AGRON 604 ADVANCES IN CROP GROWTH AND DEVELOPMENT (2+1)

Dr. K .K .Agrawal

Principal Scientist,

Department of Agronomy, College of Agriculture,
Jawaharlal Nehru KrishiVishwaVidhyalaya , Jabalpur

M 09425163385

Kkagrawal59@gmail.com

Course content: Growth analysis: concept, CGR, RGR, NAR, LAI, LAD, LAR; validity and Limitations in interpreting crop growth and development; growth curves: sigmoid, polynomial and asymptotic; root systems; root-shoot relationship; principles involved in inter and mixed cropping systems under rain fed and irrigated conditions; concept and differentiation of inter and mixed cropping;

Growth Analysis

Growth

Growth is defined as an irreversible increase in size and volume of plant accompanied by increase in dry weight.

Development

It refers to the quality changes in plant parts. Example- Formation of flowers and fruits, falling of leaves etc.

Vegetative growth

Growth occurs from seed germination till before initiation of floral primordial. Important events are germination, seedling emergence, leaf and stem growth.

Reproductive growth

Growth that occurs from initiation of floral primordial till completion of seed formation. The important events are initiation of floral primordia, flower emergence, anthesis, pollination, fertilization, seed development and maturation.

Phases of Growth

The growth is mainly accomplished in three main phases:

Cell division

Cell elongation

Cell differentiation

Measurement of Growth

Linear measurement

Generally growth is measured in terms of increase in length of root and shoot. Stem length is taken from soil surface to the tip of uppermost node.

Short comings

Variation in seedling growth. In dark stem elongates more but remain thin, whereas in light seedling is short and thick.

Fresh weight measurement

Weight of freshly harvested plant is taken as fresh weight.

Short comings

Plant has to be removed while measuring fresh weight.

It depends on water content of tissue which keeps on changing due to variation in rate of absorption and transpiration

Dry weight measurement

Plant material is dried at 80^0 c temperature for about two or three days till constant weight.

Short comings

Dry matter may increase due to deposition of food material like starch or may decrease due to oxidation of food material as a result of excess heating.

Leaf area measurement

Measurement of leaf area is also taken as an index of growth.

Short comings

Accurate determination is difficult without having sophisticated instrument.

Volume measurement

Volume of plant part or plant can be measured by water displacement method .

Short comings

It is not accurate due to difference in compactness of tissue.

Growth Analysis

It is the method of estimating net photosynthetic production. It was worked out by (*Blackman et al 1919*)

2.1 Growth analysis: concept, CGR, RGR, NAR, LAI, LAD and LAR:-

Growth analysis concept:-

Growth analysis is a mathematical expression of environmental effects on growth and development of crop plants. This is a useful tool in studying the complex interactions between the plant growth and the environment. The problem of accounting for variation in yield in terms of growth and development of the crop is very complex due to:

- The effect of external environment on the plant physiological processes,
- The interrelation between different physiological processes, and
- The dependence of the above two on internal factors determined by the genetic constitution of the plant.

The basic principle behind this concept of analysis is the estimation of crop growth at various Stages and finally reasoning for yield variation. This would give an insight not only on the performance, of a particular genotype, but also on the impact of superimposed agronomic practices on the crop at any particular stage of growth as well as on the final yield.

Important methods of growth analysis are discussed below:

1. Crop growth rate (CGR)
2. Relative growth rate (RGR)
3. Net assimilation rate (NAR)
4. Leaf area index (LAI)
5. Leaf area duration (LAD)
6. Leaf area ratio (LAR)

1. **Crop growth rate (CGR):-** Crop growth rate (CGR) is the gain in dry matter production on a unit of land in a unit of tune.

Formula:-

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2

t_1 = first sampling, t_1 = second sampling.

Unit: - g m^{-2} day^{-1}

Example: - Calculate the CGR from following data: Dry weight of groundnut at t_1= 200 g m^{-2} (W_1), Dry weight of groundnut at t_2 = 300 g m^{-2} (W_2), Time interval of sampling (t_2-t_1) = 10 days

Solution:-

$$CGR = \frac{300 - 200}{10} = \frac{100}{10}$$

$$= 10 \text{ g m}^{-2} \text{ day}^{-1}$$

CGR of 20 g m^{-2} day^{-1} (200 kg ha^{-1} day^{-1}) is considered respectable for more crops; particularly C_3 types.CGR of 30 g m^{-2} day^{-1} (300 kg ha^{-1} day^{-1}) is obtainable from C_4 types such as maize and sorghum (Gardener et al 1988).

