in production was still higher in the case of consecutive dry spells. Potassium application of 60 kg K_2O/ha enhanced the level of production over control (no water stress) and could also restore the loss in pod yield to a noticeable extent. A marked increase in the diffusive resistance of leaves with K fertilization supports the contention that potassium plays an important physiological role in counteracting adverse conditions caused by drought.

Photosynthesis is the process through which the energy of solar radiation is directly converted in to sugar, starch and other organic components (William, 1999). Though, K is not an integral part of chlorophyll molecule, but it influences photosynthesis to a greater extent. Photosynthesis rate drastically decreases under water deficit because of both stomatal and non-stomatal factors (Umar, 1997; Singh *et al*., 2004). The reduction in photosynthetic rate is also due to decreased leaf water potential and RWC under water stress, which leads to decrease in stomatal conductance. The rate of photosynthesis is enhanced with supply of K in rooting medium because K helps in maintaining the rate by improving RWC and leaf water potential through osmotic adjustment under stress (Singh *et al*., 1997). It has also been reported that accumulation of optimum K in guard cells provides the adequate amounts of solute necessary in developing proper leaf water potential gradient required for movement into guard cells for stomatal opening necessary for photosynthesis. The amount of solar energy transformed into dry matter production, thus will be greater even in moisture stress condition under adequate K supply (Cadisch *et al*., 1993).

Effect of K levels (25, 50,100 and 200 ppm) on water relations, CO_2 assimilation, enzyme activation and plant performance under soil moisture deficit in cluster bean (Vyas *et al*., 2001) have shown that the plant water potential and RWC declined due to water stress at all K levels . However, the decline was less in plants growth at 200 ppm K level as compared to plants grown at low K levels. Wyrwa *et al*. (1998) observed that in K depleted soils under drought condition, the triticale yield got decreased by more than 50% whereas, application of 100 kg K_2O/ha increased the yield to a level which was only about 17% less than the yield of plants well supplied with water (Fig. 3).

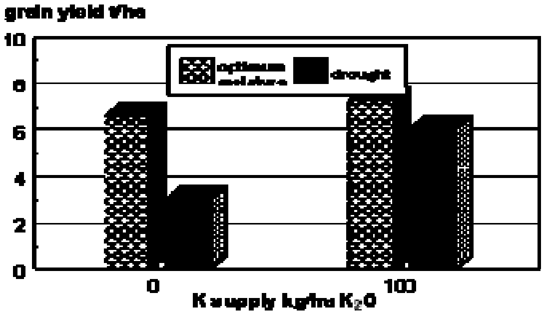


Fig. 3. Effect of potassium supply on yield of triticale as affected by drought

(Source: Wyrwa *et al*., 1998)

The yield improvement due to K application in number of crops suggests that under low moisture K application may result in yield improvement only when K availability is limiting. The evidences indicate that application of K mitigates the adverse effect of water stress by favorably influencing internal tissue moisture, photosynthetic rates and nitrogen metabolism.

Biotic Stresses

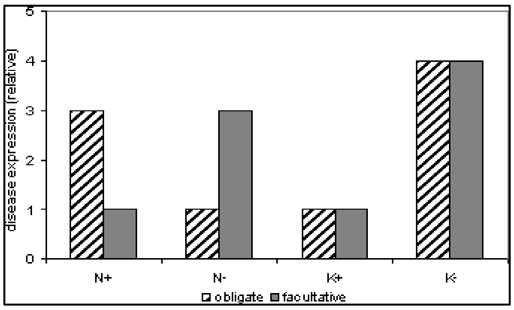
Insect, pest and disease incidence

Crops are constantly subjected to several fungal, bacterial and viral deceases. It has been observed that disease incidence, in general increases with the increase in Nitrogen level (susceptibility) that results in an increase in reducing and non-reducing sugar contents, but invariably decreases with potassium applications (Velazhahan and Ramabadran, 1992). Amongst fungal diseases especially the sheath rot caused by *Sarocladium oryzae* in rice has assumed much importance in recent years by causing heavy yield losses (Bhaskar *et al*., 2001). They reported that the sheath rot disease incident in rice increases with increase in N levels from 0 to 300 kg N/ha while, the phenol content in leaf sheath was found to increase with K application as compare to N levels. Further, it was observed that higher the phenol content, lower was the sheath rot incident probably due to growth of inhibiting pathogens.

Potassium has been shown to reduce the severity of several plant diseases. For example, Baruah and Saikia, (1989) reported that at low levels of potash the stem rot disease infestation in rice was relatively much greater ranging from 38.5 to 42.5 per cent, in comparison to optimum K levels. Potassium inhibits the accumulation of soluble carbohydrates as well as nitrogenous compounds in the tissues, thus helping to counteract a situation that favours fungal growth when K level is deficient. Similarly, lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals (Jayraman and Balasubramanian, 1988). Potassium, more than any other element, is known to reduce plant susceptibility to diseases by influencing biochemical processes and tissue structures. Due to the interaction of factors, such as environmental conditions, susceptibility of the plant or variety to disease, disease incidence and level of other nutrients, the effects of K can be variable. In a recent review it has been reported that high levels of K nutrition reduced the severity of more than 20 bacterial diseases, more than 100 fungal diseases and 10 diseases caused by viruses and nematodes (Marschner, 1995; Marschner *et al*., 1996). Potassium deficiency usually results in the accumulation of soluble N compounds and sugars in plants, which are a suitable food source for parasites. Whereas adequate K results in stronger tissue and thicker cell walls which are more resistant to disease penetration, while N has the opposite effect.

The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens especially for obligate parasites such as mildew or rust. This group of pathogens requires living plant cells to complete their life cycle. Thus, the host cell must survive the invasion by the parasite if the latter is to survive. Ample N supply helps in longevity of cells, high turnover of assimilates and high content of low molecular weight compounds. Facultative parasites, in contrast, require weak plants to be infested and killed to survive. Vigorous plant growth stimulated by ample N would suppress infestation by this group of pathogens. This may explain differences in the expression of plant diseases in relation to the nutrition of the host (Krauss, 2000) summarizes (Fig. 4) the effects of N and K on the severity of the infestation by both obligate and facultative parasites.

Fig. 4: Effect of N and K on expression of diseases



caused by obligate and facultative parasites (Source: Marschner, 1995)

As a general observation, plants excessively supplied with N have soft tissue with little resistance to penetration by fungal hyphae or sucking and chewing insects (Krauss, 2000). On-farm trials in India with soybean showed considerable less incidences with girdle beetle, semilooper and aphids when supplied with adequate potash (Fig. 5).

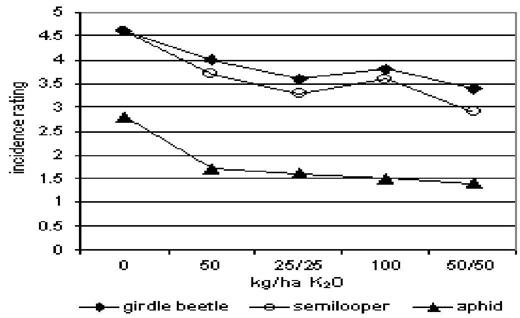


Fig.5: Pest incidence in soybean as affected by potash supply (Source: Krauss, 2000)

Similarly, excessive growth due to an unbalanced N supply can also create microclimatic conditions favorable for fungal diseases. Lodging of cereals as commonly observed at over supply with nitrogen and inadequate potash is a good example, humidity remains longer in lodged crops giving ideal conditions for germination of fungi spores.

Insufficient K also causes a pale leaf colour that is particularly attractive to aphids, which not only compete for assimilate but transmit viruses at the same time. Wilting, commonly observed with K deficiency, is another attraction to insects. Cracks, fissures and lesions that develop at K deficiency on the surface of leaves and fruits provide easy access, especially for facultative parasites.

The ratio between nitrogen and potassium plays obviously a particular role in the host/pathogen relationship. Perrenoud (1990) reviewed almost 2450 literature references on this subject and concluded that the use of potassium (K) decreased the incidence of fungal diseases in 70% of the cases. The corresponding decrease of other pests was bacteria 69%, insects and mites 63% and viruses 41%. Simultaneously, K increased the yield of plants infested with fungal diseases by 42%, with bacteria by 57%, with insects and mites by 36%, and with viruses by 78% (Fig. 6).

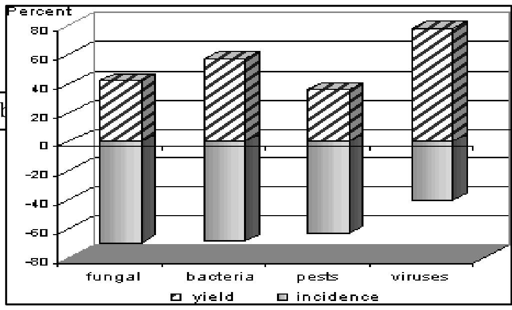


Fig.6: Effect of potassium on yield increase and pest incidences (Source: Perrenoud, 1990)

The effect of K on crop specific host/pathogen relationships for rice in Asia has recently been summarized by Hardter (1997). For example, stem rot, *Helminthosporium sigmoideum*, generally occurs at high nitrogen supply in soils poor in K. With improved K supply, the incidence decreases and yields increase. A similar inverse relationship between disease incidence and plant nutrition with K has been reported for brown leaf spot in rice (*Helminthosporium oryzae*), rice blast (*Piricularia oryzae*) or sheath blight of rice (*Thanatephorus cucumeri*s). A curative effect from applying K is also seen for bacterial diseases in rice like bacterial leaf blight, *Xanthomonas oryzae*, although highly susceptible varieties hardly responded to K in contrast to varieties with a moderate degree of resistance. The number of whitebacked plant hopper, *Sogatella furcifera,* could be substantially reduced with K in the resistant rice variety IR 2035 but K had almost no effect with the susceptible variety TN-1.

The enhanced rates of K application can induce or improve insect resistance by the following mechanisms. Accumulation of defensive phenolic compounds and their derivatives found to be toxic to insects. Thus, making the plants less palatable to insects and thereby causing non-preference (Perrenoud, 1990; Hardter, 1997).

Probable explanations for the beneficial effect of K on the host pathogen relationship focus on the following mechanisms. At insufficient K and/or excessive nitrogen, low molecular soluble assimilates like amino acids, amide and sugars accumulate in the plant cells. Correspondingly, Noguchi and Sugawara (1966) found in leaf sheaths of rice that the content of soluble N increased from 0.18 at adequate K to 0.45% at NP only. Similarly, soluble sugar increased from 1.52% to 2.43% at NP. The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens such as obligate parasites to complete their life cycle.

Conclusion

In India, moisture and temperature stresses are the most important abiotic stresses for crop productivity and yield potentials. Soil moisture alters physiological processes; root elongation, turgidity and rate of regeneration; stomatal conductance; photosynthesis and rate of crop development and maturity. It has been observed that crop responses to fertilizer K additions are often the greatest when water is either deficient or excessive. Potassium stimulates the degree and extent of root proliferation, root branching, etc. The greater root proliferation usually gives plants better access to sub soil moisture. Adequate K decreases the rate of transpiration through affecting the stomatal conductance.

Potassium usually speeds the rate of development and maturity, altering the deleterious effects of stress at critical growth stages. Under conditions where rainfall patterns are highly cyclical, drought effects can be reduced by advancing the date of pollination when most crops are highly sensitive to moisture stress.

Pulses especially chickpea experiences temperature stress under rainfed condition as this crop is taken after *kharif* crops. The crop experiences low temperature at initial stage of growth, results in poor and slow vegetative growth while, high temperature at the end of cropping sequence leads to forced maturity resulting low crop production. Potassium application helps plants to tolerate both the high and low temperatures.

Amongst abiotic stresses, soil salinity is a major constraint that affects plant growth and yield. Extra expenditure of energy for osmotic adjustments or in repair mechanism under salinity stress causes growth reduction. Potassium content in salt tolerant genotypes has been reported to be significantly higher than those of susceptible genotypes. Addition of K in salt-affected soils improves crop yields including vegetable crops.

Potassium application inhibits the accumulation pf soluble carbohydrates as well as nitrogenous compounds in the tissues. This helps to counteract a situation that favours fungal growth when K levels are deficient. Similarly lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals. Insufficient K also causes pale yellow colour to leaves that attracts aphids, wilting in crops, commonly observed in K deficient soils. Cracks, fissures and lesions that develop under K deficiency on surface of leaves and fruits provide easy access for facultative parasites.

Available literature on K shows that K application decreases incidence of fungal diseases by 70 % of the cases, bacteria by 69%, insect and mites 63% and viruses 41%. Simultaneously, increase the yield of plants infested with fungal diseases by 42% with bacteria 57% with insect and mites by 36%and with viruses by 78%.

