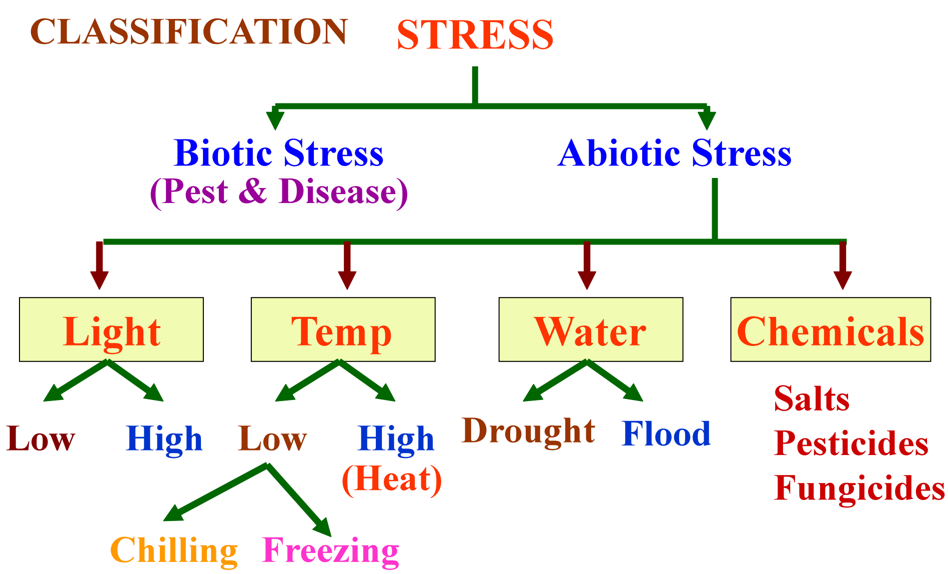
22. ENVIRONMENTAL STRESSES

The occurrence of unfavorable environmental factors such as moisture deficit / excess, high radiation, low and high temperature, salinity of water and soil, nutrient deficiency or toxicity and pollution of atmosphere, soil and water are likely to affect the crop growth in terms of morphology (plant size, architecture, malformation of plant organs, growth (height, volume, weight), physiological and metabolic processes and yield of crop plants.

Stress and strain

Any environmental factor potentially unfavorable to plant is termed as **stress**. The effect of stress on plant condition is called **strain**. According to Newton's law of motion, a force is always accompanied by a counterforce, for an action there is always equal and opposite reaction. Stress is the action and whereas strain is the reaction.



I. DROUGHT (Water stress)

Drought is defined as the deficiency of water severe enough to check the plant growth. Drought has been classified into two broad categories viz., soil drought and atmospheric drought. Soil drought leads to atmospheric drought. Atmospheric drought occurs due to low atmospheric humidity, high wind velocity and high temperature which cause a plant to lose most of its water.

Physiological changes occur due to drought

1. Functioning of stomata

In general, stomata lose their function and may die, because wilting after certain limit denatures the starch in the guard cells and also in the mesophyll cells.

2. Carbohydrates metabolism in green leaves

The very first effect of drought on carbohydrates metabolism is that starch disappears from the wilted leaves and sugar accumulates simultaneously.

3. Photosynthetic activity

CO_2 diffusion into the leaf is prevented due to decrease in stomatal opening and there by reduces photosynthetic activity in green cells.

4. Osmotic pressure

The reduced amount of water during drought causes an increase in the osmotic pressure of plant cell. This increase in osmotic pressure permits the plant to utilize better soil moisture.

5. Permeability

The permeability to water and urea increases during drought.

6. Biochemical effects

Water shortage alters the chemical composition. For example, starch is converted to sugar, besides this, there is a considerable increase in nitrate nitrogen and protein synthesis is adversely affected.