Crop growth rate is affected by a range of factors including temperature, levels of solar radiation, water and nutrient supply, crop, cultivar and its age. These factors influence the size and efficiency of leaf canopy and hence the ability of crop to convert solar energy into economic growth.

2. **Relative growth rate (RGR):-** Since CGR is an absolute measure of growth; similar values could be expected for crops of different initial weights. Compound interest equation of Blackman (1919) discussed earlier can be modified for calculating the relative growth rate (RGR) The RGR expresses the dry weight increase in time interval in relation to the initial weight. In practical situations, the mean RGR is calculated from measurements at t_1 and t_2

Formula:-

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where,

W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2

t_1= first sampling, t_1 =second sampling.

Unit: - g g^{-1} day^{-1}

Example: - Calculate the RGR from following data: Dry weight of groundnut at t_1= 5 g (W_1), Dry weight of groundnut at t_2 = 10 g (W_2), Time interval of sampling (t_2-t_1) = 7 days

Solution:-

$$RGR = \frac{\log_e 10 - \log_e 5}{7} = \frac{2.3026 - 1.6094}{7} = \frac{0.6932}{7}$$

= 0.099 g g^{-1} day^{-1}

The RGR generally, begins slowly just after germination, reaches high values soon after and then falls off (Hunt 1978). Calculation of RGR is only really useful for short harvest intervals where growth is assumed to be linear and for comparisons under similar environmental conditions (between treatments within a dial).

3. **Net assimilation rate (NAR):-** Net assimilation rate (NAR) or unit leaf rate is the net gain of assimilate per unit of leaf area and time.

Formula:-

$$NAR = \frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(t_2 - t_1)(LA_2 - LA_1)}$$

Where,

W_1 = dry weight per unit area at t_1,

W_2 = dry weight per unit area at t_2

LA_1 = leaf area at t_1, LA_2 = leaf area at t_2

t_1= first sampling, t_1 =second sampling,

Unit: - g m^{-2} $week^{-1}$ or g m^{-2} day^{-1}

Example: - Calculate the NAR from following data: W_1 = 450 g, W_2 = 570 g, LA_1 = 3.5 m^2, LA_2 = 4.0 m^2, t_2-t_1= 2 week

Solution:-

$$NAR = \frac{(570 - 450)(1.3863 - 1.2528)}{2\ (4.0 - 3.5)} = \frac{120}{2} \times \frac{0.1335}{0.5}$$

$= 16.02\ g\ m^{-2}\ week^{-1}$

NAR expresses plant's capacity to increase dry weight in terms of the area of its assimilatory surface. The term, therefore, represents photosynthetic efficiency in the overall sence and in connection with LAR and RGR it can be used lo analyse the response of plant growth to environmental conditions. As Watson (1956) explains, NAR does not measure real photosynthesis, since it represents the net result of photosynthetic gain over respiratory loss and may, therefore, vary according to the magnitude of respiration.

A second precaution concerns species comparison. Since NAR gives no direct indication of respiratory losses, this index does not necessarily serve as a direct measure of inherent photosynthetic capacities. The third limitation is of importance to the agronomists. While NAR indicates plant efficiency in producing dry matter, economic yield is subjected to additional controls and is not necessarily related to photosynthetic efficiency. Watson (1956) found no positive association between NAR and yield in five cultivars of sugar beet and three of potatoes which was confirmed by Thorne and Gillian (I960).

4. **Leaf area index (LAI):-** Leaf area index (LAI) is the ratio of leaf area to the area of ground cover. It is the leaf area (one surface only) divided by the land occupied by the plants. It is a unit less figure.

   Formula:-

$$LAI = \frac{\mathrm{LA}}{GA}$$

Where, LA= Leaf area, GA=Ground area

Example: - Calculate the leaf area index from given data: Leaf area of 80 plants in 7500 cm^2 was 2,494.58 cm^2

Solution:-

$$LAI = \frac{2494.58}{7500}$$

$= 0.33$

Leaf area typically increases after crop emergence to a maximum and then decline (Watson 1947). For maximum production of dry matter of most crops, LAI of 3 to 5 is usually necessary. Forage crops, such as grasses, with erectophile (upright) leaf orientation may require 8-10 LAI under favorable conditions to maximize light interception. Higher LAI is also required where total biomass, not the economic yield, is the objective (forage crops). LAI and its seasonal distribution varies considerably with species. Values required for max.mum production increase with the level of solar radiation.