It has established that phenol content in leaves increases with increase in K application resulting in low disease incidence (leaf sheath rot and stem rot in rice). Potassium content in shoots of tolerant genotypes of various crops has been reported to be significantly higher than those of susceptible genotypes. Plants under moisture stress have low photosynthetic rate. The decrease in solar energy harvest efficiency due to moisture could be enhanced with K application

References

- Agrawal, P, Agrawal, P., Reddy, M. and Sopory, S. 2006. Role of DREB transcription factors in abiotic and biotic stress tolerance in plants. *Plant cell reports* 25 (12): 1263-1274.
- Amtmann, A, Armengaud, P. and Volkov, V. 2004. Potassium nutrition and salt stress. In M.R. Blatt, ed, Membrane Transport in Plants. Blackwell Publishing, Oxford.
- Barber, S.A. 1963. Rainfall and responses. *Better Crops with Plant Food* 47 (1): 6-9.
- Barber, S.A. 1971. Soybean responds to fertilizer and rotation. . *Better Crops with Plant Food* 55(2): 9.
- Baruah, B.P. and Saikia, L. 1989. Potassium nutrition in relation to stem rot incidence in rice. *Journal of Potassium Research* 5: 121-124.
- Bhasker, C.V. Ramarao, G. and Reddi, K.B.2001. Effect of nitrogen and potassium nutrition on sheath rot incidence and phenol content in rice. *Indian Journal of Plant Physiology* 6: 254 – 257.
- Brady, N.C. and Weil, R.R. 2002. The Nature and Properties of Soils. Pearson Education, inc. pp.6.
- Brown, C.S. 1963. Alfalfa adoption with fertilizers. *Better Crops with Plant Food* 47 (7): 4 - 13.
- Cadisch, G., Bradley, R.S., Boller, B.C. and Nosberger, J. 1993. Effect of P and K on N2 fixation of field grown *Centrosema acutifolium* and *C. macrocarpum. Field Crop Research.* 31:329-340
- Dev, G. 1995. Potassium – An essential element. Proc. Use of potassium in Punjab agriculture. PAU, Ludhiana, July 5, 1994. pp.17-23.
- Gäth, S. 1992. Dynamik der Kaliumanlieferung im Boden. Report of the Institut für Landeskultur, Justus-Liebig-University Giessen, Germany.
- Golakiya, B.A. and Patel, M. S. 1988. Role of potassium in counteracting the effect of cyclic drought on groundnut. *Journal of Potassium Research* 4: 163-167.
- Grewal, J.S. and Singh, S.N. 1980. Effect of potassium nutrition on frost damage and yield of potato plants on alluvial soils of the Punjab (India). *Plant Soil* 57: 105-110.
- Härdter, R. 1997. Crop nutrition and plant health of rice based cropping systems in Asia. *Agro-Chemicals News in Brief* 20(4): 29-39.
- Jayraman, S. and Balasubramniam, R. 1988. Role of potassium on yield and incidence of pest and diseases in chilli. J. Potassium Res. 4(2): 67-70.
- Johnston, A.E., Barraclough, P.B., Poulton, P.R. and Dawson, C.J. 1998. Assessment of some spatially variable soil factors limiting crop yield. Proc. The International Fertilizer Society, York, UK: 419.
- Koch, K. and Mengel, K. 1974. The influence of the level of potassium supply to young tobacco plants (*Nicotiana tabacum* L.) on short term uptake and utilization of nitrate nitrogen. *Journal of Science and Food Agriculture* 25: 465-471.
- Krauss, A. 2001. Potassium and biotic stress. Ist FAUBA – Fertilizer –IPI Workshop Potassium in Argentina Agricultural Systems Nov. 20 – 21, 2001 Buenos Aires Argentina.
- Krauss, A and Johnston A.E. (2002) Assessing soil potassium, can we do better? Proc. 9th Int. Cong. Soil Sci. Faisalabad, Pakistan.
- Krauss. A. 2000. Potassium, integral part for sustained soil fertility Proc Regional IPI Workshop on Potassium and Phosphorus Fertilization effect on soil and crops, 23-24 October, 2000 Dotnuva - Akademija, Lithuania.
- Krishnasastry, K.S. 1985. Influence of potassium on proline accumulation under stress PRII Res. Review Series 2: 39-45.
- Leigh, R.A., Jones, R.G.W.1984. A hypothesis relating critical potassium concentrations for growth, distribution and functions of this ion in the plant-cell. *New Phytol.* 97: 12-13.
- Marschner, H. 1995. Mineral nutrition of Higher Plants. 2nd ed., Academic Press, pp. 436-460.
- Marschner, H., Kirkby, E.A. and Cakmak, I. 1996. Effect of mineral nutritional status on shoot-root partitioning of photo assimilates and cycling of mineral nutrients. *Journal Exp. Botany* 47: 1255-1263.
- Mengel, K. and Kirkby, E.A. 1980. Potassium in crop production. Adv. Agronomy 33: 59-110.

- Nelson, W.L.1978. Influence of K on tolerance to stress. Potassium in Soil and Crops Potash Research institute of India, New Delhi pub. pp. 203-221.
- Noguchi, Y. and Sugawara, T. 1966. Potassium and japonica rice. Intern. Potash Inst., Basel, Switzerland: 102.
- Nye, P.H.1979. Diffusion coefficient and uncharged solute in soil and soil clays. *Advances in Agronomy* 31:225-272 .
- Peoples, T.R. and Koch, D.W. 1979. Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. *Plant Physiology* 63: 878-881.
- Perrenoud, S. 1990. Potassium and plant health. IPI Res. Topic 3, Intern. Potash Institute, Basel, Switzerland.
- Rao, N.K. and Kameshwarrao, B.V. (2004) Effect of potash levels and topping on leaf potassium , yield and quality in flue cured tobacco. *Indian Journal of Plant Physiology* 9: 288-293.
- Saxena, N.P. 1985. The role of potassium in drought tolerance. *Potash Review* 16: 102.
- Sharma, G.L. and Agrawal, R.M. 2002. Potassium induced changes in nitrate reductive activity in *Cicer arietinum* L. *Indian Journal of Plant Physiology* 7 (3): 221-226.
- Sharma, K.D. Kuhad, M.S. and Sandwal, A. S. 1992. Possible role of potassium on drought tolerance in Brassica. *Journal of Potassium Research* 8: 320-327.
- Singh, A.K. and Singh, R.A. 1999. Effect of salinity on sodium and potassium and proline content of chickpea genotypes. *Indian Journal of Plant Physiology* 4:111-113.
- Singh, N., Chhonkar, V., Sharma, K.D. and Kuhad, M.S. 1997. Effect of potassium on water relations, CO_2 exchange and plant growth under quantified water stress in chickpea. *Indian Journal of Plant Physiology* 2 : 202 - 206.
- Singh, R.A. Roy, N.K. and Haque, M.S. 2004. Effect of nitrogen and potassium on sheath rot incidence and nutrient content in rice. *Indian Journal of Plant Physiology* 9 : 90-93.
- Singh, S.N. and Tiwari, U.S. 2006. Sodium and potassium ratio as an index to sodicity tolerance of tomato. *Indian Journal of Plant Physiology* 11: 329 – 332.
- Singh, S. Tiwari, T.N. Shrivastava, R.P. and Singh, G.P. 1998. Effect of Potassium on stomatal behavior, yield and juice quality of sugarcane under moisture stress conditions *Indian Journal of Plant Physiology* 3: 303 – 305.
- Singh, T., Deshmukh, P.S. and Kushwaha, S.R. 2004. Physiological studies on temperature tolerance in chickpea (*Cicer arietinum* L) genotypes. *Indian Journal of Plant Physiology* 9: 294-301.
- Skogley, E.O. 1976. Potassium in Montana soils and crop requirements. Montana Agr.Ext. Stn. Res. Report 18.
- Shrinivasa Rao, Ch. and Khera, M.S. 1995. Consequences of potassium depletion under intensive cropping. *Better crops* 79: 24 -27.
- Tester, M, Blatt, M.R. 1989. Direct measurement of K channels in thylakoid membranes by incorporation of vesicles into planar lipid bilayers. *Plant Physiology* 91: 249-252.
- Tiwari, H.S., Agrawal, R.M. and Bhatt, R.K. 1998. Photosynthesis, stomatal resistance, and related characteristics as influenced by potassium under normal water supply and water stress conditions in rice (*Oryza sativa L*). *Indian Journal of Plant Physiology* 3: 314 -316.
- Tomar, V.S. 1998. Role of potassium in water stress management in soybean . *Farmer and Parliament* 33: 15-26.
- Umar, S. 1997. Influence of potassium on solar energy harvesting efficiency of groundnut under different soil moisture stress. *Indian Journal of Plant Physiology* 2 : 315-317.
- Velazhahan, R. and Ramabadran, R. 1992. Influence of potassium fertilization on sheath rot and phenol content of rice. *Madras Agricutural Journal* 70:294-298.
- Vyas, S.P., Garg, B. K., Kathju, S. and Lahiri, A.N. 2001. Influence of potassium on water relations, photosynthesis, nitrogen metabolism and yield of Cluster bean under soil moisture stress. *Indian Journal of Plant Physiology* 6: 30 – 37.
- Warwick, W. N. and Halloran, G.M. (1991) Variation in salinity tolerance and ion uptake in accessions of beetle grass (*Diplachne fusca* L). *New Phytol.* 119: 161-168.
- William, T.P. 1999. Potassium deficiency increases specific leaf weights and leaf glucose levels in field grown cotton. *Agronomy Journal* 91: 962-968.
- Wyrwa, P., Diatta, J.B. and Grzebisz, W. 1998. Spring triticale reaction to simulated drought and potassium fertilization. Proc. 11th Int. Symposium on Codes of good fertilizer practice and balanced fertilization, September, 27-29, 1998, Pulawy, Poland: 255-259.

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Biotechnological interventions to overcome soil impairments for increased production

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The increasing human population is placing greater pressure on soil and water resources and threatening our ability to produce sufficient food, feed and fibre. As a result, there is a growing consensus within our global community that the protection of natural resources and implementation of environmentally and economically sound agriculture practices is of the utmost priority. The basic physical, chemical, and biological properties of soils must be considered to maintain sustainable agricultural practices. With the study of soil science, the importance of this heterogeneous assemblage of minerals, organic matter, organisms, air, and water as a key component of our global environment becomes self-evident. Soils provide a wide range of important ecosystem services such as a living filter for water, a sink for carbon, a regulator of atmospheric gasses, and a medium for plant growth which helps to sustain all life on this plant.

Scientific research continues to reveal how earth processes are often driven by reactions taking place in the soil. However, human evolution, and our agricultural dependence, has altered the scope of these soil processes and drastically changed the face of our planet. With the exception of minor contributions from aquaculture and hydroponics, it is the soil to which we are tied for most of our agricultural products. Over the course of our history, we have relied on our ability to alter landscapes, manage soil and water, and domesticate crops and animals to help meet our basic human requirements. Our stewardship of soil, water, and biological (e.g., microbes, insects, animals, plants) resources is a critical component of sustainable agriculture. This approach to agriculture ensures that food and fibre production is conducted in a way that minimizes degradation of natural resources and permits long-term production in an economically viable way. Sustainable agriculture takes advantage of traditional agricultural techniques, as well as the most recent technological advances. Tied closely to sustainable

agriculture, are the concepts of food security and safety, which are based around the fact that all people should have access to safe and nutritious food to sustain a healthy life.Today, farming practices which reduce erosion (e.g., no till, perennial grains) are being combined with the use of hardy and pest resistant crops (e.g., selective cross breeding, genetic engineering) to enhance long-term food and biofuel production. Of course, change rarely comes easily, and some of these practices are facing opposition from both producers and consumers. The human population is predicted to approach 10 billion by 2050 and it will be very interesting to observe how agricultural practices adapt to maintain adequate food security and energy generation.

Growing in their natural environment, plants often encounter unfavourable environmental conditions that interrupt normal plant growth and productivity. Drought, high/low temperature and saline soils are the most common abiotic stresses that plants encounter in their natural environments. Molecular and genomic analyses have facilitated gene discovery and enabled genetic engineering using several functional or regulatory genes that are known to be involved in stress response and preliminary tolerance, to activate specific or broad pathways related to abiotic stress tolerance in plants. Through the use of transgenic technology, goals such as production of plants with desired traits that were unattainable with traditional selection programs are achieved.

The ability of plants to tolerate stress conditions is crucial for agricultural production worldwide as they negatively influences the survival, biomass production, accumulation, and grain yield of most crops. As it is proposed that current perceptive of plant stress tolerance can be significantly polished by thorough characterization of individual genes and evaluating their contribution to stress tolerance, knowledge of basic biochemical pathways, and identification of key regulatory genes of stress response pathways appears crucial for tackling these problems. Through the use of transgenic technology, one can produce plants with desired traits such as tolerance to various abiotic stresses that includes water stress (flood and drought), temperature stress (high and low) and salt stress more precisely. A brief account of various problems related to soil for adequate agriculture production and their possible solutions adapting modern biotechnological tools have been discussed underneath.

Drought tolerance

Crops absorb water from the soil, carbon dioxide from the air, and light energy from the sun to produce carbohydrates through the process of photosynthesis. These carbohydrates are the basic source of plant material as they are used to pro-duce all the necessary organic components. The rate of carbohydrate production and plant growth is influenced by many environmental variables, including light intensity and duration, carbon dioxide concentration of the air, air temperature, and the amount of available water in the soil. If available water is limiting, its effects usually are greater than the other environmental variables due to the many functions of water in plants. These functions include cell turgor substrate for photosynthesis, plant cooling, media for bio-chemical processes, and transport of inorganic and organic components. Crops require large quantities of water. For example, about 2.4 million pounds of water per acre (10 in-ches of rainfall) are required to produce a 50 bushel per acre wheat crop. If that amount of stored soil water or precipitation is not available, yield losses occur.

Drought tolerance is crucial for growth and survival of species living in water scarce environments. It is used as a general term and refers to the ability of one genotype to yield better than another during severe drought stress. Resistance can be realized through different strategies plants use to survive dehydration. A common mechanism is termed drought avoidance and refers to a plant's ability to maintain effective water status under dehydrative conditions. An example of this type of strategy would be development of longer roots to access moisture in drying soils or alterations in stomata structure/function to reduce water loss. Another strategy used for survival in xeric environments is the development of dehydration tolerance, i.e., the ability to maintain function in a desiccated state. This type of strategy is exemplified by the accumulation of osmoprotectants in response to dehydrative conditions. Unravelling, the molecular mechanisms that control functional traits, such as photosynthesis and water use efficiency in response to drought, is especially relevant in view of its implication in survival, growth and biomass production. A variety of approaches have been used to alleviate the problem of drought, plant breeding, either conventional breeding or genetic engineering, seems to be an efficient and economic means of tailoring crops to enable them to grow successfully in drought-prone environments. During the last century, although plant breeders have made ample progress through conventional breeding in developing drought tolerant lines/cultivars of some selected crops, the approach is, in fact, highly time-consuming and labor- and cost-intensive. Alternatively, marker-assisted breeding (MAB) is a more efficient approach, which identifies the usefulness of thousands of genomic regions of a crop under stress conditions, which was, in reality, previously not possible. Quantitative trait loci (QTL) for drought tolerance have been identified for a variety of traits in different crops. With the development of comprehensive molecular linkage maps, marker-assisted selection procedures have led to pyramiding desirable traits to achieve improvements in crop drought tolerance. However, the accuracy and preciseness in QTL identification are problematic. Furthermore, significant genetic x environment interaction, large number of genes encoding yield, and use of wrong mapping populations, have all harmed programs involved in mapping of QTL for high growth and yield under water limited conditions. Under such circumstances, a transgenic approach to the problem seems more convincing and practicable, and it is being pursued vigorously to improve qualitative and quantitative traits including tolerance to biotic and abiotic stresses in different crops. Rapid advance in knowledge on genomics and proteomics will certainly be beneficial to fine-tune the molecular breeding and transformation approaches so as to achieve a significant progress in crop improvement in future.

A number of physiological studies have identified some traits for which presence/expression is associated with plant adaptability to drought-prone environments. Among them, traits, such as small plant size, reduced leaf area, early maturity and prolonged stomatal closure lead to a reduced total seasonal evapotranspiration, and to a reduced yield potential. Depending on the stress conditions (timing and intensity) of the target environments, some adaptive traits can be considered for yield improvement under drought if they enable plants to cope with a stress event that tends to occur every year at the same growth stage. For instance, a good level of earliness is an effective breeding strategy for enhancing yield stability in Mediterranean environments where wheat and barley are exposed to terminal drought stress. In this condition shortening crop duration, a typical escape strategy, can be useful in synchronizing the crop cycle with the most favourable environmental conditions.