Adaptation to drought

Drought resistance

Drought resistance is defined as the capacity of plants to survive during the period of drought with little or no injury. There are three important categories of plants growing in the areas facing drought. They are ephemerals, succulents and non-succulent perennials

1. Ephemerals

These are short lived plants and they complete their life cycle within a short favourable period during rainy season. They pass dry periods in the form of seeds. They are called as *drought escaping plants*.

2. Succulent plants

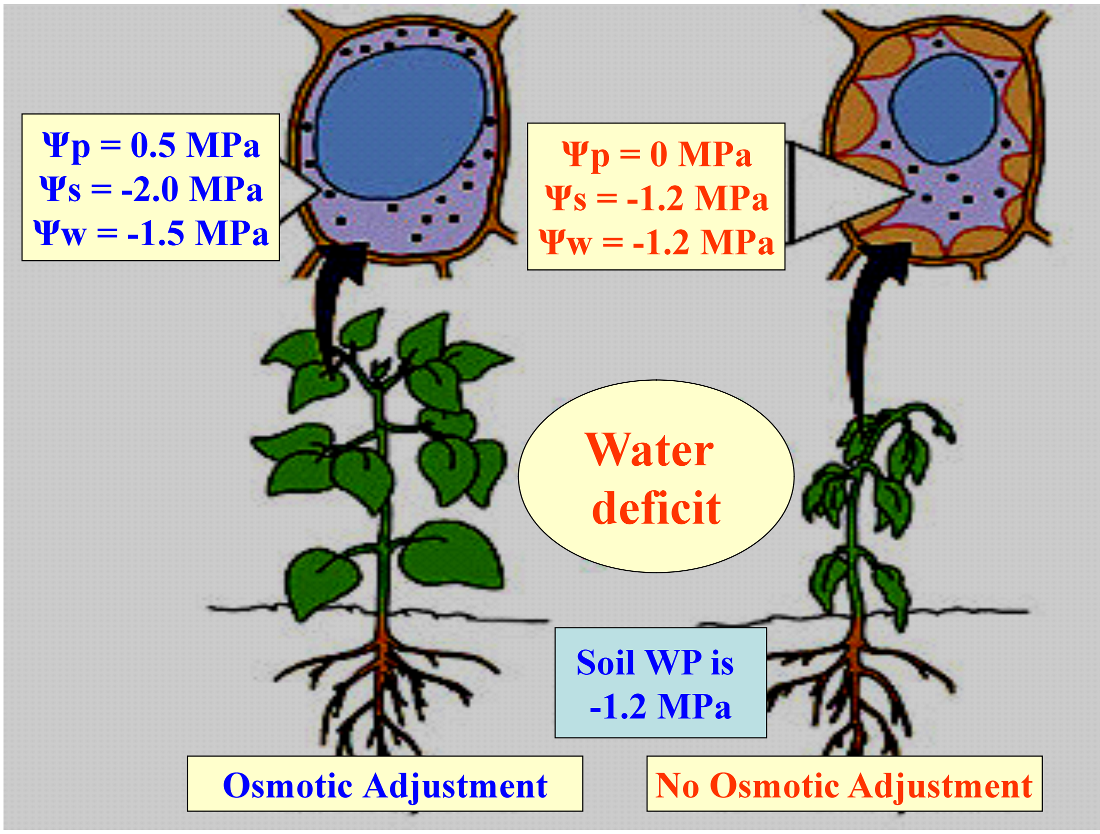
These plants accumulate large quantities of water and use it slowly during dry period. Thus, they pass dry periods or drought without facing it. Such plants develop several morphological adaptations for reducing transpiration such as thick cuticle, reduced leaf area, sunken stomata etc.

3. Non succulent plants

These plants are in fact the real drought enduring (tolerant) plants. They tolerate drought without adapting any mechanism to ensure continuous supply of water. They develop many morphological adaptations which are collectively called *xeromorphy.* They develop, in general, greyish colour, reflecting surfaces, smaller leaves, extensive root system, leaf fall during dry season, sunken stomata and thick cuticle etc. They develop an elaborated conducting system. The stomata remain closed mostly in dry periods.