The LAI at which the canopy first reaches maximum CGR is called critical LAI. The LAI with 95 per cent solar radiation interception has been adopted as the critical LAI by most crop physiologists. The LAI at maximum CGR is called optimum LAI, because the CGR decreases

as the LAI increase beyond the optimum.

5. **Leaf area duration (LAD):-** Leaf area duration (LAD) expresses the magnitude and persistence of leaf area or leafiness during the period of crop growth. It reflects the extent or seasonal integral of light interception.

Formula:-

$$LAD = \frac{(LA_2 + LA_1)(t_2 - t_1)}{2}$$

Where, LA_1 and LA_2 are leaf areas at times t_1 and t_2 respectively.

Unit: - $cm^2\ d^{-1}$

If LAI is plotted against time, it produces a function that indicates assimilatory capacity of crop during the period. The LAI declines rapidly in some crops which may restrict growth Management practices which can prolong the duration of leaf surface in an active state may improve the yield. LAD provides a means for comparing treatments on the basis of their leaf persistence. It is usually determined by measuring the area beneath leaf growth curve for selected parts of the season.

6. **Leaf area ratio (LAR):-** Leaf area ratio (LAR) is the ratio of the total leaf area to the whole plant dry weight and is a further measure of the efficiency of leaf surface in producing dry matter.

Formula:-

$$LAR = \frac{(LA_1/W_1) + (LA_2/W_2)}{2}$$

Unit: - $m^2\ g^{-1}$

Example: - Calculate the LAR from following data: $W_1 = 450$ g, $W_2 = 570$ g, $LA_1 = 3.5\ m^2$, $LA_2 = 4.0\ m^2$

Solution:-

$$LAR = \frac{(3.5/450) + (4.0/570)}{2} = \frac{(0.008) + (0.007)}{2} = \frac{0.015}{2}$$

$= 0.0075\ m^2\ g^{-1}$

2.2 Validity and Limitations in interpreting crop growth and development:-

Advantages of growth analysis:-

1. We can study the growth of the population or plant community in a precise way with the availability of raw data on different growth parameters.
2. These studies involve an assessment of the primary production of vegetation in the field i.e. at the ecosystem level (at crop level) of organization.
3. The primary production plays an important role in the energetic of the whole ecosystem.
4. The studies also provide precise information on the nature of the plant and environment interaction in a particular habitat.
5. It provides accurate measurements of whole plant growth performance in an integrated manner at different intervals of time.

Drawbacks/Limitation of Growth Analysis:-

In classical growth analysis sampling for primary values consist of harvesting (destructively) representative sets of plants or plots and it is impossible to follow the same plants or plots throughout whole experiment.

2.3 Growth curves: sigmoid, polynomial and asymptotic:-

1) **Sigmoid growth curve: -** Typical growth pattern of an annual plant is represented in figure 2.1. This can be divided into three phases.

I. Lag period of growth: During this period the growth rate is quite slow because it is the initial stage of growth.

II. Log period of Growth: During this period, the growth rate is maximum and reaches the top because at this stage the cell division and physiological processes are quite fast.

III. Senescence period or steady state period: During this period the growth is almost complete and become static. Thus the growth rate becomes zero.

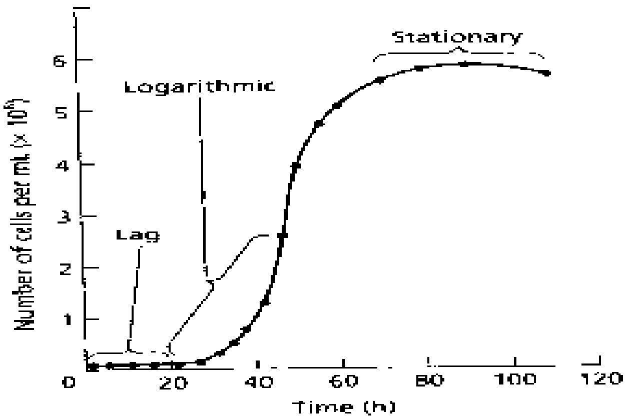


Figure 2.1 A typical sigmoid growth curve

If the growth rate is plotted against time, an 'S' shaped curve is obtained which is called sigmoid curve or grand period curve

The growth curve described above is seen in most cases, although there is a considerable difference due to variations in plant species as well as environmental factors. It is also apparent that growth in all parts of a multi cellular plant is not uniform. In higher plants, it is restricted only to the meristematic zones which are found near the root and the shoot tips, in the vascular cambium and in certain parts of young leaves.

