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# Water Deficit and Crop Growth

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## Water deficit

- Every plant has requirement of some physical factors, like light, temperature, air, water, etc. and for some chemical factors, for example, inorganic nutrients, organic molecules etc. In optimum amount and in available form at a right time as its nutritional requirements for its proper growth and development.
- Any deviation from this optimal condition of any factor essential for its growth will lead to aberrant change in physiological processes and due to this, plant body will experience tension and this state can be referred as plant under stress.
- Water stress is due to a low water potential in the plant as a result of low soil water potential, high evaporative demand and/or a substantial resistance to water flow through the plant. The water deficit affects many processes in the crop, although most of the effects are related to the reduction in growth, the most sensitive process, and to stomata closure. Mild to moderate deficits do not affect harvest index, and in some species they may.
- Mild to moderate deficits do not affect harvest index, and in some species they may increase it. Instead severe water deficits reduce the HI. The effect of water stress on crop yield can be quantified by Stewart's equation which establishes that the relative reduction in yield is directly proportional to the relative reduction in ET, with an empirical coefficient ($K_y$) which ranges between 0.8 and 1.5.
- Traditionally, 'plant water deficit' or 'plant water stress' has been defined as being when plant water status is reduced sufficiently to affect normal plant functioning (e.g., plant growth, stomata conductance, rate of photosynthesis).
- Generally, plant water deficits can be considered as being induced by either insufficient available soil water, or a high atmospheric evaporative demand. Plant

water deficits induced by lack of soil water may continue for days, possibly weeks, until they are either alleviated by rain or irrigation or the plant dies.

**I. Plant water deficits occur when any plant process is affected by:**

- Limited water absorption by roots because of dry, cool, or poorly aerated soil;
- High evaporative demand, on account of low relative humidity, high air temperature, high wind speed, high radiation, or combinations of the four;
- A combination of limited water absorption and high evaporative demand.

**II. Plants response to water stress :**

- **Decreased leaf area** :-
  - ➢ As the water content of the plant decreases, its cells shrink and the cell wall relax which results in lower turgor pressure.
  - ➢ The plasma membrane becomes thicker and more compressed because it covers a smaller area than before.
- **Leaf abscission**
  - ➢ Desert plants drop all their leaves during a drought and sprout new ones after a rain.
  - ➢ This cycle can occur two or more times in a single season.
- **Root extension into deeper, moist soil :-**
  - ➢ Mild water deficits also affect the development of the root system.
  - ➢ Root elongation occurs due to water stress to fulfill the requirement of water to plant.
- **Stomata close during water deficit in response to Abscisicacid** :-
  - ➢ Uptake and loss of water in guard cells changes their turgor and modulates stomatal opening and closing.
  - ➢ Because guard cells are located in the leaf epidermis , they can lose turgor as a result of a direct loss of water by evaporation to the atmosphere.
  - ➢ The decrease in turgor causes stomatal closure.
  - ➢ ABA is synthesized at a higher rate and more ABA accumulates in the leaf apoplast.
- **Wax deposition on the leaf surface** :-

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- A common development response to water stress is the production of a thicker cuticle that reduces water loss from the epidermis.
- Osmotic adjustment is a net increase in solute content per cell that is independent of the volume changes that result from loss of water.

- **Osmotic stress changes gene expression:-**
  - The accumulation of compatible solutes in response to osmotic stress requires the activation of the metabolic pathway that biosynthesize these solutes.