Transgenic plants have been developed either to up-regulate the general stress response or to reproduce specific metabolic or physiological processes previously shown to be related to drought tolerance by classical physiological studies. Transcription factors as well as components of the signal transduction pathways that coordinate expression of downstream regulons are thought to be optimal targets for engineering of complex traits, such as stress tolerance. Successful examples are transgenic crops engineered with genes encoding the DREBs/CBFs transcription factors. The transgenic plants showed increased stress tolerance as well as the over induction of downstream stress related genes and/or higher levels of soluble sugars and proline. A recent report has shown that rice plants overexpressing the SNAC1 (stress responsive NAC1) transcription factor showed improved drought tolerance and yield potential under field conditions. The leaves of SNAC1-overexpressing plants lost water more slowly showing an increased stomatal closure and ABA sensitivity. Ectopic expression of a stress induced rice gene encoding a calcium-dependent protein kinase (OsCDPK7) also resulted in enhanced levels of stress responsive genes that contribute to improved salt and drought tolerance.

Water use efficiency

Water scarcity, caused by the rapidly increasing world population and the accompanying increases in water use for social and economic development, threatens sustainable world crop production that consumes most of the global water resources. Freshwater is a limited and dwindling global resource; therefore, efficient water use is required for food crops that have high water demands, such as rice, or for the production of sustainable energy biomass.

Water use efficiency (WUE), measured as the biomass produced per unit transpiration, describes the relationship between water use and crop production. In water-limiting conditions, it would be important to produce a high amount of biomass, which contributes to crop yield, using a low or limited amount of water. Environmentally sustainable biomass production in bioenergy crops would also reduce competition for land use and limited water resources with food crops required to feed the growing population.

The water-use efficiency (WUE) at physiological level is defined as the ratio between biomass and seed produced over water consumed. WUE in plants can be improved by increasing carbon assimilation while keeping the transpiration rate, or by reducing the transpiration rate while the carbon assimilation is kept. Now it is a well-known fact that there is a genetic basis for WUE and it is possible to perform breeding for this trait. Although WUE variation has been observed in plants, only recently its molecular characterization and dissection has started in various plant species. So far, the engineering of major field crops for improved WUE with single genes has not yet been achieve. Among the genes involved in the regulation of this phenomenon, ascorbate peroxidase (apx2), erecta, hardy and the transcription factor GT-2 LIKE (gtl1) stand out. *Arabidopsis thaliana* mutant also has a high housekeeping expression of the *apx*2 gene conferring water stress tolerance and a higher WUE.

Root architecture

Root system architecture (RSA) – the spatial configuration of a root system – is an important developmental and agronomic trait, with implications for overall plant architecture, growth rate and yield, abiotic stress resistance, nutrient uptake, and developmental plasticity in response to environmental changes. Root architecture is modulated by intrinsic, hormone-mediated pathways, intersecting with pathways that perceive and respond to external, environmental signals. The recent development of several non-invasive 2D and 3D root imaging systems has enhanced our ability to accurately observe and quantify architectural traits on complex whole-root systems. Coupled with the powerful marker-based genotyping and sequencing platforms currently available, these root phenotyping technologies lend themselves to large-scale genome-wide association studies, and can speed the identification and characterization of the genes and pathways involved in root system development. This capability provides the foundation for examining the contribution of root architectural traits to the performance of crop varieties in diverse environments.

The rate of root system growth and its vertical and horizontal spread can affect seedling vigour, neighbour competition, and exploitation of different limiting resources, such as phosphorus, nitrogen, and water, through root growth or support of symbioses, and can be highly specific to environmental conditions – a root architecture which may favour the growth of a plant under low water conditions, may impede its growth in flooded soil. The specific growth and development characteristics of a plant's root system also confers some degree of developmental plasticity to the organism in dealing with nutrient and water availability, seasonal and climate changes, beneficial or disease causing organisms, or toxic compounds in soil. Together, these qualities of anchor- age, soil nutrient exploitation, and developmental plasticity as determined by root architecture can have far-reaching effects on maximal yield, especially under stress, and yield stability, and a greater understanding of the genes and pathways involved in root architectural development may be translated into the breeding of improved crop varieties.

As with any phenotypic manifestation, all of these simple root architecture components: branch number, branching pattern, length, orientation, angle, and diameter are developmentally controlled by complex interacting genetic pathways, which also modulate growth and developmental responses in response to the perception of environmental cues. Most familiar factors are genetics, environment, and the interaction between the two – as belonging to either "intrinsic pathways" or extrinsic "environmental response pathways." Hormones, their receptors, signalling components, and transcription factors (TFs) make up the main chemical and molecular components of the intrinsic pathways. Extrinsic response path- ways involve similar networks of receptors for environmental stimuli and their downstream signal transduction and TFs. Many components of the environmental perception and response net- works are shared with or inter-regulated by intrinsic response pathways, and are also mediated by hormonal regulation in order to effect a growth response to external signals.

Recent studies have also identified micro-interfering RNAs (miRNAs) and small-interfering RNAs (siRNAs) which affect RSA by the post-transcriptional regulation of components involved in root growth and environmental perception and response and are themselves transcriptionally inter regulated by feedback loops within the same intrinsic and extrinsic pathways. To date, the vast majority of research elucidating the genes and pathways involved in root architecture development has been done with the simple, dicot tap root system of *Arabidopsis thaliana*. This has allowed for the gradual application of this knowledge in discerning conserved developmental pathways shared with monocot crown root systems, primarily studied in cereal crops such as rice and maize.

Lateral roots are important to plants for the uptake of nutrients and water. Several members of the *Aux*/*IAA* gene family have been shown to play crucial roles in lateral root development. Several gene controlling crown root included *crl1*, *crl4*, *Crl5* and*CAND1*were cloned and characterized. In plants, root hairs are important organs for the uptake of nutrients and water from the rhizosphere and serve as sites of interaction with soil microorganisms. A novel basic helix-loop-helix (bHLH) transcription factor and *OsAPY* have been reported to regulate root hair development in rice. In recently, *OsARF12*controlling root length were cloned. Although, so many genes related rice root had been cloned, but they all characterized by rice mutants. As well known, the rice root traits were controlled by quantitative trait loci (QTLs) derived from natural variations. In rice, QTLs have been identified to control root axis length, root number, root thickness, root dry weight, branching index and root to shoot ratio.

Wild and cultivated soybean both contributed alleles towards significant additive large effect QTLs on chromosome 6 and 7 for a longer total root length and root distribution, respectively. Epistasis effect QTLs were also identified for taproot length, average diameter, and root distribution. These root traits will influence the water and nutrient uptake in soybean. Two cell division-related genes (D type cyclin and auxin efflux carrier protein) with insertion/deletion variations might contribute to the shorter root phenotypes observed in *Glycine soja* compared with cultivated soybean. Based on the location of the QTLs and sequence information from a second *G. soja* accession, three genes (slow anion channel associated 1 like, Auxin responsive NEDD8-activating complex and peroxidase), each with a nonsynonymous single nucleotide polymorphism mutation were identified, which may also contribute to changes in root architecture in the cultivated soybean. In addition, Apoptosis inhibitor 5-like on chromosome 7 and slow anion channel associated 1-like on chromosome 15 had epistatic interactions for taproot length QTLs in soybean.

Nitrogen use efficiency

Nitrogen use efficiency (NUE) can be defined in a variety of ways that emphasize different components of the soil and plant system or economic returns to fertilizer use. Plants require large amounts of nitrogen (N) for their growth and survival. This N accounts for approximately 2% of total plant dry matter. N is a necessary component of proteins, enzymes, and metabolic products involved in the synthesis and transfer of energy. At present, the increase in investment in agriculture is mainly due to the use of nitrogen fertilizer because it directly affects yield. Nitrogen fertilizer consumption has been increasing since the early 1960's, and has stabilized slightly over the last decade. Plants can only use approximately 30-40% of the applied N, and more than 40% of the N fertilizer is lost via leakage into the atmosphere, groundwater, lakes and rivers. Such leakage results in serious environmental pollution. Improving crop and N management is required to optimize crop production and reduce environmental risks due to N losses.

In the last 40 years, the amount of synthetic nitrogen (N) applied to crops has risen dramatically, from 12 to 104 Tg ⁄ year, resulting in significant increases in yield but with considerable impacts on the environment throughout the world. This, along with increasing N fertilizer costs, has created a need for more nitrogen use efficient (NUE) crops, that is, crops that are better able to uptake, utilize and remobilize the nitrogen available to them. The importance of advances in research and technology in agriculture, and particularly in the area of NUE, has prompted experts to call for a second Green Revolution, which would allow for increased productivity using sustainable agricultural methods.

When trying to identify genes involved in NUE, several approaches have been commonly used. First, gene identification can occur through a mapping approach, whereby traits are identified through genetic crosses using distinct populations, and then Quantitative Trait Loci (QTLs) can be cloned by positional cloning. Secondly, traits may be identified by random or site-specific mutations in the gene, through forward or reverse genetic approaches. Finally, genes believed to be important, based on our prior knowledge of a gene product and its function, can be used. While the functional genomics analysis of a gene, including the analysis of knockouts, and gene expression patterns may be useful in identifying candidate genes, it is difficult to predict the effect of the over-expression of a gene, based on these types of studies. In this review, we have restricted ourselves to those genes that have been over-expressed or known to be involved in nitrogen uptake and ⁄ or efficiency.

Biotechnology can be applied to enhance the discovery and validation of genes controlling NUE and its component traits, to develop molecular markers for accelerating breeding progress independent of growth environment, and to introduce transgenes that modify key physiological processes contributing to NUE. The tools of biotechnology thus can help overcome some of the previous challenges to improving NUE. Once N has entered the cell, NR is the first assimilatory enzyme and is of interest not only because of its assimilatory role, but also because of the influence this enzyme has on both N uptake proteins NRT1.1 and NRT2.1. Patents have been issued pertaining to the stacking of N uptake and N metabolism genes in maize utilizing yeast genes (YNT1; yeast nitrate transporter 1, YNR1; nitrate reductase 1). Alteration of the YNT1 amino acid sequence to improve enzymatic activity by the technique of DNA shuffling has shown success when expressed in field-grown maize, with improved nitrate uptake in low-N conditions.

Salinity tolerance

Salinity stress has negative impact on agricultural productivity and restricting the use of land. It is estimated that 6% of the world's total land and 20% of the world's irrigated areas are affected by salinity (Unesco Water Portal, 2007). It is important to raise salt tolerant plants to effectively use salt affected agricultural land for sustainable crop production. Salinity is a soil condition characterized by a high concentration of soluble salts. The genetic engineering has proven a revolutionary technique to generate salt tolerant plants as one can transfer desired gene from any genetic resource and/or alter the expression of existing gene(s). There are examples of improved salinity tolerance in various crop plants through the use of genetic engineering. About 6.5% (831 million ha) of the world's total area (12.78 billion ha) is affected by salt in soils (FAO, 2011). Area under salt stress is on the increase due to many factors including climate change, rise in sea levels, excessive irrigation without proper drainage in inlands, underlying rocks rich in harmful salts etc. Vast areas of land are not utilised due to salinity and alkalinity problems.

Ion cytotoxicity occurs when salt accumulates to toxic concentrations in fully expanded leaves, causing leaf death. Substitute of K+ by Na+ in biochemical reactions leads to conformational changes and loss of protein function, as Na+ and Cl– ions penetrate hydration shells and interfere with non covalent interactions between amino acids. If the rate of leaf death generated by ion cytotoxicity is greater than the speed at which new leaves are formed, the photosynthetic ability of the plant will no longer be able to supply the carbohydrate requirement of young leaves, which further reduces their growth rate. Halophytes, while taxonomically widespread, are comparatively exceptional amongst the flowering plants and virtually all crop plants are glycophytes. However, there is considerable variability in the tolerance of glycophytes to salt. Plants develop various physiological and biochemical mechanisms in order to survive in soils with high salt concentration. Principle mechanisms include, but are not limited to, (1) ion homeostasis and compartmentalization, (2) ion transport and uptake, (3) biosynthesis of osmoprotectants and compatible solutes, (4) activation of antioxidant enzyme and synthesis of antioxidant compounds, (5) synthesis of polyamines, (6) generation of nitric oxide (NO), and (7) hormone modulation. There are five possible ways, to develop salt tolerant crops: (1) develop halophytes as alternative crops; (2) use interspecific hybridization to raise the tolerance of current crops; (3) use the variation already present in existing crops; (4) generate variation within existing crops by using recurrent selection, mutagenesis or tissue culture, and (5) breed for yield rather than tolerance. These all remain possible solutions to the problem.

The genetic engineering has confirmed an innovative technique to create salt tolerant plants as one can transfer desired gene from any genetic resource and alter the expression of existing gene(s). There are many examples of superior salinity tolerance in different crop plants through the use of genetic engineering. The majority of experiments have used rice, tobacco and Arabidopsis; transformations involving the synthesis of compatible solutes have been more popular.

Plant growth promoting rhizobacteria (PGPR) for enhancing crop productivity

Sustainability in agricultural production has emerged as a major concern for today. Commensurate with the present day aversion to the use of chemical fertilizers and pesticides; there is an overt emphasis on use of organic inputs and microbial inoculants which play an important role in sustainable agriculture. Problem of low soil fertility can be managed by replenishing the soil with organic carbon resources, increasing farmer's access to biofertilizers.

The rhizosphere is a thin zone of soil surrounding the root zone that is immensely influenced by the root system. Compared to the neighbouring bulk soil, this zone is rich in nutrients, due to the accumulation of a variety of organic compounds released by the roots through exudation, secretion and rhizodeposition. Rhizosphere represents the main source of bacteria with plant-beneficial activities. These bacteria are generally defined as PGPR. They comprise a diverse group of rhizosphere colonizing bacteria which, when grown in association with a plant, stimulate growth of the host plant. PGPR can affect plant growth and development indirectly or directly. In indirect growth promotion, the bacteria decrease or eliminate certain deleterious effects of a pathogenic organism through various mechanisms, including induction of host resistance to the pathogen.

In direct promotion, the bacteria may provide the host plant with synthesized compounds which may facilitate uptake of nutrients; fix atmospheric nitrogen; solubilize minerals such as phosphorus, zinc and potassium; produce siderophores, which solubilize and sequester iron; synthesize phytohormones, including auxins, cytokinin and gibberellins, which are useful at various stages of plant growth; or synthesize enzymes that modulate plant growth and development.

Mechanisms of plant growth promotion

Plant growth promotion by bacteria can also occur as an outcome of the provision of nutrients that are not adequately available in the soil. These nutrients include phosphate, nitrogen, zinc, potassium and iron.