2) Polynomial growth curve: - The parabolic response curve is typically a flat-topped one with decrease in grain yield on both sides of an optimum (Figure 2.2). The curve could be fitted by a quadratic equation

$$y= a+ bx +cx^2$$

Where,

y= Yield per unit area,

x= Plant population, and

a ,b and c = regression constants

3) Asymptotic growth curve: - When yield is the product of vegetative crop growth, the density-yield relationship is asymptotic. In an asymptotic relationship, with increase in density, yield rises to a maximum and then relatively constant at high densities. Further increase in plant density above this maximum does not increase the yield. (Figure 2.2)

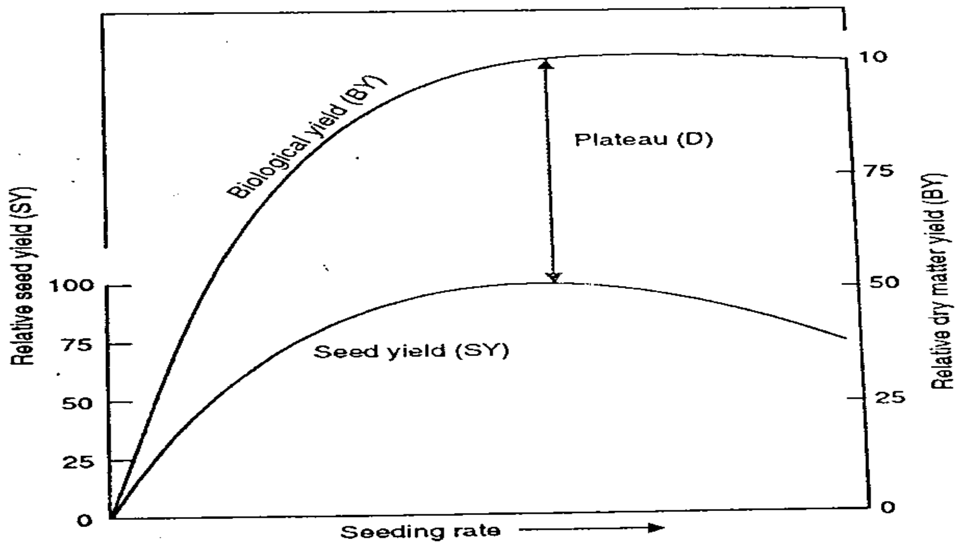


Figure 2.2 Parabolic and asymptotic relation between plant population and yield (Garnder et al. 1988).

The yield of individual plants declines rapidly over the higher range of populations, but the rate is slower at higher densities. In this case, a dense stand for efficient radiation interception must be achieved as quickly as possible, but if the stand is too dense, the only loss is from greater seeding expense. This partly explains why recommended seed rates for fodders are higher than that for grain. The curve for biological yield can be defined by the expression for a rectangular hyperbole.

$$y = \mathrm{Ax} \times \frac{1}{1 + \mathrm{Abx}}$$

Where,

y = dry matter yield per unit area, A = the apparent maximum yield per plant, x = number of plants per unit area, and b = the linear regression coefficient of the reciprocal of yield per plant and plant population.

In this expression, the term *l/(1+Abx)* represents the manner in which the maximum plant yield (A) is reduced by the increasing competition resulting from greater plant density. In consequence, it may be termed the competition function. It is to be noted that 1/x is a measure of the area available per plant and that the environment resources are available to the plant on an area basis (Holliday 1960).

