

Abiotic Stress in Crop Plants

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Stress

Stress is usually defined as an external factor that exerts a disadvantageous influence on the plant. In both natural and agricultural conditions, plants are frequently exposed to environmental stresses. The complex nature of the environment, along with its unpredictable conditions and global climate change, are increasing gradually, which is creating a more adverse situation. A number of abnormal environmental parameters are collectively termed abiotic stress. Plant stress is the adverse reaction of plants to environmental conditions that are unfavorable to growth.

Stressor

A stressor is a chemical or biological agent, environmental condition, external stimulus or an event that causes stress to an organism.

Strain

Strain is the biologic changes of plants under the influence of plant stress. Strain can be elastic or plastic depending on the degree and lasting time of stress.

- Elastic strain: Up to a point, a strain may be completely reversible and when the stress is relieved, the plant becomes normal.
- Plastic strain: Beyond the point of elastic strain, the strain may be partially reversible or partially irreversible, which is called plastic strain or permanent set.

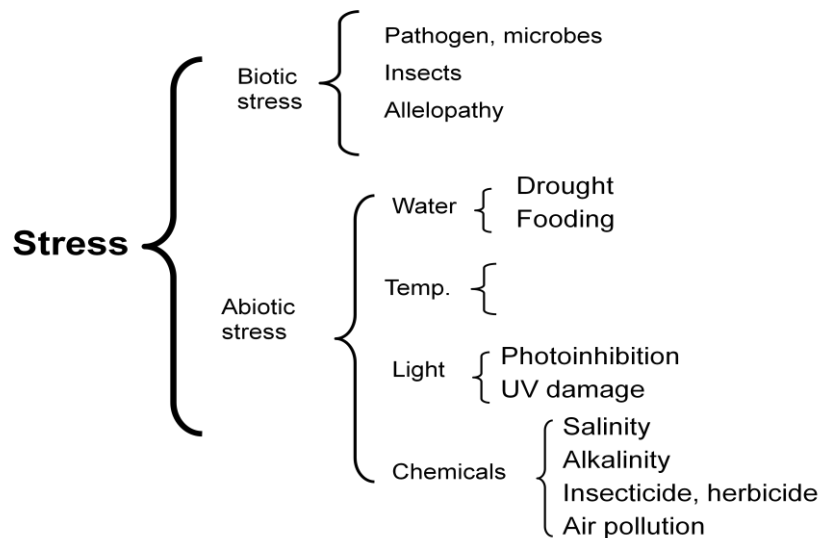


Fig. 1. Various stresses in plants

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Abiotic stress

Abiotic stress is defined as the negative impact of non-living factors on the living organisms in a specific environment. Plants are frequently exposed to a plethora of unfavorable or even adverse environmental conditions, termed abiotic stresses (such as salinity, drought, heat, cold, flooding, heavy metals, ozone, UV radiation, etc.) and thus they pose serious threats to the sustainability of crop yield. Abiotic stresses remain the greatest constraint to crop production worldwide. It has been estimated that more than 50% of yield reduction is the direct result of abiotic stresses. Abiotic stress leads to a series of morphological, physiological, biochemical and molecular changes that adversely affect plant growth and productivity.