The plants develop several protoplasmic peculiarities such as cell size, cell structure, increased permeability, increased imbibition power, elasticity, small vacuoles, higher osmotic pressure etc.

Osmotic adjustment



Methods to overcome drought

- Selection of drought tolerant species
- Adjusting the tome of sowing in such a way that the crop completes its lifecycle before the onset of drought
- Seed hardening with KCl, KH_2PO_4, $CaCl_2$ or Thiourea
- Thinning of poorly established plants
- Mulching to minimize the evaporative loss
- Foliar spray of antitranspirants such as Kaolin, PMA, Waxes and Silicone oils
- Foliar spray of KCl
- Foliar spray of growth retardants such as CCC and MC

HIGH MOISTURE STRESS - FLOODING / WATER LOGGING

Water logging refers to a condition when water is present in excess amount than its optimum requirement. It creates an anaerobic situation in the rhizosphere due to which the plant experiences the stress (O_2 deficient stress).

Nature of Water logging Stress

In the water logged soils, water gets filled in the pores of the soil which are previously occupied by O_2. Such soils suffer O_2 deficiency.

This O_2 deficiency depresses growth and survival of plants growing in it.

Flood sensitive plants (eg. Tomato, soybean and sunflower) are killed in the water logged conditions, while the tolerant species (eg. Rice) withstand water logging for a considerable time. However, continuous submergence of rice for more than 10 days is also deleterious resulting in death and decay of the plants.

Plant Water Relations in Flooding Stress

The flooding often induces stomatal closure mostly in C_3 plants. This causes lower water flow in these plants. This also results in leaf dehydration because of reduced root permeability. Ultimately, wilting of leaves occurs due top the restricted water flow from the roots to the shoots.

Occurrence of these changes in leaves, shoots or roots is due to the transfer of toxic substances (acetaldehyde / alcohol) produced under anaerobic conditions in the roots as well as the levels of PGRs transported from the roots to shoots via transpiration stream.

Levels of Endogenous PGRs under Flooding Stress

Endogenous levels of PGRs such as GA and cytokinins (CK) are reduced in the roots. This has enhanced levels of ABA and ethylene in the shoots causing stomatal closure and early onset of senescence respectively.

It is also reported that levels of auxins are reduced and that of Aminocyclopropane -1-Carboxylic Acid (ACC), precursor for the ethylene biosynthesis are increased under flooding stress.

Important roles played by these endogenous PGRs during high moisture (flooding) stress are summarized in the following table.

Effect of flooding stress on the endogenous levels of PGRs and their effect on plants

Sl. No.	Level of PGR in plants	Effects on plants under water logging
01.	Reduced Auxins	Causes “Hypertrophy” (Swelling of stem base by collapse or enlargement of cells in cortex)
02.	Decreased GA	Causes reduction in cell enlargement and stem elongation
03.	Decreased CK	Results in early on-set of senescence and reduced rate of assimilate partitioning to the sinks
04.	Increased ABA	Cause stomatal closure with consequential decrease in the rate of gas exchanges during photosynthesis, respiration and transpiration; results in efflux of K+ from the guard cells; decreases ion transport due to lower rate of transpiration; decrease the starch formation in the guard cells resulting in stomatal closure
05.	Increased Ethylene	Causes “Epinasty” of leaves (uneven growth of leaves due to more cell elongation on upper side than the lower side of the leaf); induces senescence and Hypertrophy in plants.

Thus, the O_2 stress in the roots under flooding produces signals, via transpiration stream, to the leaves affecting stomatal behaviour ultimately.