2.4 Root systems:-

The root system of a plant constantly provides the stems and leaves with water and dissolved minerals. In order to accomplish this root must grow into new regions of the soil. The growth and metabolism of the plant root system is supported by the process of photosynthesis occurring in the leaves. Photosynthate from the leaves is transported via the phloem to the root system. Root structure aids in this process. This section will review the different kinds of root systems an look at some specialized roots, as well as describe the anatomy of the roots in monocots and dicots.

Root Systems:

1. **Taproot System: -** Characterized by having one main root (the taproot) from which smaller branch roots emerge. When a seed germinates, the first root to emerge is the radicle, or primary root. In conifers and most dicots, this radicle develops into the taproot. Taproots can be modified for use in storage (usually carbohydrates) such as those found in sugar beet or carrot. Taproots are also important adaptations for searching for water, as those long taproots found in mesquite and poison ivy.

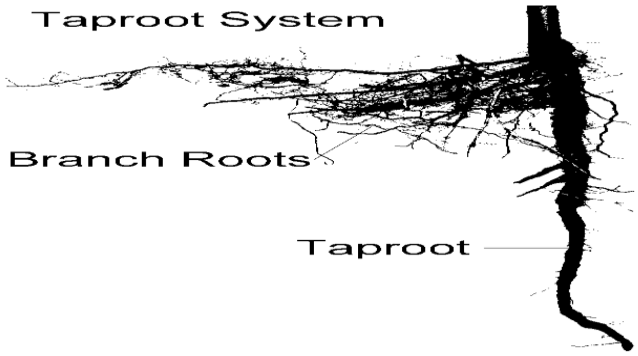


Figure 2.3 Taproot System

2. **Fibrous Root System:-** Characterized by having a mass of similarly sized roots. In this case the radicle from a germinating seed is short lived and is replaced by adventitious roots. Adventitious roots are roots that form on plant organs other than roots. Most monocots have fibrous root systems. Some fibrous roots are used as storage; for example sweet potatoes form on fibrous roots. Plants with fibrous roots systems are excellent for erosion control, because the mass of roots cling to soil

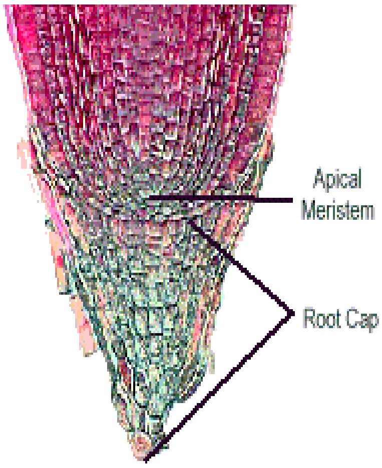
particles.

Figure 2.4 Fibrous root System

Root Structures and Their Functions:-

1. **Root Tip:** the end 1 cm of a root contains young tissues that are divided into the root cap, quiescent center, and the subapical region.
2. **Root Cap:** root tips are covered and protected by the root cap. The root cap cells are derived from the rootcap meristem that pushes cells forward into the cap region. Root cap cells differentiate first into columella cells. Columella cells contain amylopasts that are responsible for gravity detection. These cells can also respond to light and pressure from soil particles. Once columella cells are pushed to the periphery of the root cap, they differentiate into peripheral cells. These cells secrete mucigel, a hydrated polysaccharide formed in the dictyosomes that contains sugars, organic acids, vitamins, enzymes, and amino acids. Mucigel aids in protection of the root by preventing desiccation. In some plants the mucigel contains inhibitors that prevent the growth of roots from competing plants. Mucigel also lubricates the root so that it can easily penetrate the soil. Mucigel also aids in water and nutrient absorption by increasing soil:root contact. Mucigel can act as a chelator, freeing up ions to be absorbed by the root. Nutrients in mucigel can aid in the establishment of mycorrhizae and symbiotic bacteria.
3. **Quiescent Center:** behind the root cap is the quiescent center, a region of inactive cells. They function to replace the meristematic cells of the rootcap meristem. The quiescent center is also important in organizing the patterns of primary growth in the root.
4. **Subapical Region:** this region, behind the quiescent center is divided into three zones. Zone of Cell Division - this is the location of the apical meristem (~0.5 -1.5

mm behind the root tip). Cells derived from the apical meristem add to the primary growth of the root. Zone of Cellular Elongation - the cells derived from the apical meristem increase in length in this region. Elongation occurs through water uptake into the vacuoles. This elongation process shoves the root tip into the soil. Zone of Cellular Maturation - the cells begin differentiation. In this region one finds root hairs which function to increase water and nutrient absorption. In this region the xylem cells are the first of the vascular tissues to differentiate.



