

Compacted soils: Characteristics, causes, management and impact on crop

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1. Introduction :-

The soil compaction is the physical form of soil degradation that changes the soil structure and influences the soil productivity. Unlike salinity, water logging or the soil erosion that can be remarked from the soil surface, the soil compaction causes a hidden degradation of the soil structure that is difficult to locate and rationalize. Other means, compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water. Most soils are composed of about 50 per cent solids (sand, silt, clay and organic matter) and about 50 per cent pore spaces (which is filled by air or water).

The soil compaction can be defined as “the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby, increasing the bulk density”. So, the soil compaction involves the changes in physical properties of the soil (bulk density and soil porosity) and these modified physical parameters of the soil are determinants of the influence of the soil compaction on chemical properties of the soil, soil fauna, and diversity and plant growth (Fig. 1), observed at certain depth (subsoil compaction). Except a few cases where a slight degree of top soil compaction can be beneficial for some type of soils especially sandy soils, in most cases, it has negative effects on the soil. The subsoil compaction is a serious problem because it is expensive and difficult to alleviate and it has been acknowledged as a serious form of the soil degradation. The soil compaction in forests, due to mechanized operations, can be severe but shows more spatial variability than in agricultural lands due to less systemic mechanized operations and presence of stumps and heavy roots in the soil.

Soil compaction can be the disruption and lessening of the large pores within the soil. The presence of extra soil moisture at the time of any field operation is the foremost aspect leading to soil compaction. The construction purposes, a compacted soil is the perfect but under normal crop production, a compacted soil can be a serious problem. Penetration into the soil by tillage implements and crop roots is restricted. Soil compaction can also be one of the underlying agents of soil erosion, nutrient lessening and pollution. It is also important to be aware that soil compaction is a phenomenon associated not only with agriculture, but also with forest harvesting, amenity land use (e.g. localized trampling), pipeline installation, land restoration and wildlife pathways.

2. Causes of the soil compaction :-

Compaction can be a natural phenomenon caused by freezing and drying or an artificial phenomenon caused by the mechanical operations. Conventional agricultural practices can also degrade the soil by the soil compaction. In modern agriculture, most of the field operations from sowing to harvesting are done mechanically by using heavy wheeled machines which can compact the soil at every passage. The soil compaction by a machine, in general, depends on the soil strength and loading of machine. The soil strength is influenced through the organic matter, water content, soil structure, and texture while the loading is expressed by axle load, number of tyres, tyre dimensions and soil tyre interaction. Aggregate the pressure on the soil increases the chances of the soil compaction. Increasing the frequency of passages of machines over a soil increases its dry bulk density and cone index resulting in the top soil compaction and unsuitable physical soil conditions for seed emergence. However, a major portion of the total soil compaction is caused by the first passage or early passages of the machine and 10 passes can affect the soil up to 50 cm depth. Animal trampling can cause the soil compaction and can degrade the soil structure. The soil compaction caused by grazing animals through hoof action is likely to be more widespread within the paddocks as compared to the soil compaction caused by mechanical implements which is limited under the tracks. Physical deterioration by grazing animals depends on the trampling intensity, soil moisture, plant cover, land slope, and land use type. Animal caused the soil compaction could range from 5 to 20 cm and might affect the soil bulk density, hydraulic conductivity, macro pore volume, and penetration resistance of the soil.

In contrast to the cultivated lands, harvesting operations in forest cause more soil compaction because of: (1) the use of heavy machinery for harvesting; (2) felling, pushing, pulling, and lifting of logs; (3) during transport of logs that exert a combined pressure on the soil; (4) no tillage operations in forests to loosen the soil. In the forests, harvesting operation causes different types of the soil disturbances and probability of the soil compaction is directly related to harvesting system and harvesting density. Mostly severe soil compaction is caused when thinning and clear felling operations are carried out with machines and these operations can compact the soil up to the depth of 60 cm leaving the effects for > 3 years. The use of light weight multi functioning machines can reduce the passages and ultimately the degradation of the soil. Natural causes (tree roots, precipitation, seasonal cycles, etc.) of the soil compaction are not as harmful as anthropogenic causes: the soil compaction associated with natural causes is limited in top 5 cm of the soil and the soil compaction due to the trampling and urban pressure on a site can compact the soil up to 20 cm while mechanical operations can compact the soil up to 60 cm.