**III. Resistant or sensitivity of plants to stress depend on :-**

- The species of plant
- The genotype
- Development age

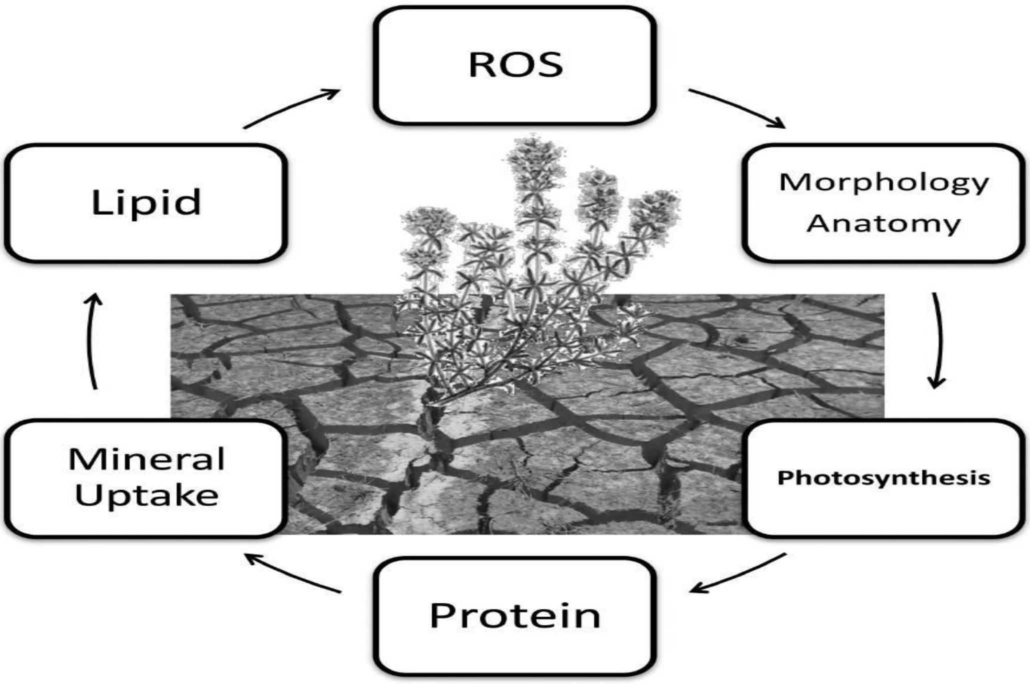


**Fig.1.** Effects of drought stress on plants. Reducing available water in the plant environment, declines water content, water potential and turgor pressure. This condition affects lipids, proteins, photosynthesis, mineral uptake, morphology and anatomy and reactive oxygen species (ROS) (Moradi, P., 2016) .

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**Mechanisms of Water Deficit :**

- Plants are always exposed to fluctuation of environmental factors. Water stress is one of the main abiotic factors limiting plant growth and development on most areas of the world. Declining available water triggers various adaptive processes to cope with water deficit stress.
- Plants and how they react to water deficit can be summarised in three ways i.e. escaping drought, dehydration tolerance/avoidance and desiccation tolerance.
- Escaping the drought is shortening the life cycle mainly in reproductive phase and desiccation tolerance can be performed in both reproductive and vegetative phases of some specific plants.
- Avoidance mechanisms are employed to maintain the balance between water uptake and water loss, while tolerance mechanisms are trying to keep the plant functions the same level as unstressed level.
- Major molecular mechanisms attributed as tolerance strategies include osmotic adjustment, Reactive Oxygen Species (ROS) scavenging, cellular components protection membrane lipid changes and hormone inductions.
- In some cases, drought resistance is described as the adaptation of plant involving drought avoidance, drought tolerance, drought escape and drought recovery ( Fang and Xiong, 2015). Since, drought tolerance is characterized by the capability of plants to grow satisfactorily under water deficit condition (Turner, 1979).