Phosphate Solubilisation: Organic phosphorus represents from 50% to 80% of the total soil P, and most plants are unable to utilize these sources of P. The phosphate applied in the form of superphosphates is readily converted into insoluble forms. Several microorganisms are known to solubilize the abundant sources of phosphorus, such as rock phosphate. Thus, the application of bio-fertilizers capable of phosphate solubilization, could bridge the gap. Phosphate solubilizing microorganisms render the insoluble phosphates into soluble form through the process of acidification, chelation, exchange reactions and phosphatases production. Although, several mechanisms may be involved, the most important is through the production of organic acids. Evidently, these organic acids solubilize insoluble forms of phosphate to usable forms, such as orthophosphate, thus increasing the potential availability of phosphate for plants. The low molecular weight organic acids released by P solubilizing bacteria, which through their hydroxyl and carboxyl groups chelate the cations (mainly Ca^{2+}), bound to phosphates, thereby converting it into soluble forms. Examples of recently studied associations include *Enterobacter agglomerans* in tomato; *Rhizobium* sp. and *Bradyrhizobium japonicum* in radish; *Rhizobium leguminosarum* bv. phaseolin in maize; *Azotobacter chroococcum* and *Bacillus circulans*, *Rhizobium* and *Pseudomonas* in *Salicornia*; and *Pseudomonas chlororaphis* and *P. putida* in soybean.

Siderophore production: Iron, in spite of being the fourth most abundant metal ion on the earth's crust, is not readily available to microorganisms due to the presence of its insoluble oxyhydroxide polymeric form under aerobic conditions at physiological pH. Since the amount of soluble iron in the soil would be much low to support microbial growth, soil microorganisms secrete low molecular mass (400-1000 Daltons) iron binding compounds known as siderophores which bind Fe^{3+} with a very high affinity (Kd $=10^{-20}$ to 10^{-50}) and transport it across the cell wall and cell membranes into the cell by means of a cellular receptor and then make it available for microbial growth. Production and secretion of siderophores by the PGPR can prevent the proliferation of phytopathogens (especially fungal) and thereby facilitate plant growth. Although, fungal phytopathogens also synthesize siderophores, the fungal siderophores generally have a lower affinity for iron than the siderophores produced by PGPR. Therefore, the PGPR gives a tough competition to the fungal phytopathogens for available iron.

In the rhizosphere, microbial activity plays an important role in iron acquisition. *Pseudomonas* spp. have been used as providers of heterologous siderophores for plants.

Nitrogen Fixation: Agriculture has become increasingly dependent on chemical sources of nitrogen. Besides being costly, the production of chemical nitrogen fertilizers depletes nonrenewable resources and poses environmental hazards. To complement and eventually substitute mineral fertilizers with biological nitrogen fixation would represent an economically beneficial and ecologically sound option. However, despite nitrogen's abundance in the atmosphere, it must first be reduced to ammonia before it can be metabolized by plants to become an integral component of proteins, nucleic acids, and other biomolecules. The most important microorganisms that are currently used agriculturally to improve the nitrogen content of plants including a range of Rhizobia, each specific for a limited number of plants. Other nitrogen-fixing bacteria, notably *Azospirillum* spp., are also employed as bacterial inoculants.

IAA Production: The phytohormones auxins, cytokinins, gibberellins, and ethylene and abscisic acid (ABA) play key roles in the regulation of plant growth and development. Consequently, many PGPB with the ability to alter phytohormone levels can affect the plant's hormonal balance. Production of auxin is widespread among soil bacteria (estimated to be ~80% of all soil bacteria). One of the important aspects of the bacterial-plant interaction that has received worldwide attention is the bacterial production of IAA. IAA produced by PGPR influences root respiration rate and root proliferation which results in an increased mineral and water uptake by the plants It is well-established that auxin promote lateral and adventitious root formation and may either stimulate or inhibit root elongation depending on the concentration. Bacteria belonging to the genera *Azospirillum*, *Pseudomonas*, *Xanthomonas*, *Rhizobium* as well as *Alcaligenes faecalis*, *Enterobacter cloacae*, *Acetobacter diazotrophicus* and *Bradyrhizobium japonicum* have been known to produce auxins which help in stimulating plant growth.

Modulation of Ethylene the stress hormone

Root-associated as well as symbiotic PGPR can improve plant nutrition and growth, plant competitiveness and responses to external stress factors. Ethylene is an important growth hormone produced by almost all the plants, which mediates a wide range of plant responses. Ethylene is usually considered as an inhibitor of plant growth, but at low levels can actually promote growth in several plant species, including Arabidopsis. For many plants, a burst of ethylene is required to break seed dormancy, but following germination, a sustained high level of ethylene would inhibit root elongation. In addition, ethylene is synthesized in plant tissues from the precursor 1-aminocyclopropane- 1-carboxylic acid (ACC) during biotic and abiotic stress conditions (salt, drought, flood and heavy metals), which in turn retards root growth and causes senescence in crop plants.

The direct precursor of ethylene in the plant biosynthetic pathway, ACC is exuded from plant roots together with other amino acids. A number of PGPR contain the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which cleaves the plant ethylene precursor ACC to ammonia and α-ketobutyrate and thereby lowers the level of ethylene in a developing or stressed plant. PGPR that contain the enzyme ACC deaminase, when bound to the seed coat of a developing seedling, ensure that the ethylene level does not become elevated to the point where initial root growth is impaired. Also, plants that are treated with ACC deaminase containing PGPR are dramatically more resistant to the deleterious effects of stress-induced ethylene conditions like, flooding, heavy metals, the presence of phytopathogens, drought and high salt. In each of these cases the ACC deaminase containing PGPR markedly lowered the level of ACC in the stressed plants thereby limiting the amount of stress-induced ethylene synthesis and hence the resulting damage to the plant. Such, PGPR are beneficial to plant growth since in the natural environment plants are often subjected to stresses that produce ethylene. The ACC deaminase activity has been reported in several PGPR such as *Kluyvera ascorbata* SUD165, *P. putida* UW4, *P. putida* GR12-2, *Azospirillum brasilense* Cd, *Enterobactor cloacae* CAL2 and *Rhizobium leguminosarum*.

Biocontrol agents for plant disease control

Rhizobacteria are effective competitors in the rhizosphere which can establish and persist on roots of agronomically grown plants. PGPR may promote plant growth directly on healthy plants or indirectly when controlling phytopathogens or pests in different crops. They can be isolated from any other plant part besides the roots as well as from the plant surface or interior. PGPR also exhibit several mechanisms of biological disease control, most of which involve competition and production of metabolites which affect the pathogen directly. Examples of such metabolites include antibiotics, cell wall degrading enzymes, siderophores and HCN.

Some PGPR do not produce metabolites against the pathogens and are spatially separated from them. These two traits suggest that alteration of host defence mechanisms account for the observed disease protection. Induced systemic resistance (ISR) or systemic acquired resistance (SAR) is defined as the activation of chemical and physical defences of the plant host by an inducer which could be a chemical or a microorganism, leading to the control of several pathogens. A few examples of PGPR and biocontrol products are: *Agrobacterium radiobacter* K1026 (Nogall®), *Bacillus pumilus* QST 2808 (Sonata® TM), *B. pumilus* GB34 (YieldShield®), B. *subtilis* GBO3(Kodiak®), *Pantoea agglomerans* C9-1 (BlightBan C9-1®), *P. agglomerans E325* (Bloomtime®), Pseudomonas aureofaciens Tx-1(Spot-Less®T), *P. syringae* ESC-10 and ESC-11 (Bio-save®), *P. fluorescens* A506 (BlightBan®).

Soil quality enhancement using PGPRs

PGPR protect plant disease and improve soil quality by increasing the organic carbon, total nitrogen and total phosphorus as well as the CO_2-released and microbial contents in the form of microbial biomass carbon, nitrogen and phosphorus. A number of production strategies have been developed to improve soil quality and crop health through the management of rhizobacteria in agricultural production systems. The success of these treatments depends upon the ability to successfully incorporate and subsequently manipulate these beneficial microbial populations in the field over the course of a growing season. Organic amendments, such as green manures (plough-down crops) manures and composts (including organic solid wastes) can all provide a source of food substrates of varying quality for competing microbial communities. Beneficial bacteria can be applied directly, as a cell suspension to the compost but are more usually introduced in carriers such as granular peat formulations, mineral soils and bacterial encapsulations within polymer gels such as xanthan gum or alginate or in xanthan gum and talc mixtures.

Bioremediation

Contamination of soil environment by hydrocarbons (mostly petroleum hydrocarbons) is becoming prevalent across the globe. This is probably due to heavy dependence on petroleum as a major source of energy throughout the world, rapid industrialization, population growth and complete disregard for the environmental health. The amount of natural crude oil seepage was estimated to be 600,000 metric tons per year with a range of uncertainty of 200,000 metric tons per year. Release of hydrocarbons into the environment whether accidentally or due to human activities is a main cause of water and soil pollution. These hydrocarbon pollutants usually caused disruptions of natural equilibrium between the living species and their natural environment. Hydrocarbon components have been known to belong to the family of carcinogens and neurotoxic organic pollutants.

Heavy metals contaminated soil from industrial waste; electronic wastes etc. on the other hand pose a serious threat to both man and animals in the environment if not properly remediated to the innocuous level. Environmental pollution by heavy metals which are released into the environment through various anthropogenic activities such as mining, energy and fuel production, electroplating, wastewater sludge treatment and agriculture is one of the world's major environmental problem. Heavy metals or trace metals refer to a large group of trace elements which are both industrially and biologically important. Initially, heavy metals are naturally present in soils as natural components but as of now, the presence of heavy metals in the environment has accelerated due to human activities. This is a widespread problem around the world where excessive concentration of heavy metals such as Pb, Zn, Cr, Cu, Cd, As and Hg can be found in soils. Soil contamination by heavy metals is consequently the most critical environmental problems as it poses significant impacts to the human health as well as the ecosystems. The contaminants are able to infiltrate deep into the layer of underground waters and pollute the groundwater as well as the surface water. Heavy metals in the soil subsequently enter the human food web through plants and they constitute risk to the ecosystem as they tend to bioaccumulate and can be transferred from one food chain to another. Heavy metals are discovered in various food chains where the results are usually detrimental to microorganisms, plants, animals and humans alike.

Many techniques of remediation of contaminated soil have been developed, such as physical, chemical degradation, photodegradation. However, most of these methods have some drawbacks in completely remediating hydrocarbon contaminated soil. Some of these methods leave behind daughter compounds which are more toxic to the environment than the parent compounds. Biological treatment offers the best environmental friendly method for remediating hydrocarbon and heavy metal contaminated soil because it utilized the capability of the indigenous microorganisms in the soil environment to break down the hydrocarbons and heavy metals into innocuous substances. Biological remediation, a process defined as the use of microorganisms or plants to detoxify or remove organic and inorganic xenobiotic compounds from the environment is a remediation option that offers green technology solution to the problem of environmental degradation. This process relied upon microbial enzymatic activities to transform or degrade the contaminants from the environment. It offers a cost effective remediation technique, compared to other remediation methods, because it is a natural process and does not usually produce toxic by-products. It also provides a permanent solution as a result of complete mineralization of the contaminants in the environment.

Bioremediation is one of the most viable options for remediating soil contaminated by organic and inorganic compounds considered detrimental to environmental health. Bioremediation is a process defined as the use of microorganisms/plants to detoxify or remove organic and inorganic xenobiotics from the environment. It is a remediation option that offers green technology solution to the problem of hydrocarbon and heavy metals contamination. The main advantage of bioremediation is its reduced cost compared to conventional techniques. Besides cost-effectiveness, it is a permanent solution, which may lead to complete mineralization of the pollutant. Furthermore, it is a non-invasive technique, leaving the ecosystem intact. Bioremediation can deal with lower concentration of contaminants where the cleanup by physical or chemical methods would not be feasible. For bioremediation to be effective, microorganisms must enzymatically attack the pollutants and convert them to harmless products. Bioremediation can be effective only where environmental conditions permit microbial growth and activity, its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate.

Many genera of microbes like *Bacillus*, *Enterobacter*, *Escherichia*, *Pseudomonas* and also some yeasts and moulds help in bioremediation of metal and chromium-contaminated soil and water by bio-absorption and bioaccumulation of chromium. The heavy metal removal by the bacteria *Pseudomonas* was attributed to the cellular growth of these organisms. Mushroom compost and spent mushroom compost (SMC) are also applied in treating organ pollutants contaminated sites. Japanese scientists have come up with a technology called 'DNA shuffling', which involves mixing the DNA of two different strains of PCB degrading bacteria. This results in the formation of chimeric bph genes, which produce enzymes capable of degrading a large range of PCBs. These genes are further introduced in the chromosome of original PCB-degrading bacteria, and the hybrid strain thus obtained is an extremely effective degrading agent.

Genes have also been isolated from bacteria that are resistant to mercury called as mer genes. These mer genes are responsible for total degradation of organic mercurial compounds. The bph genes and tod-genes for toluene degrading bacteria (pseudomonas putida Fl) have shown similar gene organisations. Both these genes code for enzymes which show a sixty per cent similarity. By exchanging the subunits of the enzymes it is possible to construct a hybrid enzyme. One such hybrid enzyme created is hybrid deoxygenase which is composed of TodCl – Bph A2 – Bph A3 – Bph A4. This was expressed in E.coli. It was observed that this hybrid deoxygenase was capable of faster degradation for Trichloroethylene (TCE) based compounds. The todCl gene from toluene degrading bacteria has been successfully introduced, in the chromosome of bacterial strain KF707. This strain then resulted in efficient de-gradation of TCE. This KF707 strain could also be grown on toluene or benzene etc.

Phytoremediation

Phytoremediation is a remediation method that utilizes plants to remove, contain or detoxify environmental contaminants. Phytoremediation appears attractive because in contrast to most other remediation technologies, it is not invasive and, in principle, delivers intact, biologically active soil. The most common plant species used in phytoremediation of organic and inorganic compounds includes willows, poplar and different types of grasses. On-site phytoremediation of petroleum hydrocarbons and heavy metals can be enhanced by employing a combination of common agronomic practices (e.g. fertilizer application, tillage and irrigation); this is because available nutrient reserves can be quickly depleted as the microbial community begins to degrade the contaminants. Therefore fertilizer applications may enhance the degradation of petroleum hydrocarbons in soil by reducing competition for limited nutrients.

Variety of contaminant-degrading enzymes can be found in plants. These include peroxidases, dioxygenases, P450 monooxygenases, laccases, phosphatases, dehalogenases, nitrilases, and nitroreductases. Phytoremediation is based upon the basic physiological mechanisms taking place in higher plants and associated microorganisms, such as transpiration, photosynthesis, metabolism, and mineral nutrition. Plants dig their roots in soils, sediments and water, and roots can take up organic compounds and inorganic substances; roots can stabilize and bind substances on their external surfaces, and when they interact with microorganisms in the rhizosphere. Absorbed substances may be transported, stored, converted, and accumulated in the different cells and tissues of the plant. Finally, aerial parts of the plant may exchange gases with the atmosphere allowing uptake or release of molecules. A series of six phytotechnologies have been identified by Interstate Technology and Regulatory Cooperation (ITRC, 2001) which may address different contaminants in different substrates, and which rely on one or more of the plant properties.