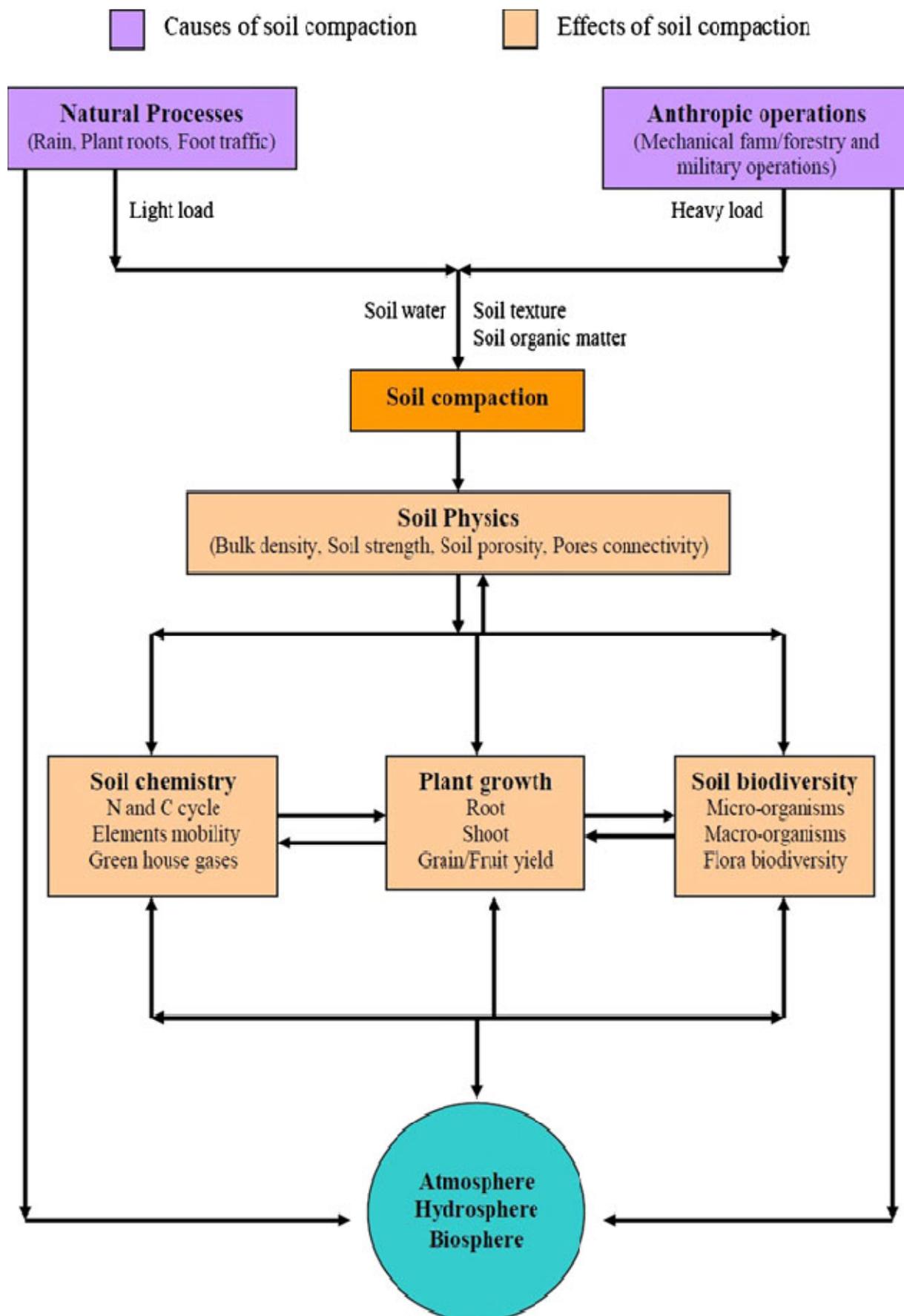


Fig. 1 : Causes of soil compaction and their effects on soil physical properties with ultimate direct effects on soil chemistry, plant growth and soil biodiversity while indirect effects on exchanges of matter with external compartments

