Moisture Stress - Effect on Plants and Its Adaptation to Stress

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Introduction

Water, which makes up 80–90% of non-woody plant biomass, is the primary channel for the movement of nutrients and metabolites, making it the key molecule in all plant physiological activities. Drought is a condition that reduces turgor and water potential in plants to the point that they have trouble performing their regular physiological processes.

Water Stress – Why and How?

Water stress occurs in plants when the rate of transpiration increases or when the water supply to the roots becomes limited. The water deficiency is the main source of water stress. "Physiological drought" is the term used to describe the scenario when water is present in the soil solution but cannot be absorbed by plants due to excessive soil salinity, flooding, and low soil temperature. Although the degree of tolerance varies from species to species, all plants can withstand water stress.

Effect Of Water Stress on Crop Production

Water Relations

Water relations refer to the movement and distribution of water within plant cells and tissues. Under water stress conditions:

Water Potential

Turgor pressure in plant cells drops as a result of a decrease in water potential. Turgor pressure is necessary for the growth and expansion of cells.

- **Osmotic Adjustment**: Plants may accumulate osmolytes like proline, glycine betaine, and sugars to maintain cell turgor and osmotic balance.
- **Hydraulic Conductivity**: Water stress can hinder the uptake of water from the soil and its movement to the leaves by decreasing the hydraulic conductivity of roots. affects transpiration, translocation, and absorption, changing the water status. Turgor is lost as a result of the increase in air dryness caused by the absorption lag behind transpiration.

Photosynthesis

Photosynthesis is the process by which plants convert light energy into chemical energy. Water stress affects photosynthesis by:

- **Stomatal Closure**: To conserve water, plants close their stomata, reducing CO_2 uptake, which is crucial for the photosynthetic process.
- **Photosynthetic Apparatus Damage**: Drought conditions can lead to oxidative stress, damaging chlorophyll and photosynthetic proteins.
- **Reduction in Photosynthetic Rate**: Lower photosynthetic efficiency and the synthesis of carbohydrates are the outcomes of both decreased CO_2 input and damaged photosynthetic equipment. Because moisture stress decreases photosynthetic rate, chlorophyll content, and leaf area while increasing assimilate saturation in leaves, it decreases photosynthesis. Stomata close to minimize transpiration when there is insufficient moisture. As a result, less carbon dioxide enters the leaf, which lowers the photosynthetic rate. By decreasing both leaf area and photosynthetic rate per unit leaf area, moisture stress is known to inhibit photosynthesis. Water stress also affects assimilate translocation, which restricts photosynthesis.

Moisture Stress in Vegetative Stage

During the vegetative stage, water stress impacts the plant as follows:

- **Leaf Area Development**: Water stress limits leaf expansion and development, reducing the plant's photosynthetic surface area.
- **Stem and Root Growth**: Both stem elongation and root growth are inhibited, leading to

shorter plants and a less extensive root system. A smaller root system further limits water and nutrient uptake.

The effects of moisture stress on yield and its qualities are more significant during the reproductive stage than during the vegetative stage. However, photosynthesis and accumulation are the most significant effects on plants at this stage of growth and development due to stress.

Respiration

Increase with mild drought but more serve drought lowers water content and respiration. Respiration is the process by which plants convert sugars into energy. Under water stress:

- **Increased Respiration Rate**: Plants often increase their respiration rate to cope with stress, which consumes more carbohydrates.
- **Energy Allocation**: More energy is used for maintenance and stress responses rather than growth, leading to reduced biomass accumulation.

Anatomical Changes

Decrease in size of the cells and inter cellular spaces, thicker cell wall, greater development of mechanical tissue. Stomata per unit leaf tend to increase. Water stress induces several anatomical changes to help plants conserve water:

- **Cuticle Thickness**: The cuticle, a waxy layer on leaves, may thicken, reducing water loss through transpiration.
- **Stomatal Density and Size**: Stomata may become smaller and more densely packed to limit water loss.
- **Leaf Morphology**: Leaves may become smaller and thicker, reducing the surface area for water loss but also limiting photosynthesis.

Metabolic Reaction

Metabolic processes are altered under water stress:

- **Enzyme Activity**: Water stress can affect the activity of various enzymes, disrupting metabolic pathways.
- **Osmolyte Accumulation**: Compounds like proline and sugars accumulate to protect cellular structures and maintain osmotic balance.
- **Secondary Metabolites**: Plants may increase the production of secondary metabolites, such as flavonoids and terpenes, which can protect against stress but divert resources from growth.