The idea that plants can be used for environmental remediation is not new. Extensive research on using plants for treating radionuclide contamination was conducted in Russia in the early 1960s. Since then, there have been a number of reports that aquatic plants such as water hyacinth, duckweed and water velvet can accumulate heavy metals from contaminated water. Recently the value of terrestrial plants for environmental remediation has been recognized. Crop plants such as Indian mustard have been used to extract heavy metals from soil and translocate them to the leaves and stalks of plants. Aquatic plants can be used in Phytoremediation especially to remediate sites contaminated with heavy metals. For example, water hyacinth (*Eichhornia crassipes*) has been used for purifying not only domestic wastewater but also industrial wastewater. It can readily absorb, accumulate and concentrate heavy metals such as Pb, Fe, Cu, Cd, Hg and Ni. Other studies have evaluated the potential of water hyacinth to absorb various organic chemicals – phenols and toxaphene; and to remove even radioactive metals from effluents. Cell suspension cultures of *Datura innoxia* have been found to remove a wide variety of metal ions from solutions.

A better understanding of the biochemical processes involved in plant heavy metal uptake, transport and accumulation will certainly improve phytoremediation using modem genetic approaches. One strategy for improving the phytoremediation potential of high biomass plant species is the introduction of genes responsible for metal accumulation and resistance from the wild metal accumulators. In the absence of known “phytoremediation genes” this may be accomplished via somatic and sexual hybridization followed by extensive screening and backcrossing of progeny. Mutagenesis of selected high biomass plant species may also produce improved phytoremediation cultivars. Phytoremediation of heavy metals is designed to concentrate metals in plant tissues, thus minimizing the amount of hazardous waste, which needs to be treated and deposited at hazardous waste sites. But an economical method of reclaiming metals from plant residue should be developed.

At present, methods for further concentration of metals in plant tissues include sun, heat air drying, environmentally safe ashing or incineration, composting, pressing and. compacting, and acid leaching. These plants can then be harvested and burned to recover the metals. Plants can be useful in treating other chemicals also. Submerged roots of sunflowers can concentrate radioactive wastes from the water.

Conclusion

Recently developed biotechnological techniques are providing new and exciting possibilities for enhancing both food production. With increased awareness of agroecosystem functioning and best management practices, biotechnology and agricultural practices have evolved together to solve a range of problems and promote agricultural sustainability. Through the use of transgenic technology, one can produce plants with desired traits such as tolerance to various abiotic stresses that includes water stress (flood and drought), temperature stress (high and low), and salt stress more precisely. Along with this PGPR could be used to improve nitrogen-fixation, enhance the availability of minerals, alter susceptibility to environmental stress, and stimulate the production of plant growth hormones. Such microbial interactions also improve physicochemical soil properties, particularly aggregate formation. Therefore the need of the hour is the promotion of PGPR with multiple attributes in ecofriendly sustainable production of crop plants for the benefit of mankind. Combining both plants and microorganisms in bioremediation increases the efficiency of remediation. The recent approaches of bioremediation such as microbial-induced calcite precipitation (MICP) through urease hydrolyzing bacteria, biomineralization of toxic heavy metals, genomics and proteomics of biological treatments to the contaminants, root–microbe interaction and detoxification of heavy metals have been proven as promising techniques to remediate the contaminated soil ecosystems. Microbe-assisted phytoremediation can be best applied at sites having relatively shallow contamination of pollutants that are amendable to the processes such as biomineralization, biostimulation, mycoremediation, cyanoremediation, hyperaccumulation and rhizofiltration. All these approaches using biotechnological tools can be successfully used to overcome soil impairment and increase soil fertility which in turn will enhance the crop productivity.

References

- Akpjnar BA, Lucas SJ and Budak H (2013) Genomics Approaches for Crop Improvement against Abiotic Stress. The Scientific World Journal. http://dx.doi.org/10.1155/2013/361921
- Ashraf M (2012) Inducing drought tolerance in plants: Recent advances. Biotechnology Advances 28: 169–183.
- Bhattacharyya PN and Jha DK (2012) Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol 28:1327–1350
- Bian M, Zhou M, Sun D and Li C (2013) Molecular approaches unravel the mechanism of acid soil tolerance in plants. The Crop Journal 1: 91-104
- Biotechnology for the Development of Drought Tolerant Crops. https://www.isaaa.org/resources/publications/pocketk/32/default.asp]
- Bremont JFJ, Kessler MR, Liu JH and Gill SS (2013) Plant Stress and Biotechnology. BioMed Research International. http://dx.doi.org/10.1155/2013/170367
- Gupta B and Huang B (2014) Mechanism of salinity tolerance in plants: physiological, biochemical, and molecular characterization. International Journal of Genomics, Article ID 701596, 18p.
- Hao QN, Zhou XA, Sha AH, Wang C, Zhou R and Chen SL (2011) Identification of genes associated with nitrogen use efficiency by genome-wide transcriptional analysis of two soybean genotypes. BMC Genomics 12: 525.
- Jamil A, Riaz S, Ashraf M and Foolad MR (2011) Gene expression profiling of plants under salt stress. Critical Review on Plant Science, 30 (5), 435–458.
- Munns, R and Tester, M. 2008. Mechanisms of salinity tolerance. Annual Review on Plant Biology, 59:651–681.
- Peixoto RS, Vermelho AB, Rosado AS (2011) Petroleum-Degrading Enzymes: Bioremediation and New Prospects. Enzyme Research. DOI:10.4061/2011/475193
- Podile AR and Kishore K (2007) Plant growth-promoting rhizobacteria. In: Plant associated bacteria. Springer Netherlands, pp. 195–230.
- Singh, KN, Chatrath, R (2001) Salinity tolerance. In: Reynolds M.P., Monasterio J.I.O., McNab A., editors. Application of Physiology in Wheat Breeding. CIMMYT; Mexico, pp. 101–110.

Soil erosion modelling for sustainable agriculture

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You can manage only if can measure". This statement is also applicable for sustainable management of agricultural land. Soil erosion is unavoidable in agricultural land and agricultural land must be managed with the fact that soil is eroding and resulting into soil nutrient and other important factors that affect the crop productivity. In many situations, measurement of soil erosion is practically cost and labour expansive and predictions or modeling become necessary. Soil erosion model also helps in understanding the impact of management option. This paper deals with the some of the models used for soil erosion. An attempt has been made to describe the erosion process, factors effecting soil erosion and most commonly used soil erosion model.

Soil erosion is defined as the detachment, transportation and deposition of soil particles from one place to another by the action of wind, water or gravity forces. Although, the term erosion was in use in the 19th century, the term soil erosion was introduced at the beginning of 20th century, and did not come into general use until 1930s. The word erosion is of Latin origin being derived from the word *erodere*-to eat away (*rodere*-to chew). The term erosion was first used in geology to describe the forming of hollows by water, the wearing away of solid material by action of river water; while surface wash and precipitation erosion was called "ablation" (*abatio*-to carry away). In addition to erosion and ablation, a number of other terms "corrasion" (*corradere*-to chew to gether), "corrosion" (*corodere*-to chew to pieces), "abrasion" (*abrodere*-to scrape off) and "denundation" (*denundere*- to strip) were also used. Soil erosion can be classified on the basis of rate, agent causing erosion and process of erosion. Table.1 presents the classification of soil erosion based on agents causing erosion.

Table 1. Classification of erosion by the active factors.

S.N	Factor	Term	
		English	**International**
1	Water	Water erosion	Aquatic erosion
1.1	Precipitation, Rain	Precipitation erosion, Rain erosion	Pluvial erosion
1.2	River	River erosion	Fluvial erosion
1.3	Torrent	Torrent erosion	Torrential erosion
1.4	Lake	Lake erosion	Limnic erosion
1.5	Reservoir	Reservoir erosion	Lacustrine erosion
1.6	Sea	Sea erosion	Marine erosion
2	Glacier	Glacier erosion	Galcial erosion
3	Snow	Snow erosion	Nival erosion
4	Wind	Wind erosion	Aeolian erosion
5	Organisms	Biological erosion	Organogenic erosion
5.1	Plants	Erosion caused by plants	Phytogenic erosion
5.2	Animals	Erosion caused by animals	Zoogenic erosion
5.3	Man	Erosion caused by man	Anthropogenic erosion

Source: Zachar D.C. (1982).

Our discussion in this section is confined to water erosion and here after erosion shall be understood as water erosion unless specified.

Factors effecting erosion

Erosion is resulted due to dispersive and transporting power of the water, as in case of splash erosion, first the soil particles are detached from the soil surface by the action of raindrop and then transported with surface runoff. There is a direct relationship between the soil loss and runoff volume. The major factors, which affect the amount of, soil erosion in large extent, can be summarized as:

Climatic factors

The climatic factors which affect the soil erosion are rainfall characteristics, atmospheric temperature and wind velocity. Rainfall characteristic is the one of the most effective factor among them. Rainfall characteristic includes amount, intensity, frequency and duration of rainfall. High rainfall intensity of rainfall has bigger raindrop size, which has higher kinetic energy and more erosive power. Rainfall characteristics, which produce more runoff amount and rate cause more erosion. Frequent rain maintains the soil moisture in a desirable range, which reduces infiltration capacity of soil and thus produces more runoff. A uniform distribution of rainfall throughout the year always reduces the total erosion by maintaining the soil moisture within the optimum range for good vegetation over the land surface.

Soil factors: Soil erosion has direct relation with runoff. All soil properties responsible for higher infiltration rate like, low bulk density, high porosity, large particle size, low moisture content, grainular structure etc. cause low runoff and soil erosion. High cohesive force between soil particle results into lower detachability of particles as in case of clayey soil. On the other hand large particle size reduces transportation of the detached particles.

Topographic factors: The land slope and length of the slope are the two topographic factors, which strongly influence the soil erosion. As the length of the land in the direction of slope increases, detachment of soil particles goes on increasing. When the slope of the land is doubled, the particle size that can be transported increases sixteen times.

Vegetation: Vegetation plays important role in reducing soil erosion. In presence of good vegetation soil erosion can be reduced significantly. The vegetation helps in reducing soil erosion in following ways

- Kinetic energy of falling raindrops is absorbed by the leaves and stems of the vegetation, which reduces the detachment of soil particles.
- Some of the rainfall is intercepted by leaves and stems and reduces runoff.
- Vegetation physically obstruct the velocity of flowing runoff
- Roots of the vegetation binds soil particles
- In presence of good vegetation, evapotranspiration rate is faster, thus soil moisture reduces and infiltration increases.
- Decayed roots increase porosity of soil.
- Growth of certain soil fauna like earthworm is accelerated in presence of vegetation. These soil faunas pulverize soil and increase porosity.

Soil Erosion Process Models:

Several models have been developed to estimate soil loss from watershed as a result of soil erosion process, outflow of sediments carried by runoff to streams. Evaluation of soil loss from watershed is required while assessing the severity of soil erosion and its effect on agricultural production. Soil loss can be estimated as a function of parameters of watershed and rainfall. Some of the commonly used soil loss models are discussed here.

1. Universal soil loss equation

There have been sincere attempts to develop soil loss estimation models, beginning from the sixties of 20th century. The most effective model on the soil loss was presented by Wischmeier and Smith (1965) and improved by Wischmeier and Smith (1978). The model is popularly known as Universal Soil Loss Equation (USLE). This also opened a new chapter for research in this field and formed the basic structure of most of the soil loss models after this period. Ghanshyam Das (2000) states that USLE appears to have been based on the Musgrave (1947) equation with necessary modifications. The USLE can be written as:

$$A = R\,K\,L\,S\,C\,P$$

Where A = estimated gross soil erosion, t/ha/yr
R = rainfall erosivity factor, joule/ha/yr or t-m-cm/ha-s
K = soil erodibilty factor, t/ha/unit of R
S = slope factor
L = slope length factor
C = crop management or vegetative cover factor
P = supporting conservation practice factor

Rainfall erosivity factor (R): is the measure of erosive capability of rainfall. It is the function of rainfall intensity and amount of rainfall. Many indices have been developed for the R. EI_{30} index is most commonly used to represent the rainfall erosivity.

$$EI_{30} = \sum_{i=1}^{n} E_i . I30_i / 100$$

Where E_i = total kinetic energy of ith rain storm
$I30_i$ = maximum intensity of ith rain storm for 30 min duration
n = number of rain storm having rainfall more than 2.5 mm

$$E = \sum KE \,.\, P$$

Where KE = kinetic energy of segment of rain having uniform intensity
P = amount of segment of rain having uniform intensity

$$KE = 201.3 + 89 \log I$$

Where I = rainfall intensity, cm/h

Calculation of EI_{30} index requires rainfall data recorded from automatic recording raingauge. A simplified equation has been developed by Hardaha et al. (1996) for the Malwa region of Madhya Pradesh. The equation uses total erosive rainfall (ER) i.e. storms having rainfall more than 12.5 mm and expressed as:

$$EI_{30} = 9.524\ ER + 5.60$$

Rambabu et al. (1978) prepared an iso-erodent map of India from which the approximate erosion value can be obtained directly.

Soil erodibility factor: The soil erodibility factor (K), converts units of R to amount of erosion. It is the average soil loss from a standard plot with 9 % slope, 22.1 m long kept fallow by periodic tillage up-and-down the slope per unit value of R. Value of K can be determined experimentally for any soil on standard plot. The value of K is estimated based on soil characteristics as given by Foster et al.(1981)

$K = 2.8\times10^{-7} M^{1.14} (12-a) + 4.3\times10^{-3} (b-2) + 3.3\times10^{-3} (c-3)$

Where, K = Soil erodibility, Mg/ha/(MJ-mm/ha-hr)

M = Particle size parameter, (%silt + %very fine sand)(100-%clay)

a = Organic matter content, %

b = soil structure code (very fine granular-1; medium or coarse granular-3; blocky, platy or massive-4)

c = profile permeability class (rapid-1; moderate rapid-2; moderate -3; slow to moderate-4; slow-5; very slow-6)

Table 2 can be used when organic matter content and textural class of the soil is known.

Slope length factor (L): Length of the slope on which the overland flow occurs, effects the rate of soil erosion. On large slope length, there is a higher concentration of overland flow, and also a higher velocity of flow, which triggers a higher rate of soil erosion. Slope length factor is defined as ratio of soil loss from a given slope length to that from a land having slope length equal to 22.1 m, if all other conditions remain unchanged. Mathematically it can be expressed as:

$L = (L_p/22.1)^m$

Where L_p = Actual unbroken length of slope (m).