3. Effects of soil compaction :-

- Soil water contents, soil texture and structure, and soil organic matter are the three main factors which determine the degree of compactness in the soil.
- Soil physical properties such as bulk density, strength, and porosity; can be used to directly quantify the soil compactness.
- Modified soil physical properties due to soil compaction can alter elements mobility and change nitrogen and carbon cycles in favour of more emissions of greenhouse gases under wet conditions.
- Severe soil compaction induces root deformation, stunted shoot growth, late germination, low germination rate, and high mortality rate.
- It decreases soil biodiversity by decreasing microbial biomass, enzymatic activity, soil fauna, and ground flora.
- It is restricted to elastic domain and do not consider existence of preferential paths of stress propagation and localization of deformation in compacted soils.

4. Impact of soil compaction on soil properties :-

• Effect of bulk density on soil compaction :

Bulk density is defined as the oven dry mass of soil per unit volume. Good soil structures are described by increased in soil macro aggregates and porosity. The bulk density is increase with increase in soil compaction, as compacting forces squeeze the volume of soil via eliminating pore spaces. Another significance associated with improve in bulk density might be due to compaction is high penetration resistance, fewer infiltration, great runoff, and more soil erosion. Under different tillage regimes, bulk density varies, as conventional tillage initially occasioned in high porosity and low bulk density in early season, whereas later on due to compaction-causing agents, the number of pores decreases and bulk density increases, could be prolonged. Nevertheless, under conventional tillage system, initially bulk density and penetration resistance are more, while the action of natural biological agents (e.g., worms, fungi) improves productivity of soil by enhancing aggregate stability, porosity, and organic matter and reducing bulk density.

The soil compaction is significant decrease in soil porosity and soil aeration, roots show stunted growth and poor root proliferation. Root-soil compaction interaction may be complex, depends on the extent of soil compaction and the degree of modifications in soil properties. Reduction in root growth might be associated with mechanical injury to taproots, high penetration resistance of compacted soil, and less nutrient bioavailability. Soil compaction decreases plant growth by reduction of the development of plants. However, seed

germination in compacted soil also depends on clay contents and soil moisture level. Poor seed germination and stunted root growth in compacted soils having high clay contents under dry climate was renowned. Reductions in soil water availability due to poor water infiltration and less number of macro pores account for reduced root growth and lower N uptake.

- **Effect of porosity on soil compaction :**

Soil consists of three kinds of pores which are micro, meso and macro pores in soil. The air is filled macro pore in soil in which supply oxygen to soil fauna and flora. The decrease in macro pores occasioned in the development of anoxia conditions and interferes with crop growth and development. The alteration in the pore size distribution due to compaction ensued in increased runoff, reduced infiltration, and great erosion losses. The weighty use of farm apparatuses enforced high axle load and ground pressure on the soil, producing shrinkage in pores, consequently, and volume of pores reduced. The tillage systems which are conventional tillage, widespread releasing of soil progresses more macro pores at the beginning season, whereas future on, macro pores became condensed due to soil compaction. In the influence of frequent wheeling on pore size distribution and pore volume, they further noted that no visible macro pores were perceived in highly compacted zone (Fig. 2).

- **Effect of soil moisture content on soil compaction :**

Soil moisture content is the most prompting factor that makes soil susceptible to compaction, as penetration resistance upsurges and soil water potential declines. The rising soil moisture content causes reduction in macro pore spaces and leads to decline in load support capacity of the soil and permissible ground pressure. Additionally, contribution of soil water content towards soil compaction is dependent on deformability of soil, pre-compression value, stress dissemination ability, and contact area between soil and tire. Soil gets compacted up to a certain value of soil moisture availability, regarded as optimum soil moisture; above this limit, decrease in soil compaction occurred as soil becomes increasingly plastic and incompressible. Thus, it can be suggested that in order to minimize compaction, it is important to till soil at appropriate soil water content. Decrease in total porosity is accompanied with increase in soil moisture content, causing compaction to deeper in soil profile. Depth and width of compacted zone are governed by high moisture content, causing low structural porosity and high structural deformation. The increase in soil moisture content caused decrease in aggregate diameter and porosity, while increase in bulk density which is a character of compacted zone leads to increase in aggregate tensile strength. The effect of soil moisture is much stronger in the subsoil than in the topsoil; however, for comparison and calculation of soil moisture content, determination of liquid, plastic, and solid limits of soil might be a better scale.