Mitigation of High Moisture (Water logging) Stress

1. Providing adequate drainage for draining excessive stagnating water around the root system.
2. Spray of growth retardant of 500 ppm cycocel for arresting apical dominance and thereby promoting growth of laterals
3. Foliar spray of 2% DAP + 1% KCl (MOP)
4. Nipping terminal buds for arresting apical dominance and thus promoting growth sympodial branches (as in cotton) for increasing productivity
5. Spray of 40 ppm NAA for controlling excessive pre-mature fall of flowering/buds/young developing fruits and pods
6. Spray of 0.5 ppm brassinolide for increasing photosynthetic activity

7. Foliar spray of 100 ppm salicylic acid for increasing stem reserve utilization under high moisture stress
8. Foliar spray of 0.3 % Boric acid + 0.5 % $ZnSO_4$ + 0.5 % $FeSO_4$ + 1.0 % urea during critical stages of the stress.

SALT STRESS

Salt stress occurs due to excess salt accumulation in the soil. As a result, water potential of soil solution decreases and therefore exosmosis occurs. This leads to physiological drought causing wilting of plants.

Classification of saline soil: 1. Saline soil 2. Alkaline soil

1. Saline soil

In saline soils, the electrical conductivity is greater than 4 dS/m, exchangeable sodium percentage is less than 15% and pH is less than 8.5. These soils are dominated by Cl^- and SO^{2-}_4 ions.

2. Alkaline soil

Alkaline soils are also termed as sodic soils wherein, the electrical conductivity is less than 4 dS/m, exchangeable sodium percentage is greater than 15% and pH of the soil is greater than 8.5. These soils are dominated by CO^-_3 and HCO^-_3 ions.

Classification of plants

Plants are classified into two types based on the tolerance to salt stress. They are halophytes and glycophytes.

1. Halophytes

Halophytes are the plants that grow under high salt concentrations. They are again divided into two types based on extreme of tolerance.

Euhalophytes: can tolerate extreme salt stress

*Oligohalophyte*s: can tolerate moderate salt stress

2. Glycophytes

Glycophytes are the plants that cannot grow under high salt concentration.

Effect of salt stress on plant growth and yield

1. Seed germination

Salt stress delays seed germination due to the reduced activity of the enzyme, α-amylase

2. Seedling growth

The early seedling growth is more sensitive. There is a significant reduction in root emergence, root growth and root length.

3. Vegetative growth

When plants attain vegetative stage, salt injury is more severe only at high temperature and low humidity. Because under these conditions, the transpiration rate will be very high as a result uptake of salt is also high.

4. Reproductive stage

Salinity affects panicle initiation, spikelet formation, fertilization and pollen grain germination.

5. Photosynthesis

Salinity drastically declines photosynthetic process. Thylakoid are damaged by high concentration of salt and chlorophyll *b* content is drastically reduced.

Mechanism of salt tolerance

1. Some plants are able to maintain high water potential by reducing the transpiration rate.
2. Salts are accumulated in stem and older leaves in which metabolic processes take place in a slower rate.
3. Na^+ (sodium ion) toxicity is avoided by accumulating high amount of K^+ ions.
4. Accumulation of toxic ions in the vacuole but not in the cytoplasm.
5. Accumulation of proline and abscissic acid which are associated with tolerance of the plants to salt.

Relative salt tolerant crops

Tolerant crops: Cotton, sugar cane, barley

Semi tolerant crops: Rice, maize, wheat, oats, sunflower, soybean

Sensitive crops: Cow pea, beans, groundnut and grams

Mitigation of Salt Stress

1. Seed hardening with NaCl (10 mM concentration)
2. Application of gypsum @ 50% Gypsum Requirement (GR)
3. Incorporation of daincha (6.25 t/ha) in soil before planting
4. Foliar spray of 0.5 ppm brassinolode for increasing photosynthetic activity
5. Foliar spray of 2% DAP + 1% KCl (MOP) during critical stages
6. Spray of 100 ppm salicylic acid
7. Spray of 40 ppm of NAA for arresting pre-mature fall of flowers / buds / fruits
8. Extra dose of nitrogen (25%) in excess of the recommended
9. Split application of N and K fertilizers
10. Seed treatment + soil application + foliar spray of Pink Pigmented Facultative Methnaotrops (PPFM) @ 10^6 as a source of cytokinins.