Hormonal Relationships

Plant hormones play a critical role in stress responses:

- **Abscisic Acid (ABA)**: Levels of ABA increase under water stress, leading to stomatal closure and activation of stress-responsive genes.
- **Growth Hormones**: Levels of auxins, gibberellins, and cytokinins decrease, slowing down growth and development.
- **Ethylene**: Ethylene production may increase, which can accelerate senescence and leaf abscission.

Water stress affects nutrient dynamics in several ways:

- **Nutrient Uptake**: Reduced water availability limits the uptake of nutrients from the soil.
- **Nutrient Transport**: Water stress can impair the transport of nutrients within the plant, leading to deficiencies in vital elements like nitrogen, potassium, and phosphorus.
- **Nutrient Use Efficiency**: Plants under stress may alter their metabolic processes to prioritize essential functions, affecting overall nutrient use efficiency.

Growth And Development

Water stress impacts overall plant growth and development:

- **Cell Division and Expansion**: Reduced water availability limits cell division and expansion, stunting overall plant growth.
- **Biomass Accumulation**: Water stress leads to reduced biomass accumulation in both vegetative and reproductive tissues.

Developmental Delays

Stress can impair a plant's lifetime and output by delaying developmental phases like blooming and fruit set. The physiological processes that are most vulnerable to drought include growth and development, with water stress restricting growth more than any other abiotic stress. Water shortages affect a number of physiological functions, which inhibits plant growth. Usually, the organ that is most affected is the one that is growing the fastest during stressful times. Drought before flowering delays maturity, but drought after flowering accelerates it. Moisture stress affects plant root development, leaf area, leaf expansion, and seed germination.

Reproduction And Grain Growth

Water stress during the reproductive stage is particularly critical:

- **Pollination and Fertilization**: Stress can reduce pollen viability and stigmatic receptivity, leading to poor pollination and fertilization.
- **Seed and Fruit Development**: Water stress can reduce seed and fruit size and number, affecting yield quality and quantity.

Grain Filling: Stress decreases photosynthate transfer to developing grains during grain filling, which lowers grain weight and quality. The number of fruits and the weight of each grain are determined by drought at blooming and grain development, respectively. In cereals, panicle initiation is crucial, and pollen drying may result from drought during anthesis. While vegetative and grain filling stages are less susceptible to moisture stress, drought during grain development lowers output.

Yield

The cumulative effect of water stress on all these processes results in:

- **Reduced Yield**: Lower biomass production, poor reproductive success, and smaller grain size all contribute to reduced overall crop yield.
- **Quality Reduction**: Stress can also affect the nutritional and commercial quality of the yield, impacting market value and food security. The effect on yield depends hugely on what proportion of the total dry matter is considered as useful material to be harvested. If it is aerial and underground parts, effect of drought is as sensitive as total growth.

Crop Adaptations

The ability of crop to grow satisfactorily under water stress is called drought adaptation. Adaptation is structural or functional modification in plants to survive and reproduce in a particular environment. Crops survive and grow under moisture stress conditions mainly by two ways:

(i) Escaping drought

(ii) Drought resistance

1. Escaping Drought

The simplest way for plants to adapt to dry conditions is to avoid the drought period. Many desert plants, known as ephemerals, only survive during the rainy season and germinate at the start of the rainy season. They only live for five to six weeks. These plants are not drought tolerant because they lack a mechanism to deal with moisture stress. Inhibitors of germination act as a safeguard. The primary adaptation of cultivated crops to grow in arid environments is their capacity to reach maturity before the soil dries out. Few crops, nevertheless, have a growing season that brief enough to qualify as ephemerals. Some pearl millet cultivars reach maturity 60 days after seeding.

2. Drought Resistance

Plants can adapt to drought either by avoiding stress or by tolerating stress due to different mechanisms. These mechanisms provide drought resistance. Drought resistance is the ability of a crop to withstand and perform well under conditions of limited water availability. This trait is crucial for maintaining productivity in arid and semi-arid regions. Drought resistance involves multiple physiological, morphological, and biochemical adaptations that enable plants to survive, grow, and produce yield under water stress. Here's an elaboration on key aspects of drought resistance:

Physiological Adaptations

1. Stomatal Regulation

- **Stomatal Closure:** To reduce water loss through transpiration, plants can close their stomata. This reduces water loss but also limits CO_2 uptake, affecting photosynthesis.
- **Stomatal Density and Size:** Some drought-resistant plants have fewer and smaller stomata, which reduces the overall water loss.

2. Osmotic Adjustment

- **Accumulation of Osmolytes:** Plants accumulate Osmo protectants such as proline, glycine betaine, and soluble sugars. These compounds help maintain cell turgor and protect cellular structures from dehydration.
- **Water Potential Maintenance:** By adjusting the osmotic potential, plants can maintain

water uptake and cellular hydration even under low soil moisture conditions.