M = an exponent equal to 0.5 for slope > 5%

0.4 for slope 4-5%

0.3 for slope < 3%

Table2. Values for soil erodibilty factor for different types of soil

Soil type	K based on percent organic matter in soil		
	0.5 %	2.0%	4.0%
Fine sand	0.36	0.31	0.22
Very fine sand	0.94	0.81	0.63
Loamy sand	0.27	0.22	0.18
Loamy very fine sand	0.98	0.85	0.67
Sandy loam	0.60	0.54	0.42
Very fine sandy loam	1.05	0.92	0.74
Silt loam	1.07	0.94	0.74
Clay loam	0.63	0.56	0.47
Silty clay loam	0.83	0.72	0.58
Silt clay	0.56	0.51	0.43

Slope gradient factor (S): Soil erosion is greatly influenced by slope of the land. On steep slope the flow velocity of runoff is high resulting in increased scouring, cutting and transportability of soil. Soil gradient factor is defined as the ratio of soil loss from a given degree of slope to that from land having 9.0% slope, if all other conditions remain unchanged. Empirically it can be expressed as:

$$S = (0.43 + 0.30\, s + 0.043\, s^2)/6.613$$

Where, s = slope of the filed in percentage

Crop management factor (C): Crop management factor or vegetative cover factor is defined as the ratio of soil loss from a land with given crop rotation and cover to that from a land clean tilled and kept permanent fallow. Vegetative cover acts many ways in reducing the soil erosion as discussed earlier. Table 3 presents value of factor C for some of the vegetative covers.

Conservation practice factor (P): A bare fallow land surface causes maximum soil erosion, especially when it is cultivated along the slope. Conservation practice factor is the ratio of soil loss from a land having specified conservation practice to the land ploughed up and down the slope, if all other conditions remain unchanged. Any practice adopted to reduce runoff amount and its velocity shall reduce the soil erosion. Table 4 presents value of P for Indian conditions.

Table 3. Crop management factor for some crop/grass covers at few ICAR centers in India

Crop	Centres		
	Kota	Agra	Lucknow
Moong	0.39	-	0.45
Gram	0.54	-	-
Groundnut	0.41	-	0.42
Soybean	0.42	-	-
Guar	0.59	0.42	-
Guar + Arhar	-	-	0.35
Maize	0.50	-	-
Jowar	0.62	0.64	-
Jowar + Arhar	0.33	-	0.28
Jowar + Gram	-	0.32	-
Bajra	-	0.61	-
Til	-	0.51	0.39
Natural vegetation	0.14	-	-
Grass (Doob)	0.22	-	-
Grass	0.01	0.13	-

Source: Gurmel singh et al. (1981)

Table 4. Values of conservation practice factor for different types of conservation practice.

Land slope	Conservation practice factor

%	Contour cultivation	Contour strip cropping	Bench terracing
< 1	0.80	-	-
1-2	0.60	0.30	-
2-4	0.60	0.25	-
4-7	0.50	0.25	-
7-12	0.60	0.30	-
12-18	0.70	0.35-0.40	-
>18	0.80-0.90	0.40-0.45	0.28

2. Soil Loss Equation Model for South Africa (SLEMSA)

SLEMSA was developed by Elwell (1978) for the southern region of Africa and is a modification over USLE. This model has been designed to predict mean annual soil loss, raising from sheet erosion on area of arable land. Framework of SLEMSA is presented in fig1. Bhargav (1999) has modified the SLEMSA model for Indian conditions for conservation practices in use by incorporating conservation practice factor (P). The modified model is Z = K.C.X.P

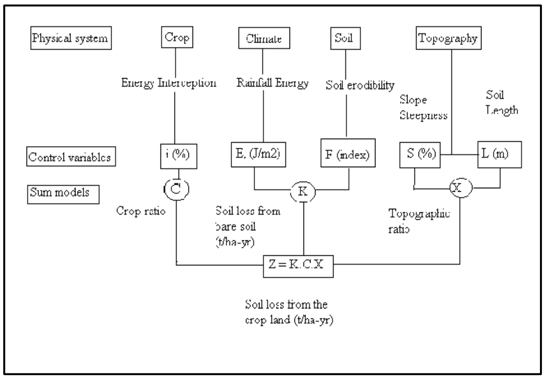

Fig.1. Framework of SLEMSA model. (Elwell, 1982)

3. Soil Erosion Model for Mediterranean Region (SEMMED)

A soil erosion model SEMMED (Soil Erosion Model for Mediterranean regions) was developed for the test site Ardèche, France (De Jong, 1997). SEMMED comprises several modules, each of which describes a part of the erosion process such as soil particle detachment, moisture storage in the top soil and transport of soil particles by overland flow. SEMMED uses (multi-temporal) Landsat TM images to account for vegetation properties and it uses a digital terrain model in a GIS to account for topographical properties. Spectral vegetation indices allow a pixel-by-pixel assessment of vegetation properties and the multi-temporal approach enables the assessment of the change of vegetative cover in one growing period. Fig 2. shows flow chart of the model.

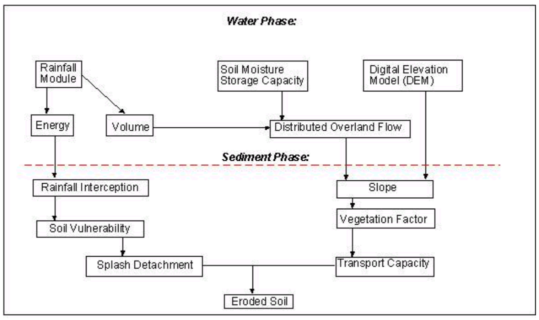

Fig.2. SEMMED Model.(Source: De Jong, 1997)

4. Modified universal soil loss equation (MUSLE)

MUSLE has been modified by Williams (1975) for predicting sediment yield by replacing its rainfall erosivity factor with runoff factor. The model can estimate sediment yield on a per storm basis against the average soil loss on annual basis. The MUSLE is:

$$Y = 11.8\,(Q\,q_p)^{0.56}\,KLSCP$$

Where, Y = Sediment yield from an individual storm

Q = storm runoff volume

q_p = peak runoff rate

Estimation of sediment yield from very large watershed is not very accurate due to variations in climatic factors, soil characterstics, land slope, crop management, erosion control practices and watershed hydraulics within the watershed area. Such watershed is divided into subwatersheds of les than 25 sq. km and sediment yield can be computed using routing model as:

$$RY = \sum_{i=1}^{n} Y_i . e^{-BT_i} (D50_i)^{0.5}$$

Where, RY = sediment yield from entire watershed, t

Y_i = sediment yield from i^{th} sub-watershed, t

B = Routing coefficient

T_i = travel time from sub-watershed i to the watershed outlet, h

$D50_i$ = median particle diameter of the sediment for sub-watershed i, mm

Das and Chouhan (1990) observed that the value of B is equivalent to 1/K where K is the storage coefficient.

5. Morgan, Morgan and Finney Model

Morgan et al. (1984) developed a model for estimating annual soil loss from field size area on hill slopes. Inputs and flow chart of the model is illustrated in fig.3. For determination of annual rate of soil loss, the model compares the prediction of splash detachment and transport capacity of the overland flow. The lower of these two is considered as annual rate of soil loss. Some of the limitations of the model are:

- The model is more sensitive to change in the annual rainfall and soil parameters, when erosion is transport limited and also sensitive to changes in rainfall interception and annual rainfall, when erosion is detachment sensitive.
- It requires precise information on rainfall and other associated parameters, for having accurate prediction.
- This model can not be employed for predicting the sediment yield from the drainage basin.
- Like USLE, it is also not suitable for predicting the soil loss, resulting from an individual storm.

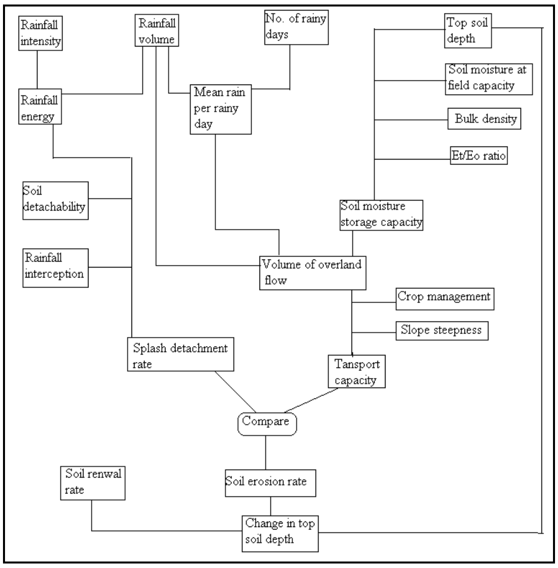

Fig.3. Morgan et al. model for soil erosion

6. WEPP Model

Water Erosion Prediction Project (WEPP) model (Nearing et al.,1989) has capability of predicting spatial and temporal distribution of net soil loss/gain for the entire hill slope for any period of time. It contains its own process based hydrology, water balance, plant growth, residue decomposition and soil consolidation models as well as a climatic generator and many other components, that broaden its range of usefulness. The basic equation used for estimation of erosion from land is represented as:

$$dG/dx = D_f + D_i$$

where, G = sediment concentration;
x = distance down slope,
D_i = Inter-rill erosion,
D_f = Rill erosion.

$$D_i = K_i.I_e.\sigma_{ir}.SDR_{rr}.F_{nozzle}.(Rs/W);$$

Where, K_i = inter-rill erodibility,
I_e = effective rainfall intensity,
σ_{ir} = inter-rill runoff rate,
SDR_{rr} = sediment delivery ratio,
F_{nozzle} = adjustment factor to account for sproinkler irrigation nizzle impact variation,
Rs = rill spacing, and
W = width of the rill.
Df = Dc (1-G/Tc) ;
Where, Dc = rill detachment capacity = Kr (τ_f-τ_c),
Tc = transport capacity of flow in rill,
Kr = rill erodibilty of soil,
τ_f = flow shear stress, and
τ_c = critical shear stress.

Tiwari et al. (2000) compared the WEPP predictions with the measured natural runoff plot data and found that the model efficiency is 0.71 % in terms of annual soil loss with average magnitude of error 2.01 kg m-2. It was concluded that WEPP is comparable with USLE and MUSLE.

7. Quasi Three-dimensional Runoff model for soil erosion

Victor Demidov (2001), used quasi three-dimensional runoff model for soil erosion modeling. The developed soil erosion model allows to simulate the temporal and spatial variations in erosion by raindrop impact and overland flow, sediment transport and deposition.

Structure of the Model

Quasi Three Dimensional Model of Rainfall Runoff Formation - A physically based model of rainfall runoff formation is based on using differential equations which describe the processes of overland, groundwater, subsurface, channel flow as well as vertical moisture transfer in soil. The catchment is represented in the horizontal plane by rectangular grid squares. The main channel and the tributaries of different orders are represented by the boundaries of grid squares.

The model describes the following processes:

1. Vertical moisture transport in the unsaturated zone (the one-dimensional Richard's equation is used; the calculations is carried out for each grid square of hill slope);
2. Groundwater flow and the interaction of surface and groundwater on the hill slope and in the river channel (the two-dimensional Boussinesq equations are used);
3. Overland flow (the two dimensional kinematic wave equations are applied);
4. Unsteady flow in the river network (the one-dimensional kinematic wave equations are used).

The organization of the interaction between components of the hydrological modeling system allows taking feedback into account. Coupling of the calculations of the vertical moisture transport with the overland and groundwater flow is accomplished by means of a special procedure.

Modeling Soil Erosion and Sediment Transport in the River Basin

A soil erosion and sediment transport model was developed as a separate block of the hydrological modeling system. The soil erosion model describes the temporal and spatial variations of the soil erosion and the sediment transport in the river basins during flood events (erosion by raindrop impact and overland flow, sediment transportation and deposition).

The erosion rate by raindrop impact, D_r (kg $m^{-2}s^{-1}$), is expressed by the following equation

$$D_r = K_r K_s \, i \, F_r R^{\beta}$$

where K_r = soil erodibility factor for erosion by raindrop impact,

K_s = fraction of bare soil,

i = ground surface slope,

R = rainfall intensity (cm/s),

β = an exponent, and

F_r = is the factor reflecting influence of the water depth on erosion by raindrop impact that is expressed as

$$F_r = \exp(1 - h D^{-1}) \quad \text{if } h > D$$
$$= 1 \quad \text{if } h \le D$$

Where h is the flow depth (m); D is the median diameter of raindrops that is determined from D = $0.0193 R^{0.182}$

The erosion rate by overland flow impact, De (kg $m^{-2}s^{-1}$) , is calculated as :

$$De = Ke(\tau/\tau_c - 1) \quad \text{if } \tau > \tau_c$$
$$= 0 \quad \text{if } \tau \le \tau_c$$

Where Ke is the overland flow soil erodibility coefficient; τ is the shear stress(kg $m^{-2}s^{-1}$) and τ_c is the critical shear stress, which is taken to be :

$$\tau_c = \rho \, g \, i \, (ni^{-0.5} V_p)^{-1.5}$$

Where ρ is the water density (kg/m^3); g is the acceleration of gravity (ms^{-2}) ; n is the Manning roughness coefficient ; V_p is the pickup velocity (m/s) that is determined by the equation

$$V_p = 1.14 \, (g \, a \, d)^{0.5}$$

Where a (= $P_T \rho^{-1}$-1) and P_T is the sediment density (kf/m^3) ; d is the grain diameter (m).

The sediment transport capacity,G_T (kg $m^{-1}s^{-1}$), is calculated by means of the Engelund-Hansen's equation

$$G_T = 0.04 \, (V V^{*2} P_T)/(\psi a \, g)$$

where V is the flow velocity (m/s); V* is the shear velocity (m/s); ψ is the criterion which is equal ψ = a d h^{-1} i^{-1}.

The sediment transport by the overland flow is described by two-dimensional sediment continuity equation

$$\partial/\partial t \, (hC) + \partial/\partial x \, (G_x) + \partial/\partial y \, (G_y) = E$$
$$E = -(1-\varepsilon) \, P_T \, \partial/\partial t \, (z)$$

Where C is the sediment concentration (kg m^{-3}); G_x and G_y are the sediment transport rate in the x and y direction respectively; ε is the soil surface porosity; z is the soil surface elevation (m); E is the erosion or deposition rate on surface slope (kg m^{-2} s^{-1}).

Sediment routing in channels is described by the one-dimensional sediment continuity equation. Numerical integration of these equations is carried out an implicit finite difference scheme.

8. Lisem model

The LISEM model (De Roo et al.2001) is one of the first examples of a physically based model that is completely incorporated in a raster Geographical Information System. Incorporation means that there are no conversion routines necessary; the model is completely expressed in terms of the GIS command structure. Furthermore, the incorporation facilitates easy application in larger catchments, improves the user friendliness, and allows remotely sensed data from airplanes or satellites to be used. If required, the model can be linked easily with other GIS's. Processes incorporated in the model are rainfall, interception, surface storage in micro depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall, detachment by overland flow, and transport capacity of the flow. Also, the influence of tractor wheelings, small paved roads (smaller than the pixel size) and surface sealing on the hydrological and soil erosion processes is taken into account.