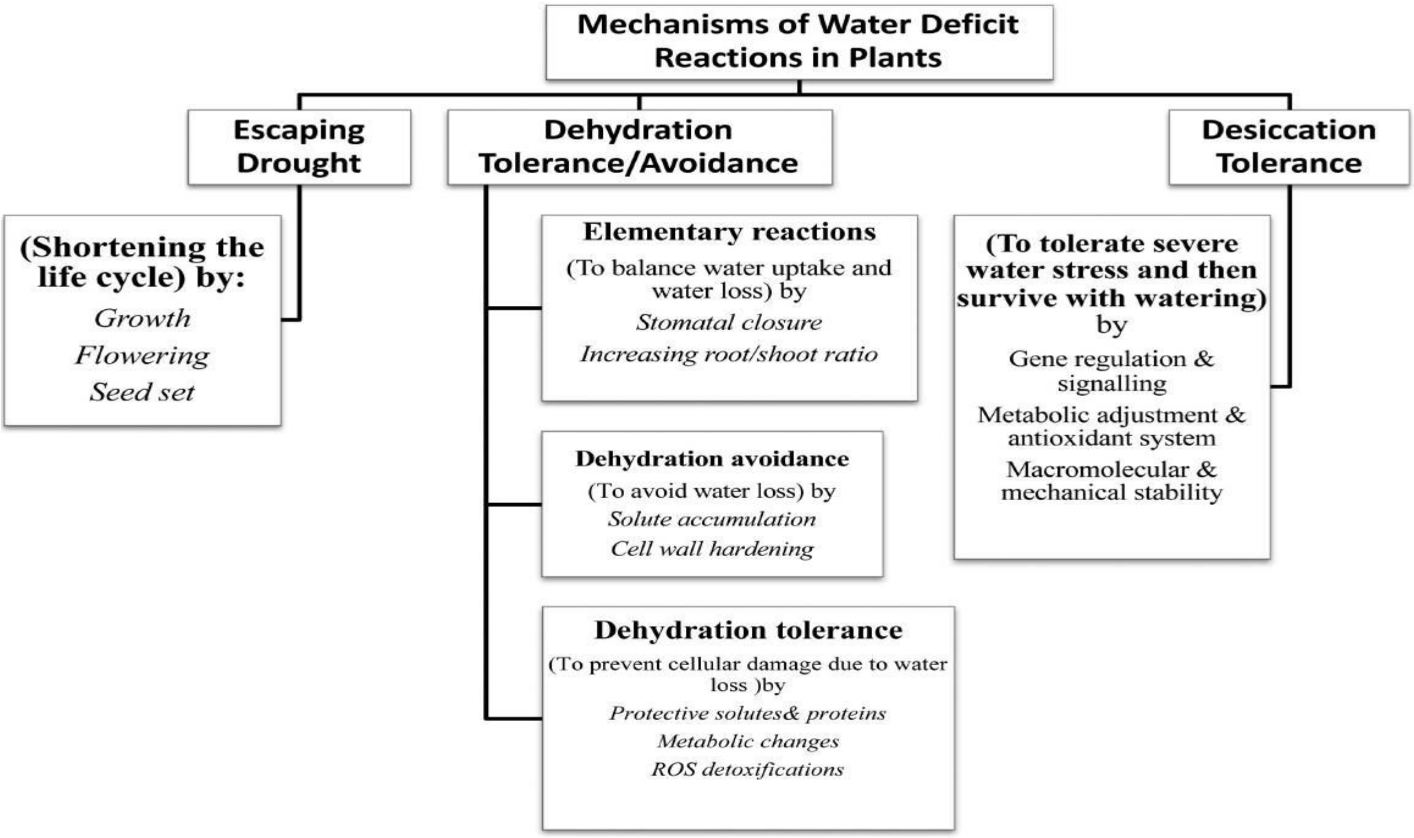


**Fig. 2.** Main mechanisms of plant reactions to water deficit. Possible processes of each mechanism have been indicated in the boxes (Moradi, P., 2016).