3. Hydraulic Conductivity

- **Root Hydraulic Conductivity:** Enhanced ability of roots to conduct water helps plants maintain water supply to the leaves under drought conditions.
- **Aquaporins**: These are water channel proteins that facilitate water movement across cell membranes. Increased expression of aquaporins can improve water uptake and transport.

Morphological Adaptations

1. Root System Architecture

- **Deep Root Systems:** Plants with deeper roots can access water from deeper soil layers, which is crucial during drought conditions.
- **Root Density:** Increased root density in the upper soil layers can enhance water uptake from light rains or irrigation.

2. Leaf Modifications

- **Leaf Size and Shape:** Smaller leaves reduce the surface area for transpiration, conserving water. Some plants develop thicker leaves with fewer stomata.
- **Leaf Rolling:** Some plants roll their leaves to reduce the surface area exposed to sunlight, thereby reducing water loss.

3. Cuticle And Epidermal Adaptations

- **Thicker Cuticle:** A thicker cuticle layer on leaves reduces water loss by providing a barrier to evaporation.
- **Trichomes:** Hair-like structures on leaves (trichomes) can reflect sunlight, reducing leaf temperature and water loss.

4. Stress-Responsive Proteins

- **Heat Shock Proteins (HSPs):** These proteins help in the proper folding and functioning of other proteins under stress conditions.
- **Late Embryogenesis Abundant (LEA) Proteins:** LEA proteins protect cellular structures and enzymes from dehydration damage.

5. Hormonal Regulation

- **Abscisic Acid (ABA):** ABA plays a central role in mediating drought responses by regulating stomatal closure, gene expression, and osmotic adjustment.
- **Ethylene and Cytokinins:** Balance between these hormones influences stress responses, with ethylene often promoting senescence and cytokinins supporting growth.

6. Avoiding Stress

- Stress avoidance is the ability to maintain a favourable water balance, and turgidity even when exposed to drought conditions, thereby avoiding stress and its consequences.
- A favourable water balance under drought conditions can be achieved either by

(i) conserving water by restricting transpiration before or as soon as stress is experienced

(ii) accelerating water uptake sufficiently so as to replenish the lost water.

Method To Overcome Plant Water Stress

1. Adjusting the plant population

The plant population should be lesser in dry land conditions than under irrigated conditions. The rectangular type of planting pattern should always be followed under dry land conditions. aUnder limited moisture supply the adjustment of plant population can be done by

a) Increasing the inter-row distance

By adjusting a greater number of plants within the row and increasing the distance between the rows reduces the competition during any part of the growing period of the crop. Hence it is more suitable for limited moisture supply conditions.

b) Increasing the intra-row distance

Here the distance between plants is increased by which plants grow luxuriantly from the beginning. There will be competition for moisture during the reproductive period of the crop. Hence it is less advantageous as compared to above under limited moisture supply.

2. Mid-Season Corrections

The contingent management practices done in the standing crop to overcome the unfavourable soil moisture conditions due to prolonged dry spells are known as mid-season conditions.

- **Thinning:** This ca be done by removing every alternate row or every third row which will save the crop from failure by reducing the competition.

- **Spraying:** In crops like groundnut, castor, redgram, etc., during prolonged dry spells the crop can saved by spraying water at weekly intervals or 2 per cent urea at week to 10 days interval.
- **Ratooning:** In crops like sorghum and bajra, ratooning can practice as mid-season correction measure after break of dry spell.

3. Mulching

It is a practice of spreading any covering material on soil surface to reduce evaporation losses. The mulches will prolong the moisture availability in the soil and save the crop during drought conditions.

4. Weed Control

Weeds compete with crop for different growth resources more seriously under dryland conditions. The water requirement of most of the weeds is more than the crop plants. Hence, they compete more for soil moisture. Therefore, the weed control especially during early stages of crop growth reduce the impact of dry spell by soil moisture conservation.

5. Water Harvesting and Life Saving Irrigation

The collection of runoff water during peak periods of rainfall and storing in different structures is known as water harvesting. The stored water can be used for giving the lifesaving irrigation during prolonged dry spells.

Conclusion

Moisture stress has significant impacts on plant growth, development, and productivity. However, plants have evolved remarkable adaptations to cope with water scarcity, including morphological, physiological, and molecular responses. Understanding these adaptations is crucial for developing strategies to improve crop resilience and sustainability in water-limited environments. By leveraging plant breeding, genetic engineering, and agronomic practices, we can enhance plant moisture stress tolerance, ensuring food security and mitigating the effects of climate change on agriculture.

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