After rainfall begins, some is intercepted by the vegetation canopy until such time as the maximum interception storage capacity is met. Besides interception, direct through fall and leaf drainage occur, which, together with overland flow from upslope areas, contribute to the amount of water available for infiltration. The amount of water remaining after infiltration begins to accumulate on the surface in micro-depressions. When a predefined amount of depressions are filled, overland flow begins. Overland flow rates are calculated using Manning's n and slope gradient, with a direction according to the aspect of the slope. When rainfall ceases, infiltration continues until depression storage water is no longer available. Soil detachment and transport can both be caused by either raindrop impact or overland flow. Whether or not a detached soil particle moves, depends upon the sediment load in the flow and its capacity for sediment transport. When water and sediment reach an element with a channel, they are transported to the catchment outlet. Sedimentation within a channel appears when the transport capacity has been exceeded.

When there are no sufficient field measurements available, the distribution of a desired input variable can be derived from digitized soil or land use maps. A raster-based GIS is the ideal tool to serve needs and fulfill requirements associated with the DEM and the geostatiscal interpolation techniques. Further advantages of using a GIS are

1) the possibilities of rapidly producing modified input-maps with different land use patterns or conservation measures to simulate alternative scenarios,
2) the ability to use very large catchments with many pixels, so the catchment can be simulated with more detail, and
3) The facility to display the results as maps.

A series of maps can be produced showing the variation with time of spatial patterns of soil erosion, sedimentation and runoff over the catchment. These maps can be compared by subtraction to yield maps indicating how erosion or sedimentation might be affected by certain control measures within the catchment or they can be viewed successively to create a video of the modelled process. Runoff can also be displayed as an overlay on the landform surface

The main advantage of incorporating models in GIS is that the ‘source code’ of the model then resides on the comprehensible abstraction level of one or two lines of source code, a GIS command, per process (e.g. interception, infiltration and sediment routing). Such a high level of abstraction simplifies model modification, maintenance and reusability of parts of the model in other models. The current implementation of LISEM is less than 200 lines (exclusive comments).

Input

LISEM needs a number of input files and maps to run. These inputs are described below. Rainfall file: Data from multiple raingauges can be entered in an input data file. A map is used as input to define for each pixel which raingauge must be used. For every time increment during the simulation of a storm, the model generates a map with the spatial distribution of the rainfall intensity. Thus, the model allows for spatial and temporal variability of rainfall. In the future, this approach allows for the input of e.g. radar data indicating rainfall intensity patterns changing in space and time: e.g. to simulate a thunder storm which moves over a catchment.

Tables for the soil water model: Within the catchment, soil profiles are defined. The vertical soil water movement is simulated by subdividing a soil profile in a user defined number of layers (e.g. 12).

Command file: When the model is run, the user is prompted for the selection of the catchment, the rainfall event, a few tuning parameters and the desired output. Alternatively, the user can specify this information in a command file. This interface empowers the user to:

- Select the catchment by specifying the directory of the topographical, soil and land use map database;
- Select the soil water model parameters by specifying the directory of the soil water tables. Separating the map database and the soil water tables permits optional sharing of the soil water tables between different catchments;
- Select the rainfall event by specifying the rainfall file; Select the starting and ending time of the simulation;
- Select the overall simulation time step, and the minimum time step for the soil water sub-model;
- Select a precision factor of the soil water sub-model;
- Select a number of parameters and coefficients used in the detachment and transport formulas, such as settling velocity of the soil particles and a splash delivery ratio. If necessary, a few of these parameters could be used for calibrating the sediment part of the model;
- Select names of the output files: e.g. hydrograph files (main outlet and outlets of predefined sub-catchments), runoff maps at several times, soil erosion map and the ‘results’ file with totals.

Output

The results of the LISEM model consist of:

- a text-file with totals (total rainfall, total discharge, peak discharge, total soil loss etc.);
- a ASCII data file which can be used to plot hydrographs and sedigraphs.
- Pc-Raster maps of soil erosion and deposition, as caused by the event;
- PcRaster maps of overland flow at desired time intervals during the event.

Validation of lisem

The model results are compared with observed data (validation). Statistical criteria determine the 'goodness of fit'. The model user has to decide whether the results are satisfactory. If so, the simulations end and the 'final results' are produced. If the validation is not satisfactory, there are several options:

- Modify the model;
- Re-calibrate the model;
- Change the resolution (pixel-size or simulation time step);
- Collect more data;
- Collect better data (measurement errors);
- Collect different data (other variables);

This procedure is repeated until satisfactory results are obtained. There are various erosion process models available and use depends upon the data required in the model and the data available.

References

- Bhargav, K.S.(1999). A modified SLEMSA model for Naurar subcatchment of Ramganga river. Unpublished master's thesis. Submitted to GBPAUT, Pantnagar.
- Das G. and Chouhan H.S.(1990) Sediment routing for mountainous Himalayan region. Trans. ASAE.
- De Jong S. M. (1997) DeMon - Satellite Based Desertification Monitoring in the Mediterranean Basin - www.geog.uu.nl/fg/demon.html.
- De Roo A.P.J., C.G. Wesseling, N.H.D.T. Cremers, R.J.E. Offermans C.J. Ritsema and K. van Oostindie(November 2001). Lisem: a physically-based hydrological and soil erosion model incorporated in a gis. www.odyssey.maine. edu/gisweb/spatd6/egis/eg94023.html
- Elwell, H.A.(1978). Modelling soil loss in southern Africa. Jl. of Agric. Engg. Res.
- Foster G.R., McCool D.R., Renard K.G., and Mobdenhaur W.C. (1981) Conversion of Universal soil Loss Equation to SI Metric Units. Jl. Soil Water Cons.
- Ghanshyam Das (2000). Hydrology and Soil Conservation Engineering. Prentice Hall of India. New Delhi.
- Gurmel Singh, Ram Babu and Subhash Chandra (1981) Soil loss prediction research in India. Bull. T 120/D-9, CSWCR & TI Dehradun.
- Hardaha M.K., Kale V.S. and Nema R.K. (1996). Erosive rains and erosion index for Indore. Indian Jl. of Soil Conservation. Vol. 24 no 3, p 193-196.
- Musgrave G.W.(1947) The quantative evaluation of factors in water erosion, a first approximation. Jl. Soil Water Cons.
- Nearing M.A., Foster G.R., Lane L.J. and Finkner S.C. (1989) A process based soil erosion model for USDA Water Erosion Prediction Project. Trans.ASAE 32(5).
- Ram Babu, Tejwani K.G., Agrawal M.C. and Bhusan I.S.(1978) Determination of erosion index and Isoerodent map of India. Indian Jl. of Soil Cons. Vol. 6(1)
- Williams,J.R.(1975). Sediment yield prediction with universal equation using runoff energy factor. In: Sediment yield workshop Oxford, Nov.1972.Present and prospective of technology for predicting sediment yield and sources. Proceeding: Oxford, USDA Sedimentation Lab.
- Wischmeir W.H. and Smith D.D.(1965) Predicting rainfall erosion losses from cropland east of the rocky mountains. USDA Handbook No. 282, Washington D.C.
- Wischmeir W.H. and Smith D.D.(1978) Predicting rainfall erosion losses – A guide to conservation planning. USDA Handbook No. 537, Washington D.C.
- Tiwari A.K, Risse L.M. and Nearing M.A. (2000) Evaluation of WEPP and its comparison with USLE and RUSLE. Trans. ASAE vol.43(5) pp:1129-1135.
- Victor Demidov (November 2001). Modeling Soil Erosion and Sediment Transport on Watersheds with the Help of Quasi Three-dimensional Runoff Model. www.epa.gov/OWOW/watershed/proced/demidov.html
- Zachar D.C. (1982). Soil Erosion. Scientific Publishing Co. Amestrdam.

Suitability of medicinal plants based biodiversity conservation in problem soils

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Preamble

Plants have been one of the important source of medicines even since the dawn of human civilization. In spite of tremendous developments in the field of allopathy during 20th century, plants still remain one of the major sources of drugs in modern as well as traditional systems of medicine throughout the world. Approximately one-third of all pharmaceuticals are of plant origin, wherein fungi and bacteria are also included. Over 60% of all pharmaceuticals are plant based. Over three-quarters of the world population relies mainly on plants and plant extracts for health care. More than 30% of the entire plant species, at one time or other, were used for medicinal purposes. It is estimated that world market for plant derived drugs may account for about Rs.2,00,000 crores. Presently, Indian contribution is less than Rs.2000 crores. India has been known to be a rich repository of medicinal plants since ancient time. The agro-climatic condition prevailing in India provides an ideal habitat for the natural growth of variety of plants and herbs, which provide raw materials for pharmaceutical, phytochemical, food flavouring and cosmetic industries. Majority of the commercial supply of medicinal plants derived from the forest. Due to increasing realization of health hazards and toxicity caused by synthetic drug and antibiotics, the demand for herbal drugs is increasing day by day (Sivaraman, 2001). At present there is acute shortage of most of the raw drug material for preparation of the medicines used in Indian Systems of Medicines. However, the supply from the natural forests is reducing due to over exploitation and negligible efforts for the regeneration of useful herbs. If the existing process of exploitation of herbs will remain continues, many more biodiversity of useful medicinal and aromatic plants will not be available within few years. Therefore, for achieving the health and nutritional security besides to have the pressure off from our natural forest, the cultivation of these medicinal and aromatic plants on available culturable land is a need of an hour through developing location specific suitable medicinal plants based agroforestry models.

Scenario of Medicinal Plants

About 12.5% of the 4,22,000 plant species documented worldwide reported to have medicinal value; the proportion of medicinal plants to the total documented species in different countries ranges from 4.4% to 20% (Schippmann et al. 2002). The global importance of medicinal and aromatic plants materials is evident from the trade at national and international levels. According to the World Health Organization (WHO) more than 1 billion people rely on herbal medicines to some extent. The WHO has listed 21,000 plants that have reported medicinal uses around the world. India has a rich medicinal plant flora of about 2500 species. Of these, 2000 to 2300 species are used in traditional medicines while at least 150 species are used commercially on a fairly large scale. India and Brazil are the largest exporters of medicinal plants (Hanfee, 1998). Medicinal and aromatic plants have a high market potential with the world demand of herbal products growing at the rate of 7 percent per annum (Anonymous, 1998). The indigenous system of medicine namely Ayurvedic, Siddha and Unani have been in existence for several centuries. These systems of medicine cater to the needs of nearly seventy per cent of our population residing in the villages. Apart from India these systems of medicines are prevalent in Korea, China, Singapore, West Asia and many other countries. Besides the demands made by these systems as their raw material, the demand for medicinal plants made by the modern pharmaceutical industries has also increased manifold. Thus medicinal plants constitute a group of industrially important crops, which bring appreciable income to the country by way of export (Singh et.al 2003).

It is considered internationally that China is one of the megadiversity countries in the world, where the number of species, as a whole, make up more than one tenth of the total number of species in the world. There are about 5000 species of medicinal plants out of which over 1700 species commonly encountered. In addition, numerous species of animals and microorganisms have been widely employed for medical purpose and in public health. Species of fruit trees, oil-bearing plants and fibber plants are too numerous to mention. All these are the treasures of China and of all the human beings.

Similarly, India is one of the 12 mega diversity countries having a vast variety of flora and fauna, commands 7% of world's biodiversity and supports 16 major forest types, varying from the alpine pastures in the Himalayas to temperate, sub-tropical forests, and mangroves in the coastal areas.

India stands second in the world, contributing nearly 15,000 flowering plants endemic to the country (having 17% tree species). Indian biological diversity is estimated to over 45,000 plant species and 81,000 animal species, representing 7% of world's flora and 6.5% of world fauna, respectively. Enormous diversity in topography and climatic conditions in the country provides ecological security to about 11% of the world's total flora.

Conservation Strategy of Medicinal Biodiversity

Conservation and maintenance of available phyto-diversity of medicinal and aromatic plants is the foremost need of the day for safeguarding the benefits of the generations to come from social and economical point of view. Sustainable development in agriculture sector depends mainly on the pillar of conserved phytodiversity and germplasms of many crops. Development of new varieties/strains mainly depends on broad genetic base in the form of rich agro-biodiversity. Medicinal and aromatic plants cultivation/processing is an emerging area under agriculture sector for its sustainable development through crop diversification.

India has variety of climate, altitude and physiography resulting in aggregation of a rich flora of these plant species in diversified forest areas. Tribals have been dissolutely using these healing herbs for various ailments. There are copious tribal communities distributed over the vast stretches of our country, living in small groups ranging from plains to hilly terrain and scrubby to evergreen belts. Their knowledge of availability, utilization and domestication of medicinal plants is enormous. Thus substantial knowledge wrests in the hands of tribals as far as the use of medicinal plants is concern.

Time has come to identify, domesticate and multiply these valuable plants before they are extinct from natural habitats. Suitable measures are to be taken to conserve medicinal plant wealth through *in-situ* and *ex–situ* conservation for its full potential benefits to human kind. Indian subcontinent represents one of the greatest emporia of medicinal plant wealth and there is a lot of scope as well as unparalleled opportunities for profound research and extension in the field of medicinal plants cultivation.

Ex–situ and *in-situ* conservation strategies are used for conserving biodiversity particularly of medicinal and aromatic plants. Conservation of bio diversity in their natural habitat by restricting human and cattle interference is known as *in situ* conservation. On the other hand ex–*situ* conservation meant for conserving and maintaining biodiversity in place out of their natural habitat keeping in view suitable agro-climatic conditions needed for particular crop. In this context development of location specific suitable agroclimatic zonewise medicinal plants based agroforestry models may lead to facilitate ex-situ conservation particularly in large chunk of wastelands.

More than 1100 medicinal plants are used in folk and traditional medicines, which are found in the forests of M.P and Chhattisgarh. Tribal of Chitrakoot, Dindori, Amarkantak, Mandla, Seoni, Chhindwara, Betul, Sagar, Damoh, Jhabua, Dhar, Khargone, Khandwa and Barwani, are still using the medicinal herbs for their own treatments and for selling to private traders. States 77% rural population depends on the rich agrobiodiversity for livelihood security.

Despite the introduction of many new technologies, the productivity in culturable wasteland areas remained low. Uncertain monsoons and poor soil fertility are some of the main causes for this low productivity. Consequently, the farm income had remained stagnant over the years. This leads to a vicious circle of low investment, slow rate of technology adoption, poor yields and low profits with stagnant yields and rising labour costs arable cropping has become unviable in many areas. Hence, sustainable agriculture is needed most in the present scenario. Hence, to achieve sustainable agriculture diversification in culturable wastelands regions by identification and commercialization of new crops adapted to low water requirement is essential, which can provide renewable and unique industrial material and also can replace the existing crops whose cultivation is uneconomical. This type of crop diversification may also play a vital role in sustained use of the environment and restoration of degraded lands, besides helping in upgrading the quality of life of the resource poor farmers.