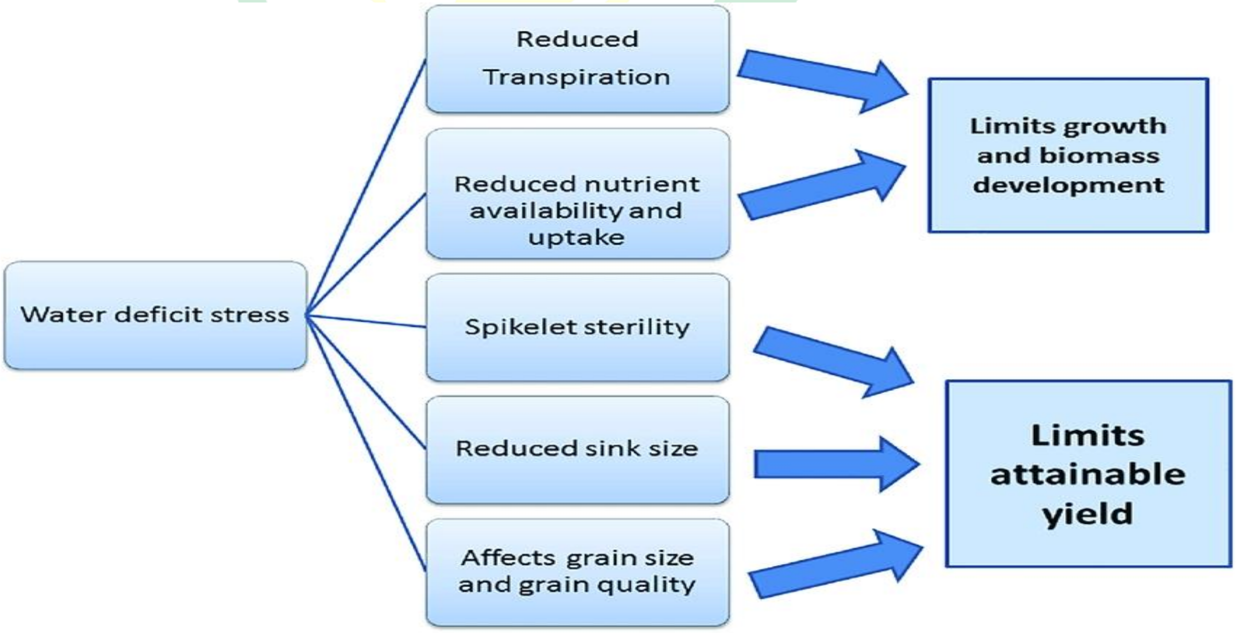


**Fig. 3.** Diagrammatic description of effect of water deficit stress on rice plant(Kumar, A. et al, 2019).

## Crop Growth

- Growth is defined as an irreversible increase in size and volume of plant accompanied by increase in dry weight.Growth is primarily associated with capture and allocation of resources.
- Crop growth depends on the capacity of the canopy to capture $CO_2$ and radiation, the capacity of the root system to capture water and nutrients from soil, and the efficiency of the crop to transform resources (water, nutrients, radiation, carbon dioxide) into dry matter. Stresses such as water deficits or soil compaction reduce growth by reducing the amount of resources captured by the crop, by reducing the efficiency in the use of resources or both.

## Types of Growth:

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

b. **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.
- ✓ **Fresh weight measurement:** Weight of freshly harvested plant is taken as fresh weight.
- ✓ **Dry weight measurement:** Plant material is dried at $80^0$ Ctemperature for about two or three days till constant weight.

- ✓ **Leaf area measurement:** Measurement of leaf area is also taken as an index of growth.
- ✓ **Volume measurement:** Volume of plant part or plant can be measured by water displacement method .

**Growth Analysis:**

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

**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.

$$CGR = \frac{W_2 - W_1}{\ldots\ldots\ldots\ldots\ldots}$$

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$^{-1}$**

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 $t_2$.

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

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, $t_2$ =second sampling.

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

**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.

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

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 $m^{-2}$ $day^{-1}$**

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.

**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.

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

Where, LA= Leaf area, GA=Ground area

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 maximum 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.

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

**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.

7. **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.

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

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

**Growth curves:**

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- Growth curve is a graph obtained by plotting the growth rate of a plant against time factor. The growth rate of a cell, a plant organ, a whole plant or the whole life cycle of plant is measured in terms of length, size, area, volume or weight. It has been found that different growth phases result in 'S' shaped curve or sigmoid curve.
- In initial stages during the phase of cell formation, the growth rate increases slowly while it increases rapidly during the phase of cell elongation or cell enlargement and again slows down during the phase of cell maturation.

1. **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.
   - 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.