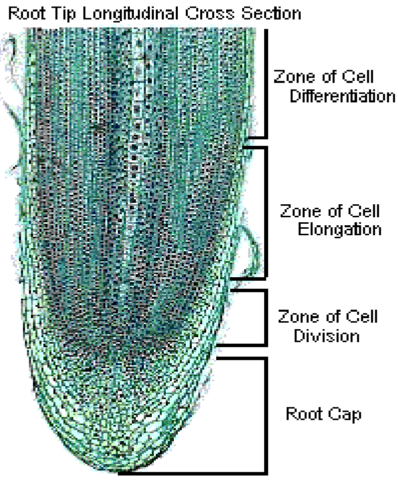


Figure 2.5 Root Cap **Figure 2.6 Root tip longitudinal cross section**

5. **Mature Root:** the primary tissues of the root begin to form within or just behind the Zone of Cellular Maturation in the root tip. The root apical meristem gives rise to three primary meristems: protoderm, ground meristem, and procambium.
6. **Epidermis:** the epidermis is derived from the protoderm and surrounds the young root one cell layer thick. Epidermal cells are not covered by cuticle so that they can absorb water and mineral nutrients. As roots mature the epidermis is replaced by the periderm.
7. **Cortex:** interior to the epidermis is the cortex which is derived from the ground

meristem. The cortex is divided into three layers: the hypodermis, storage parenchyma cells, and the endodermis. The hypodermis is the suberinized protective layer of cells just below the epidermis. The suberin in these cells aids in water retention. Storage parenchyma cells are thin-walled and often store starch. The endodermis is the innermost layer of the cortex. Endodermal cells are closely packed and lack intercellular spaces. Their radial and transverse walls are impregnated with lignin an suberin to form the structure called the Casparian Strip. The Casparian Strip forces water and dissolved nutrients to pass through the symplast (living portion of the cell), thus allowing the cell membrane to control absorption by the root.

8. **Stele:** all tissues inside the endodermis compose the stele. The stele includes the outer most layer, pericycle, and the vascular tissues.

   The pericycle is a meristematic layer important in production of branch roots. The vascular tissues are made up of the xylem and phloem. In dicots the xylem is found as a star shape in the center of the root with the phloem located between the arms of the xylem star. New xylem and phloem is added by the vascular cambium located between the xylem and phloem. In monocots the xylem and phloem form in a ring with s the central portion of the root made up of a parenchymatous pith.

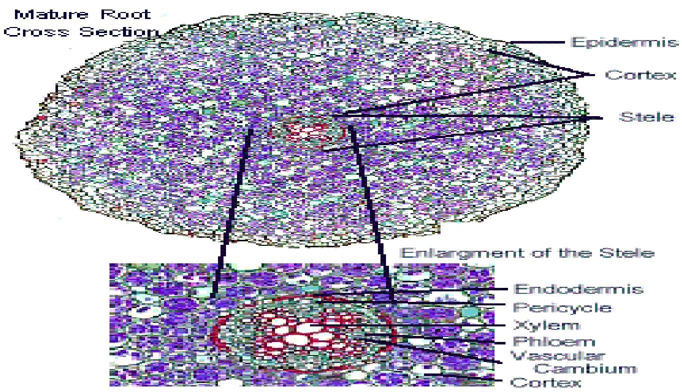


Figure 2.7 Mature root cross section

2.5 Root-shoot relationship:-

The shoot fixes $C0_2$ from the air, and the root extracts mineral nutrients and water from the soil. In this sense, there is a balance of shoot and root functions in a plant. After defoliation or root pruning, the plant acts so as to restore the balance of root and shoot functions.

Source-Sink Relations:-

Growth of non-photosynthesizing organs (sinks) is controlled by transport of sugars from photosynthesizing organs (sources) via the phloem. Sugars (mainly sucrose) are released from cells into the leaf apoplast (outside of the cell membranes) and move towards the conducting system (veins). Sucrose is actively loaded into phloem tissue and flows to sink sites under a pressure gradient. At the sink site, sucrose is unloaded from the phloem and used in growth processes or stored. During vegetative growth photosynthesis is often sink limited, while in the reproductive stages source-limitation usually becomes more important.