TEMPERATURE STRESS

Temperature stress includes both high temperature stress and low temperature stress. Low temperature stress causes chilling injury and freezing injury.

Low temperature stress

1. Chilling injury

The tropical origin plants are injured when the temperature drops to some point close to 0°C. The injury which occurs due to low temperature but above zero degree centigrade is called chilling injury.

2. Freezing injury

Freezing injury occurs when the temperature is 0°C or below.

Effect of freezing and chilling injury plants

- The lipid molecules in cell membrane get solidified i.e. changed from liquid state to solid state. Hence, the semi-permeable nature of the membrane is changed and the membrane becomes leaky.
- Inactivation of mitochondria
- Streaming of protoplasm is stopped
- Accumulation of respiratory metabolites which become highly toxic
- Ice formation inside the cell occurs.

Prevention of cold injury

- Some plants change the pattern of growth.
- The growth is completely arrested during this period.
- In cell membrane, unsaturated fatty acid content is increased.
- Intracellular ice formation is reduced.
- The quantity of free enzymes, sugars and proteins increases.

High temperature stress

The effect of high temperature is heat Injury. Heat Injury occurs when plant temperature is higher than that of environment (exceeds 35°C).

General effects of high temperature

High temperature affects

1. Seedling growth and vigour
2. Water and nutrient uptake
3. Solute transport
4. Photosynthesis and respiration
5. General metabolic processes
6. Fertilization and maturation

Cellular Changes during heat stress

When plants are exposed to temperatures higher than 45^0C it experiences heat stress. The cellular changes due to heat stress are

1. Disruption of cytoskeleton and microtubules.
2. Fragmentation of golgi complex
3. Increase in number of lysosomes
4. Swelling of mitochondria thereby resulting in decreased respiration and oxidative phosphorylation
5. Disruption of normal protein synthesis
6. Disappearance of polysomes
7. Disruption of splicing of mRNA precursors
8. Cessation of pre-RNA processing
9. Decline in transcription by RNA polymerase I

10. Inhibition of chromatin assembly
11. Decline in DNA synthesis

Acclimation to high temperature

Morphological Adaptations

- Reflective leaf hair
- Leaf waxes
- Leaf orientation
- Maximize conductive or convective loss of heat

Xanthophyll deepoxidase

Violaxanthin ⟶ Zeaxanthin

Zeaxanthin decreases membrane fluidity and stabilises the membrane

Heat Shock Proteins (HSPs)

Plants have the capacity to interact with the environment in many different ways and to survive under extreme abiotic and perhaps also biotic stress conditions. The response to heat stress (hs) is highly conserved in organisms but owing to the sessile life style it is of utmost importance to plants. The hs-response is characterised by (i) a transient alteration of gene expression (synthesis of heat shock proteins: HSP) and (ii) by the acquisition of a higher level of stress tolerance (acclimation). The induction of HSP-expression is not restricted to high temperature stress, HSPs are also linked to a number of other abiotic stresses including cold, freezing, drought, dehydration, heavy metal, and oxidative stresses. HSP are molecular chaperones, which either prevent complete denaturation (small HSP: sHSP) or are supporting proper folding (other HSP) of enzymes under or after protein denaturing conditions. Manipulation of the hs-response has the potential to improve common stress tolerance that may lead to a more efficient exploitation of the inherent genetic potential of agriculturally important plants.

HSPs are classified into different families and designated by molecular weight in kDa.

- HSP 100 k Da

- HSP 90
- HSP 70
- HSP 60
- 15 – 30 kDa low molecular mass HSPs or Small HSPs.

Functions

- HSPs 60, 70 and 90 : act as molecular chaperons, involving ATP dependent stabilization and folding of proteins and assembly of oligomeric proteins.
- Some HSPs : assist in polypeptide transport across membranes into cellular compartments.
- Some HSPS : temporarily bind and stabilize an enzyme at a particular stage in cell development, later releasing the enzyme to become active.
- Binding of HSP with particular polypeptide within subcellular compartment avoid denaturation of many proteins at high temperatures.