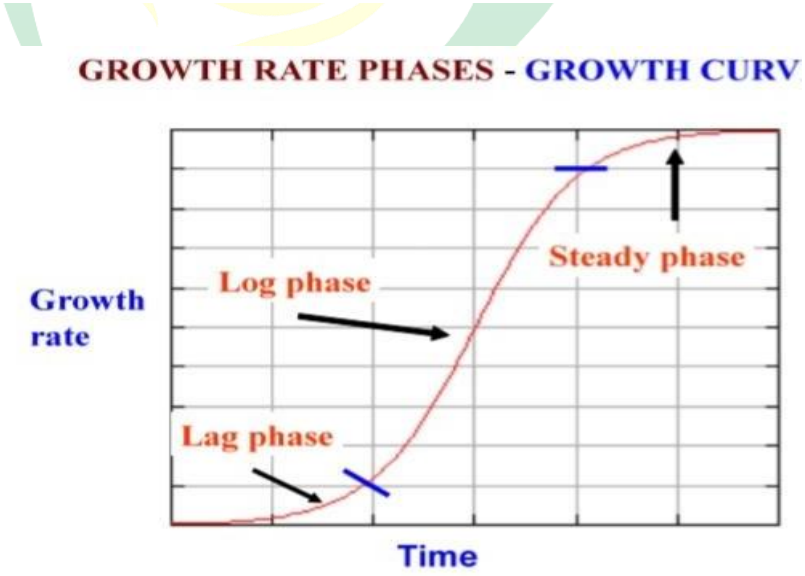



**Fig. 4.** Phases of growth –A typical sigmoid growth curve

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 5). The curve could be fitted by a quadratic equation.

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

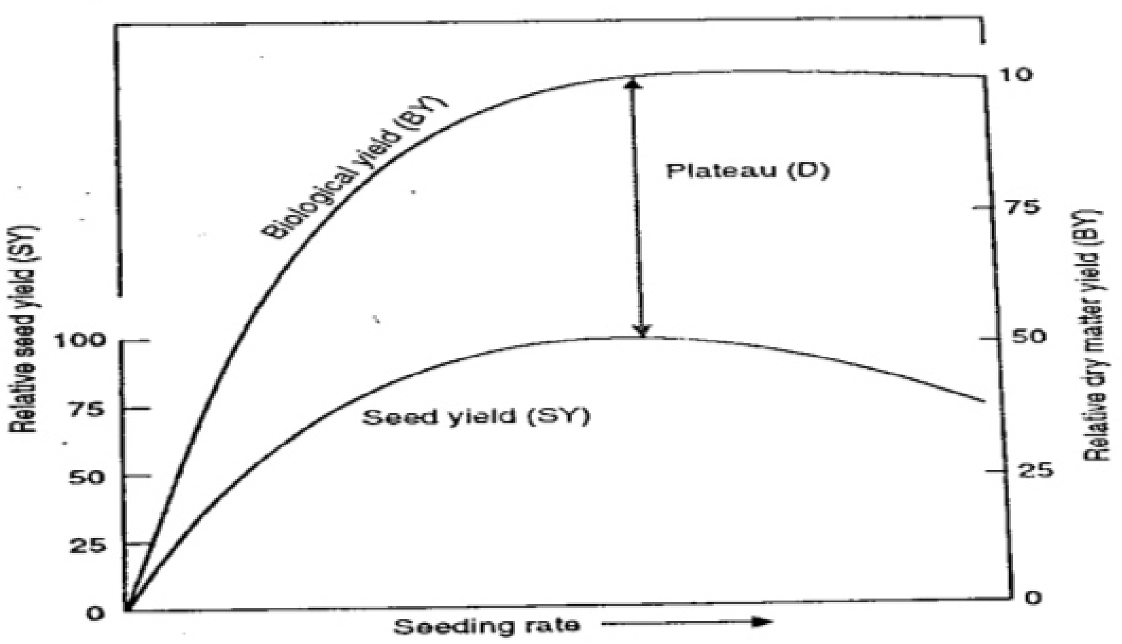
Where,

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 5).

**Fig.5.**Parabolic and asymptotic relation between plant population and yield

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.

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

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 ameasure of the area available per plant and that the environment resources are available to the plant on an area basis (Holliday 1960).

**Conclusion**

Tolerant plants accumulate or maintain high levels of particular metabolites to cope with unfavourable conditions. Reviewed compounds could be used as biochemical indicators in breeding programs to improve drought stress tolerance.Proper growth and development of crop plants is important for establishment of normal plant structure that carry out all physiological and metabolic processes and give potential yield.

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