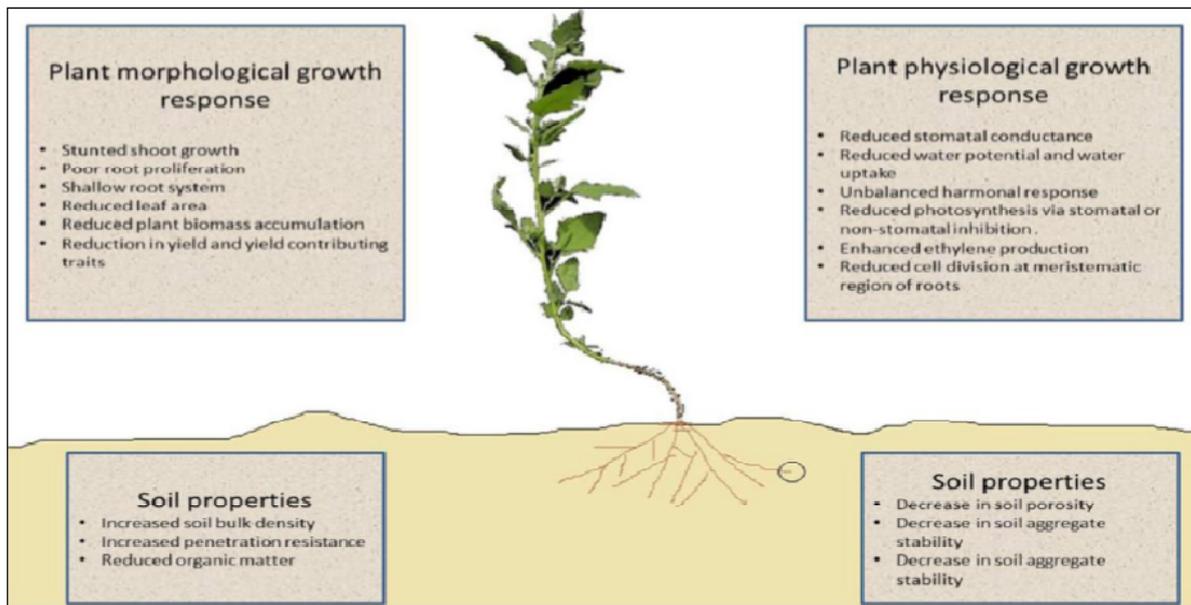


Fig. 2 : Summary of the knowledge of the effects of soil compaction on soil plant morphological and physiological growth and soil properties

- **Effect of structural stability on soil compaction :**

Soil structural stability or aggregate is a key indicator of soil structure that determines its productivity and resistance to soil erosion and degradation. It is an important index of soil quality, and soil physical properties affect soil productivity and sustainability. Soil aggregates are actually groups of soil particles that stick together as outcome of cohesive forces among particles and interaction of organic matter, cations, and anions with soil particles. Soil with high stability index is more productive, produces higher crop yield, while with low stability index, soil erosion losses are high. Soil compaction reduces formation of soil aggregates; it becomes worsen when high axle load and high moisture content together assaulted on soil. Among tillage systems, conservation tillage system resulted in high structural regeneration and aggregate formation than conventional tillage system. Sandy soils have more dispersed particles with less aggregate stability and destructive impacts on clayey soils as they have more binding of soil aggregates than sandy soils.

- **Effect of penetration resistance on soil compaction :**

The penetration resistance is produces the work done by root to enter in the soil. The greater mechanical insulence is greater will be compaction, outcomes in higher penetration resistance, which results in more work done by roots. The soil compaction is affected by significant increase in penetration resistance. The penetration resistance increases with increase in bulk density and lower soil water potential and root penetrability reduces with increase in penetration resistance. The lessening in penetration level is directly associated with proliferation in water potential. Dry soils have more penetration resistance in the presence of high soil water, low soil strength and penetration resistance.

- **Effect of soil strength on soil compaction :**

The soil strength or resistance to penetration is used for measured through soil compaction. The soil strength rises with increasing bulk density while it decreases with decreasing soil moisture content. The soil moisture is a significant factor for measuring the degree of compaction upon trampling where the deleterious impact of livestock trampling generally increases as the soil moisture at the time of trampling increases and grazing should be strictly prevented on wet soils.