Mitigation of Low Temperature Stress

1. Seed hardening with 0.01% Ammonium molybdate and foliar spray of 0.1 % ammonium molybdate at critical stages of stress
2. Foliar spray of 2% calcium nitrate spray for membrane integrity
3. Foliar spray of 2% DAP + 1% KCl (MOP)
4. Foliar spray of 500 ppm cycocel for increasing root penetration in search of moisture for alleviation
5. Spray of 100 ppm salicylic acid
6. Brassinolide (0.5 ppm) for enhancing photosynthetic activity of plants
7. Seed treatment + soil application + foliar spray of Pink Pigmented Facultative Methnaotrops (PPFM) @ 10^6 as a source of cytokinins.

Mitigation of High Temperature Stress

1. Seed hardening with 0.5% $CaCl_2$ solution for arresting membrane damage due to high temperature stress
2. Split application of N and K fertilizers

3. Foliar spray of 2% DAP + 1% KCl (MOP) (during the spray, sufficient moisture should be present in the soil for avoiding leaf scorching)
4. Folar spray of 3% Kaoline
5. Foliar spray of 0.5% zinc sulphate + 0.3 % boric acid + 0.5 % Ferrous sulphate + 1% urea
6. Spray of 40 ppm NAA for controlling pre-mature flower / fruit drops due to high temperature stress
7. Foliar spray of 1% Urea + 2 % $MgSO_4$ + 0.5 % $ZnSO_4$ (for arresting chlorophyll degradation due to high temperature stress)
8. Foliar spray of 2% calcium nitrate spray for membrane integrity
9. Foliar spray of 0.5 ppm Brassinolide for increasing photosynthetic activity during stress
10. Spray of 100 ppm salicylic acid for increase stem reserve utilization and increasing Harvest Index of crops under stress
11. Seed treatment + soil application + foliar spray of Pink Pigmented Facultative Methnaotrops (PPFM) @ 10^6 as a source of cytokinins.

Low light and UV radiation stresses

Low Light Stress

In some places (e.g. Thanjavur), the light intensity might be even up to 60000 lux in the first season but it would be low up to 30000 lux in the second season causing very poor productivity. Light quality is also very poor by showing about 400-440nm instead of the normal 600-640nm. The abnormal light intensity and quality causes reduced yield in any crops.

UV-RADIATION STRESS

UV radiation is divided into three categories

1. UV A – wavelength ranges from 320 to 400 nm and this is less lethal to the plants.
2. UV B – wavelength ranges from 280 to 320 nm and this is lethal to the plants.

3. UV C – wavelength is less than 280 nm and it is highly lethal to all biological systems.

The UV radiations cause environmental stress as the cell constituents like proteins and nucleic acids absorb UV radiation in the range of 250-400 nm (UV A and UV B) and cause death of the tissues. In general, on the outer atmosphere of the earth, CO_2, ozone and water vapour form a layer and this layer prevent the entry of UV radiation. However, ozone depletion causes easy entry of UV radiation. In general, 1% reduction in ozone (O_3) causes 2% increase in UV radiation.

UV radiation and plant response

1. UV radiation slows down the growth of plants
2. Damage the process of photosynthesis
3. Prevent maturation and ripening process
4. Accelerate genetic mutation.

Mitigation of Low Light Stress:

1. Foliar spray of 2% DAP + 1% KCl (MOP)
2. Spray of 2% coconut water
3. Spray of 40 ppm of NAA
4. 0.5 ppm Brassinolide spray
5. Spray of 100 ppm Salicylic acid
6. Spray of 500 ppm CC for arresting excessive vegetative growth
7. Split application of N and K fertilizers
8. Foliar spray of 0.3 % Boric acid + 0.5 % Zinc sulphate
9. Seed treatment + soil application + foliar spray of Pink Pigmented Facultative Methanotrophs (PPFM) @ 10^6 as a source of cytokinins.