Culturable wastelands, which have the potential for the development of vegetative cover, can easily be brought under cultivation of medicinal plants through proper land preservation and species selection. The problem areas like ravines, saline and alkaline soils, canal side wetlands, seasonally inundated forests, pasturelands and agriculture lands needs special attention for their proper use and applicable technology for its development. The technique of agroforestry involving planting of medicinal trees/shrubs and herbs in wastelands or in problem area as alternate land use not only provides the solution of reclamation of wastelands but also gives products wanted by local communities. Traditionally several species of trees having medicinal values e.g. Neem, Babool, Harra, Bahera, Aonla which are traditionally grown in wastelands. Farmers are growing these trees on farm land for different uses involving fodder, fuel, timber, gum, medicine, oil, fruit, bee keeping, green manure etc. Further, these woody perennials also help in soil amelioration. They not only add carbon to the soil but also enrich it with nitrogen and assist in nutrient retrieval from deeper layers for ultimate use by arable crops. The soil physical conditions also would be ameliorated. They act as windbreaks and help in living with the problems like acidity, alkalinity, and water logging. Besides, medicinal trees also have characteristics to differential add nutrients in the soil, which may help in regeneration of microflora depending on the tree species.

Medicinal Plants in Wasteland

As the Agricultural land is limited, the cultivation of the medicinal and aromatic crops can be promoted under the wastelands and fallow lands so that these crops may not compete or replace the existing crop area and subsequently the production of food grain will not be affected. Alternatively, these crops can be grown in the marginal lands where uneconomic crops are presently cultivated viz. kodon, kutki, niger etc. Out of 2000 to 2500 medicinal, aromatic and dye plants growing in India, only a few have commercial importance, of which some can be grown and conserve successfully in different kinds of culturable wastelands. As chemical synthesis of many complex chemicals are neither feasible nor economically viable, in near future. Hence, the importance of medicinal and aromatic plants as a commercial source of supply is likely to gain considerable momentum in future.

These alternate plants are valued for their secondary metabolites and hence their content and chemical composition is as important as the total yield. The concentration of these secondary metabolites was reported to be higher under abiotic stress conditions, probably providing drought resistance mechanism to certain plants. Some of them are highly tolerant to both biotic as well as abiotic stresses. Hence, culturable wastelands offer superior niches for cultivation of such plants. Therefore such plants can be profitably cultivated in culturable wastelands more particularly for conservation and economic crop diversification.

The major medicinal plants, which are cultivated commercially since long back in M.P., comprised of Opium, Ashwagandha (*Withania somnifera*), Isabgol (*Plantago ovata*), Sarpgandha (*Rauvolfia serpentina*), *Dioscorea alata* and *Amorphophallus companulatus*. Recently the cultivation of Safed Musli (*Chlorophytum borivillianum*), Bach (*Acorus calamus*), Muskdana (*Abelmoschus moschatus*), Senna (*Cassia angustifolia*), Chansur (*Lepidium sativum*), Guggul (*Commiphora wightii*), Kalihari (*Gloriosa superba*), Sadabahar (*Catharanthus roseus*), Akarkara (*Spilanthus acmella*), *Ocimum basilicum*, Ajwain (*Trachyspermum ammi*), Khurasani Ajwain (*Hyoscyamus niger*), Lemon grass (*Cymbopogon flexuosus*), Palma rosa (*Cymbopogon martinii*), Citronella (*Cymbopogon nardus*), Mentha (*Mentha piperita*), Kalmegh (*Andrographis peniculata*), Brahmi (*Bacopa monniera*), *Jatropha curcas*, Shikakai (*Acacia concinna*), Gataran (*Caesalpinia crusta*), Khamer (*Gmelina arborea*) and *Eucalyptus citriodora* etc. has been adapted by the farmers (Tiwari 2001).

Medicinal Plant Based Agroforestry

Potential agroforestry practices have been identified for different agro-ecozones by AICRPs on Agroforestry and many ICAR institutes under the Natural Resource Management Divisions (Solanki et al 1999), which can be extended at farmer's field on need based and location specific through Operational Research Projects (ORP). Medicinal plants based agroforestry practices demonstration has been taken up by JNKVV; Jabalpur, State Forest Research Institute; Jabalpur and Tropical Forest Research Institute; Jabalpur and many other Krishi Vigyan Kendras working under the jurisdiction of JNKVV; Jabalpur.

Agroforestry systems involve deliberately growing medicinal trees and shrubs along with arable crops and/or livestock seeking positive synergism. Two different types of medicinal plants based agroforestry systems are in practice. Firstly, as medicinal plants in upperstory trees and secondly as intercrops in other tree crops.

Traditionally several species of trees growing in upper story having medicinal values e.g. Neem, Babool, Harra, Bahera, Aonla were grown in wastelands. Farmers are growing these trees on pastureland for different uses including fodder, fuel, timber, gum, medicine, oil, fruit, bee keeping, green manure etc. Further, these woody perennials also help in soil amelioration. On the basis of D&D survey and habitat analysis herbs, shrubs and trees of medicinal importance that can grow well in different types of problem soils have been identified which can help in development of location specific need based agroforestry models under differential agroclimatic situations (Table-1). Based on parts use and medicinal importance (Table-2) the users can select the species for their land use planning.

Table-1: Suitable medicinal plants that do well on different problematic soils under agroforestry system in Madhya Pradesh

No.	Problematic Soils	Name of the species	
A	Shallow, Rocky soil	Herbs:	Punarnava (*Boerhavia diffusa*) Anantmool (*Hemidesmus indicus*), Ratti (*Abrus pricatorius*), Manjistha (*Rubia Cordifolia*), Gwar patha (*Aloe barbadensis, Aloe vera*).
		Shrub:	Gandh Babool (*Acacia farnisiana*), Jhand (*Prosopis cineraria*), Karonda (*Carissa carandus*) Gurmar (*Gymnema sylvestre*) Marorphali (*Helicteres isora*).
		Tree:	Neem (*Azadirachta indica*), Aonla (*Emblica officinalis*), Sitaphal (*Annona squamosa*), Bel (*Aegle marmelos*), *Cordia oblica, Holoptellia intigrifolia, Wrightia tinctoria* Malkagni (*Celastrus paniculata*).
B	Sandy soils	Herbs:	Khus (*Vetiveria zizanioides*), *Cymbopogon* spp., Isabgol (*Plantago ovata*), Safed musli (*Chlorophytum borivilianum, C. tuberosum*),Kali Musli (*Curculigo orchioides*), Asgandh (*Withania somnifera*), Mulethi (*Glycyrrhiza glabra*),Senna (*Cassia angustifolia*), Akarkara (*Spilanthus acmella*), Sadasuhagan (*Catharanthus roseus*).
		Shrub:	Chitrak (*Plumbago zeylanica*), Sinduri (*Bixa orellana*)
		Trees:	Bel (*Aegle marmelos*), Katha (*Acacia catechu*), Jamun (*Syzygium cumini*), Arjun (*Terminalia arjuna*), Salai (*Boswellia serrata*), Khamer (*Gmelina arborea*), *Glyricidia sapium.*
C	Saline soils	Herbs:	Satawar (*Asparagus racemosus*), Sankh puspi (*Evolvulus alsinoides*), Khus (*Vetiveria zizanioides*), *Cymbopogon* spp., Chandrsur (*Lepidium sativum*), Kalongi (*Nigella sativa*)
		Shrubs:	Karonda (*Carissa carandus*), Adusa (*Adhatoda vasica*), Nirgundi (*Vitex negundo*), Ber (*Zizyphus* spp.)
		Trees:	Neem (*Azadirachta indica*), Aonla (*Emblica officinalis*), Katha (*Acacia catechu*), Arjun (*Terminalia arjuna*), Babool (*Acacia nilotica*), Bahera (*Terminalia bellerica*), Harra (*Terminalia chebula*), Sivnag (*Oroxylum indicum*).
D	Alkaline soils	Herbs:	Sankh puspi (*Evolvulus alsinoides*), Khus (*Vetiveria zizanioides*), *Cymbopogon* spp., Jangali Pyaj (*Urginia indica*), Van lahsun (*Allium porrum*), Garlic (*Allium sativum*).
		Shrubs:	Karonda (*Carissa carandus*), Nirgundi (*Vitex negundo*), Guggal (*Commiphora* spp.)
		Trees:	Aonla (*Emblica officinalis*), Arjun (*Terminalia arjuna*), Babool (*Acacia nilotica*), Sissoo (*Dalbergia sissoo*), *Eucalyptus teritecornis*, Siris (*Albizzia procera*), Karanj (*Pongamia pinnata*)
E	Water logged soils	Herbs:	Bach (*Acorus calamus*), Brahmi (*Bacopa monniera*), Mandook Parni (*Cintela asiatica*), Brangraj (*Eclipta alba*), *Cyperus* spp. Khus (*Vetiveria zizanioides*), Talmakhana (*Astercantha longifolia*).
		Shrub:	*Hedychium spicatum*
		Trees:	*Eucalyptus teriticornis*, Arjun (*Terminalia arjuna*), Salai (*Boswellia serrata*),

Source: Upadhyaya *et. al.* (2001)

Table-2: Useful parts and uses of some potential herbs and trees, which can be grown in wastelands as tree-crop combination under agroforestry

Herbs		
Asparagus racemosus (Satavar)	Dysentery, blood, eye, kidney liver diseases, appetizer, tonic	Dry roots
Adhatoda vasica (Adusa)	Cough, bronchitis, asthama, diuretic	Dry leaves
Abutilon indicum (Atibala)	Cough, diuretic, laxative	Dry bark
Achyranthus aspera (Apmarg)	Boils, urinary, inflammatory swelling	Whole plant
Acorus calamus (Buch)	Headache, diarrhoea,	Roots
Cassia tora (Chakoda)	Eye, skin diseases ringworm	Dry leaves, seed
Curculigo orchioides (Kali musli)	Piles, Jaundice, appetizer tonic, joints pain, diarrhoea	Dry roots
Calotropis procera (Aak)	Asthma, dysentery, cough, intestinal worms	Dry roots, dry barks
Chlorophytum borivilianum (Safed musli)	Tonic	Dry roots
Curcuma angustifolia (Tikhur)	Leprosy, burning sensation, bronchitis asthma, jaundice, stone of kidney and bladder	Dry roots
Dioscorea daemona (Baichandi)	Antispasmodic, diphoretic, expectorant, cariotonic, detergent	Dry roots
Plumbago zeylanica (Chitrak)	Urine, biles, pregnancy, constipation, scabies	Root and leaves
Eclipta alba (Bhringraj)	Eye diseases, kapha, vath, bronchitis, asthma, anemia, skin disease, heart diseases	Dry plant
Evolvulus alsinoides (Shankhpushpi)	Bronchitis, brain tonic	Whole plant
Gymnema sylvestre (Gurmar)	Heart diseases, tonic, asthma, ulcer, diabetes	Whole plant
Withania somnifera (Ashwagandha)	Tonic, asthma, leucoderma	Roots

Source: Tiwari (2001)

Constraints

Some of the constraints associated with the processing of medicinal plants which may result in reducing their competitiveness in global markets and which need to be facilitated are:-

- Poor agricultural practices
- Poor harvesting (indiscriminate) and post-harvest treatment practices
- Lack of research on development of high-yielding varieties.
- Poor propagation methods
- Inefficient processing techniques leading to low yields and poor quality products
- Poor quality control procedures
- High energy losses due to processing
- Lack of current good manufacturing practices
- Lack of R&D on product and process development
- Difficulties in marketing
- Lack of local market for primary processed products
- Lack of trained personnel and equipments
- Lack of facilities to fabricate equipment locally
- Lack of access to latest technologies and market information

Conclusion

Wastelands literally means the land which is uncultivated, barren or without vegetation and which are for any reason presently unproductive or productive at a level very much below their potential. The soil properties most often associated with wastelands are steep slope, lack of fertility, salinity, acidity, stoniness, shallow soils, eroded soils, wetness or flooding. These are otherwise known as problem soils. Farmers have cultivable wastelands which has some soil cover but not much productive. Such cultivable wastelands may be turned productive by selecting especially tolerant species and varieties of crops/trees. Medicinal plants are best ameliorators in living with problem soils. These category of plants adopt stress conditions by producing secondary metabolites as defence mechanism. Such metabolites are being used as drugs to cure the ailments. Hence, most of the problem soils can be reclaimed by planting such special category of plants. Therefore, class V &VI lands belongs to enterprising farmers/lands held by small communities should be brought under cultivation by encouraging planting of medicinal plants/trees through participatory approach which will not only properly utilize the wastelands but also conserve the medicinal & aromatic plants.

Reference

- *Anonymous* (1998) Current trends in International market. Journal of Medicinal and Aromatic Plant Sciences 20:113.
- *Hanfee. F*. (1998). Wildlife Trade: A handbook for Enforcement staff. Traffic INDIA p.30.
- Schippmann U., Leaman D.J. and Cunningham A.B. (2002). Cultivation and gathering of medicinal plants on biodiversity trends and issues. In Biodiversity and the Ecosystem at Agriculture, Forestry and Fisheries. Ninth Regular session commission on Genetic resources for food and agriculture, Italy, pp. 1-21.
- Singh, M.P., Srivastava, J.L. and Pandey, S.N. (2003). Indigenous medicinal plants, Social forestry and tribals. Daya publishing house, Delhi pp 505.
- Sivaraman, K. (2001). Centrally sponsored scheme for development of medicinal and aromatic plants. Published in the SOUVENIR of National Seminar on "*Commercial Cultivation Processing and Marketing of Medicinal and Aromatic Plants.*" Organized by Department of Plant Physiology, College of Agriculture, JNKVV, Jabalpur-482004 (MP) held during Nov. 27-29, pp.1-4

- Solanki R.R., Bisariya, A.R. and Honda, A.K. (1999) A Decade of Research (1988-1999). National Research Centre for Agroforestry, Jhansi 1-44
- Tiwari, J.P. (2001) Status of medicinal and aromatic plants in Madhya Pradesh and future perspective. Published in the SOUVENIR of National Seminar on "*Commercial Cultivation Processing and Marketing of Medicinal and Aromatic Plants.*" Organized by Department of Plant Physiology, College of Agriculture, JNKVV, Jabalpur-482004 (MP) held during Nov. 27-29, pp.5-15.
- Upadhyaya, S.D., Tiwari, Gyanendra and Sharma, Aashutosh, (2001) "Scope of Medicinal Plants cultivation in wastelands of Madhya Pradesh" Published in the SOUVENIR of National Seminar on "*Commercial Cultivation Processing and Marketing of Medicinal and Aromatic Plants.*" Organized by Department of Plant Physiology, College of Agriculture, JNKVV, Jabalpur-482004 (MP) held during Nov. 27-29, pp.24-31.


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