- **Effect of soil organic matter on soil compaction :**

Organic matter is the decomposition of plant and animals residues which increase soil fertility. The adequate and sustaining amount of organic matter in the soil stabilizes soil structure and makes it more resistant to soil degradation and reduce bulk density and soil strength. Organic matter in soil plays significant role in preserving soil biological activities. High soil organic matter outcomes in higher stability index, high soil quality, and productivity, while lower organic matter contents in soil make soil more susceptible to soil compaction. Organic residues in soil profile are more significant than surface, as this organic matter attached to soil particles especially clay particles and binds micro and macro-aggregates soil, thus preventing soil from become compacted by the action of heavy machines.

5. Impact of soil compaction on plants :-

The soil compaction effects in restricted root growth, declined accessibility of nutrients, enlarged and nutrients loss by leaching, runoff, and gaseous losses to atmosphere which may impacts on plant growth. The soil is sorrow from other types of degradation such as the salinity, drastic belongings of the soil compaction on the plant growth and crop.

- **Effect on seedling emergence :** The seedling emergences are unfavourably affected through the soil compaction. The soil compaction is additional damaging to the seedling growth and survival as compared to established plants and trees.

- **Effect on plant roots :** The plants roots play an essential role in the nutrient uptake and plant development and their penetration ability is damagingly affected by the soil compaction due to improved soil strength and reduced number of macro pores. The soil compactions on roots generally vary with interspecies and for dissimilar cultivars of the same species, due to difference in root penetration ability depending on the root physiology and morphology. The surface soil compaction is a more limiting factor for the root growth than subsoil compaction. The impacts of the soil compaction on the ion uptake and root growth are more severe in saline soils than in normal soils.

- **Effect on plant shoots :** The rooting association of the plants is rigorously precious through the soil compaction, this does not always consequence in decreased shoot growth could be due to depends on the availability of nutrients in the soil. Uncertainty the soil is so seriously compacted that it reduces the mobility of ions in soil and strictly restricts the root growth.

6. Impact of soil compaction on soil biodiversity :-

The soil compaction can be positive to soil biodiversity and vice versa responsible upon the nature of the soil, climate, and extent of the soil compaction.

- **Effect of bacterial population on soil compaction :** The soil compaction occasioned in reduced soil aeration of the soil due to 13–36% decreases of air filled porosity which might be due to the lessening in microbial biomass carbon and nitrogen. Soil microbial biomass is undesirably precious through the soil compaction.
- **Effect of enzymatic movement on soil compaction :** The soil compaction is changes physico-chemical properties of soil may be due to the reduce of phosphatase, urease, amidase, and dehydrogenase happenings though sometimes proliferation in the phosphatase activity is also conveyed. The changes in the microbial communal and favour organisms accomplished of accepting these circumstances, hence, more iron and sulphate reducers, and greater methanogens were originate in compacted soils as compared to un-compacted soils.
- **Effect of soil fauna on soil compaction :** The soil fauna is an important role in the decay and integration of organic matter and home-based is interstitial places in the soil. The soil compaction vagaries the pore size availability and distribution which usually indications to the decrease of the proportion of large pores and affects the movements of nematodes and larger soil fauna. Earthworms are also described to be influenced by the soil compaction and their population decreases with increase in the soil compaction nevertheless they are capable to penetrate a soil by ingesting the soil particles.
- **Effect of soil flora on soil compaction :** The soil flora is real important in the forest ecology in terms of vegetation, productivity, aesthetics, and water and nutrient cycling. Some disturbance to the forest ecosystem and/or soil affects unfavourably the native ground flora nevertheless particular plant species are capable to illustration healthy habitat and a rapid recovery after extreme degradation of the soil. The soil compaction affects the soil biodiversity negatively and it results in reduction in the microbial biomass, enzymatic activity, soil fauna and ground flora in compacted soils.

7. Management of compacted soils :-

The soil compaction is mostly decreased soil porosity and increases soil bulk density. The management of soil compaction, especially in arid and semi-arid regions may be achieved through suitable application of some or all of the following techniques i.e. addition of organic matter, controlled traffic, mechanical loosening such as deep ripping, selecting a rotation which includes crops and pasture plants with strong tap roots able to penetrate and break down compacted soils. The land management is better practices are energetic in ensuring that soil physical conditions are not compromised and that practices which intensification the organic content, decrease tillage and sustain utilization of farming systems.