Phytohormones: - Phytohormones play an important role in plant growth, source-sink relations and root-shoot relationships. The production and action of these substances is strongly influenced by environmental factors such as water stress and nitrogen deficiency.

There is a characteristic shoot: root ratio for each species at each growth stage. Shoot: root ratios tend to increase with plant size (decrease for root crops), reflecting increasingly preferential assimilate partitioning above ground (below ground for root crops). Thus, shoot: root ratio comparisons should be made at equal dry weight, or at equal plant developmental stage, not at equal time.

Shoot: root ratios are influenced by changes in environmental conditions, such as light, nutrient availability, temperature and water supply. These changes usually reflect an adaptive advantage for the plant in acquiring the limiting resource.

2.6 Principles of inter and mixed cropping systems under rain fed condition:-

Principles of inter cropping under Rain fed condition:-

1. Modifying existing planting pattern and change it to double rows.
2. Identifying the best genotypes of the component crops from intercropping point of view.
3. Use less competitive and more compatible crops in respect of soil and water conservation.
4. Proper adjustment of time of sowing or planting considering residual moisture, canopy cover, water requirement and moisture supply.
5. Plant population of all the crops should be fixed considering the spacing required by the individual crops on high- density status.

6. Application of adequate nutrients is essential as per requirement of all the crops.
7. Weed control should be done manually and should be properly done at initial stages.
8. Integrated pest management should be followed to control pest and diseases.

Principles of mixed cropping under Rain fed condition:-

1. The leguminous crop should be mixed with non leguminous crops because legumes fix atmospheric N into the soil and add more organic matter to the soil; e.g. Gram + Wheat, pigeon pea + Pearl millet.
2. The more water requirement crop should be mixed with less water requirement crop; e.g. Wheat + Gram.
3. The more heighted crop should be mixed with surface spreading crops because gate proper space for both of crops; e.g. Sorghum + Green gram, Pigeon pea + Ground nut.
4. The same type diseases infected crops should not be mixed.
5. The same type insect and pest infected crops should not be mixed; e.g. Radish, cauliflower, Brinjal, Chillies, Tomato should not mixed with each other.
6. The fertilizer and manure requirement of mixed crop should be same.

<u>2.7 Principles of inter and mixed cropping systems under irrigated condition:-</u>

1. The time of peak nutrient demands of component crops should not overlap.
2. Competition for light should be minimum among the component crops.
3. Complimentarily should exist between the component crops.
4. The differences in maturity of component crops should be at least 30 days.
5. Competition for CO_2 and water should also be minimum among component crops.

<u>2.8 Concept and differentiation of inter and mixed cropping:-</u>

Intercropping: - It refers to growing of two or more crops simultaneously, on the same piece of land, base crop necessary in distinct row arrangement Crop intensification is in both time and space dimensions. There is intercrop competition during all or parts of crop growth.

Mixed cropping: - Cultivation of two or more than two crops, simultaneously on the same land without definite row pattern or fixed ratio. Sowing of seeds in generally by broadcasting method commonly practiced in dry land area of India. Scientific study of mixed cropping was firstly done by La-Flitze (1928).

Differences between intercropping and mixed cropping:

Intercropping	Mixed cropping
1. It refers to growing of two or more crops simultaneously, on the same piece of land, base crop necessary in distinct row arrangement.	1. It refers to cultivation of two or more than two crops, simultaneously on the same land without definite row pattern or fixed ratio.
2. Sowing of seeds in generally by drilling method	2. Sowing of seeds in generally by broadcasting method
3. The main objective is to utilize the space left between two rows of main crop especially during early growth period of main crop.	3. Main objective is to get at least one crop under any climatic hazards (flood, drought or frost) conditions.
4. More emphasis is given to the main crop and subsidiary crops are not grown at the cost of main crop thus there is no competition between main and subsidiary crop.	4. All crops are given equal care and there is no main or subsidiary crop. Almost all the crops compete with one another.
5. Subsidiary crops are of short duration and they are harvested much earlier than main crop.	5. The crops are almost of same duration.
6. Both the crops are sown in rows. The sowing time may be the same or the main crop is sown earlier than subsidiary crop.	6. Crops may be broad casted and sowing time for all the crops is the same

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