- **Addition of organic matter into the soils :** The organic matter recollects soil water and helping soil to rebound beside compaction. The maintaining an adequate amount of organic matter in the soil stabilizes soil structure and makes it more resistant and reduces bulk density and soil strength. Since organic materials possess lesser bulk density and superior porosity than that of mineral soils mixing them with soil would improve soil bulk density and porosity. Though plant residues are a common source of organic matter in the soil and manure is also used extensively by farmers to decline soil compaction and improve soil fertility.
- **Managing traffic :** The traffic management is a system that relief to maintain a zone more positive for plant growth by restricting soil compaction to the traffic lanes and a loose rooting zone. This proposes that wheel traffic, rather than tillage and cropping, influence be the main factor governing infiltration. The exclusion of wheel traffic in a well-ordered traffic agriculture system, combined with conservation tillage, runs a way to enhance the sustainability of cropping and improved infiltration, raises plant-available water, and reduces soil erosion caused by runoff. The energy requirements for different types of tillage are related to tillage depth, soil type, degree of compaction, soil moisture at the time of tilling and to the type of implements to use.
- **Deep cultivation and deep ripping :** The deep cultivation or deep ripping is a significant preparation for eliminating soil compaction, destroying hard pans and ameliorating hard setting of soils. It has become a common management practice used to shatter dense subsurface soil horizons that limit percolation of water and penetration of roots. The subsoil was to improve plant growth has received sporadic care around the world over many years. The increasing soil compaction related with mechanized agriculture and the availability of more powerful tractors and better sub-soilers, ripping can become a favourable soil management exercise. Deep ripping of compacted soil may also improve soil health and ability of plants to resist disease. The growth-stunting

disease was eradicated completely, enlarged substantially by deep cultivation, which eliminated compacted soil layers. Though, choosing the true soil moisture and the right combination of ripping depth and tine spacing can lessen the cost of ripping. Ripped soil must be allowed to settle down before seeding, otherwise seeding depth is difficult to regulator and seeds may be placed below the preset seeding depth.

- **Plant roots :** The hydrostatic pressure (Turgor) inside the elongating area of the root affords the force required to push the root cap and meristematic region through the resisting soil. Uncertainty the hydrostatic pressure is not sufficient to overcome wall resistance and soil impedance, elongation of that particular root tip ceases. The result of roots on soil structure depends on the types grown, soil constitution and environmental aspects. Plants grown in compacted soil have a smaller number of lateral roots with less dry matter as compared to plants developed under controlled situations at both low and high soil water contents. Soil compaction could be due to adverse effects upon plants growing in the soil by increasing the mechanical impedance to the growth of roots, altering the extent and configuration of the pore space. Plant species that have the ability to penetrate soils with high strength usually possess a deep tap root system.

8. Conclusion :-

Soil compaction is the worst type of land degradation that limits agricultural productivity and widespread is the current trends, its occurrence is likely to increase. As a consequence, more and heavier farm machinery and/or animals per land surface area have become common all over the world. This strengthening of the farming system has led to soil compaction and worsening in soil fertility particularly in dryland/rainfed areas. The soil compaction is adversely affects soil fertility, chiefly storage and supply of water and nutrients, through increasing soil bulk density, decreasing porosity and increasing soil strength. These argumentative belongings reduce fertilizer efficiency and crop yield, growth water-logging, runoff and soil erosion with undesirable environmental pollution harms. The practices include minimum (and zero) tillage, minimizing traffic, combining more than one farmhouse operation instantaneously using the same machine to minimize number of passes, minimizing traffic, minimizing intensity of grazing and number of animals per grazing, maintaining vegetative soil cover, loosening compacted soil by deep ripping accompanied and using a rotation which includes deep and strong rooting plants able to penetrate relatively compacted soils. Cumulative soil organic matter over stubble retention, green and brown manure or addition of plant or animal organic matter from external sources is also important in decreasing bulk density of the soil and acting as a buffer preventing or lessening the transmission of compaction to subsoil from external loads acting on the earth.