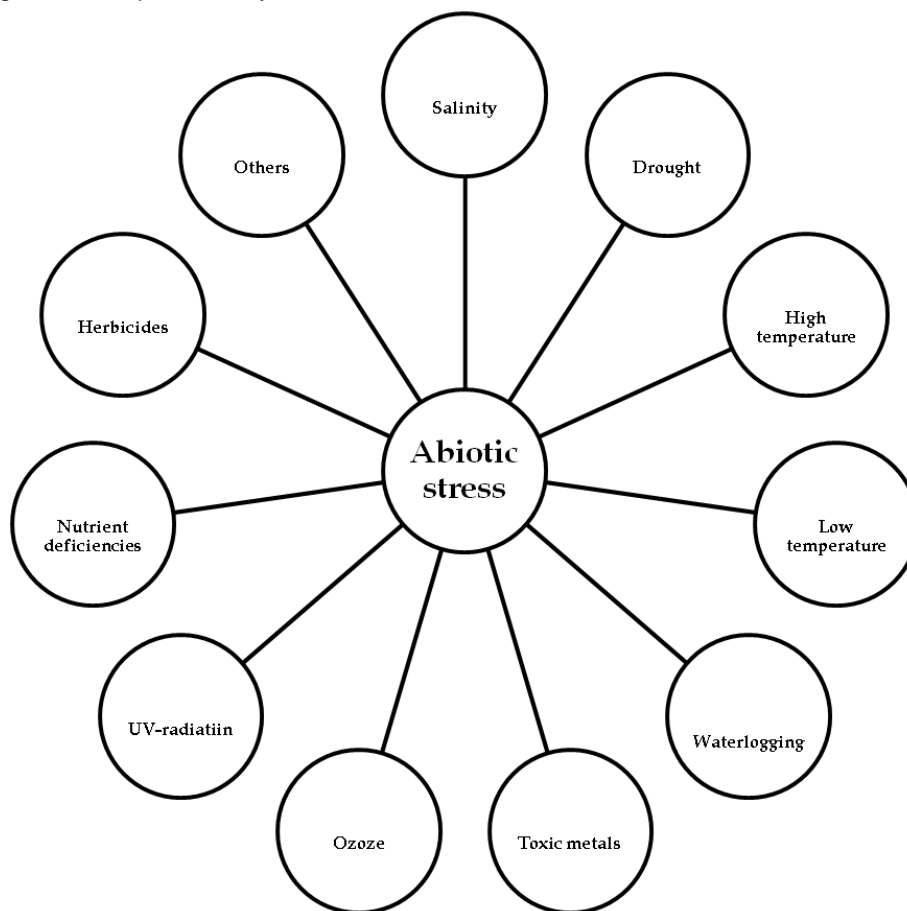


Fig. 2. Various types of abiotic stress

Abiotic stress responses in plants

Abiotic stresses modify plant metabolism leading to harmful effects on growth, development and productivity. If the stress becomes very high and/or continues for an extended period it may lead to an intolerable metabolic load on cells, reducing growth, and in severe cases, result in plant death. However, plant stress may vary depending on the types of stressor and on the prevailing period. In nature, plants may not be completely free from abiotic stresses. They are expected to experience some degree of stress by any factor(s).

Some environmental factors, such as air temperature, can become stressful in just a few minutes; others, such as soil water content, may take days to weeks, and factors such as soil mineral



deficiencies can take months to become stressful. In addition, stress plays a major role in determining how soil and climate limit the distribution of plant species. Thus, understanding the physiological processes that underlie stress injury and the adaptation and acclimation mechanisms of plants to environmental stress is of immense importance to both agriculture and the environment.

Due to global warming, and potential climate abnormalities associated with it, crops typically encounter an increased number of abiotic and biotic stress combinations, which severely affect their growth and yield. Concurrent occurrence of abiotic stresses such as drought and heat has been shown to be more destructive to crop production than these stresses occurring separately at different crop growth stages.

Table 1. Physiological and biochemical perturbations in plants caused by fluctuations in the abiotic environment

Environmental factor	Primary effects	Secondary effects
Salinity	<ul style="list-style-type: none"> • Water potential reduction • Cellular dehydration • Ion cytotoxicity 	<ul style="list-style-type: none"> • Reduced cell/leaf expansion • Reduced cellular and metabolic activities • Stomatal closure • Photosynthesis inhibition • Leaf abscission • Membrane and protein destabilization • Ion cytotoxicity • Cell death
Water deficit	<ul style="list-style-type: none"> • Water potential reduction • Cellular dehydration 	<ul style="list-style-type: none"> • Reduced cell/leaf expansion • Reduced cellular and metabolic activities • Stomatal closure • Photosynthesis inhibition • Leaf abscission • Membrane and protein destabilization • Ion cytotoxicity • Cell death
Flooding	<ul style="list-style-type: none"> • Hypoxia • Anoxia 	<ul style="list-style-type: none"> • Reduced respiration • Fermentative metabolism • Inadequate ATP production • Reactive oxygen species (ROS) production • Stomatal closure
High temperature	<ul style="list-style-type: none"> • Membrane and protein destabilization 	<ul style="list-style-type: none"> • Photosynthesis and respiration inhibition • ROS production • Cell death
Low temperature	<ul style="list-style-type: none"> • Membrane destabilization • Water potential reduction • Cellular dehydration • Ice crystal formation in cells 	<ul style="list-style-type: none"> • Reduced cell/leaf expansion • Reduced cellular and metabolic activities • Stomatal closure • Photosynthesis inhibition • Leaf abscission • Membrane and protein destabilization • Ion cytotoxicity • Cell death • Physical destruction
Metal toxicity	<ul style="list-style-type: none"> • Damage in protein and DNA • ROS production 	<ul style="list-style-type: none"> • Disruption in metabolism
All stress	<ul style="list-style-type: none"> • Excess generation of reactive oxygen species leading to oxidative stress. • Reduction of growth and yield • Loss of crop quality 	

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Role and Impact of Abiotic Limitations to Crop Yield

The general scheme proposed in Figure 1 describes the plant response to an abiotic stress with given features (duration, severity, etc.). The stress acts on a crop with given phenotypic characters to result in the final effects on growth, development, and mortality rate. The basic scheme of Figure 3 is the result of a complex causal chain, which involves plant hormones and acts at the molecular and physiological level. The knowledge of this causal chain is substantially increasing thanks to transcriptomics, metabolomics, proteomics, and other integrated research approaches.

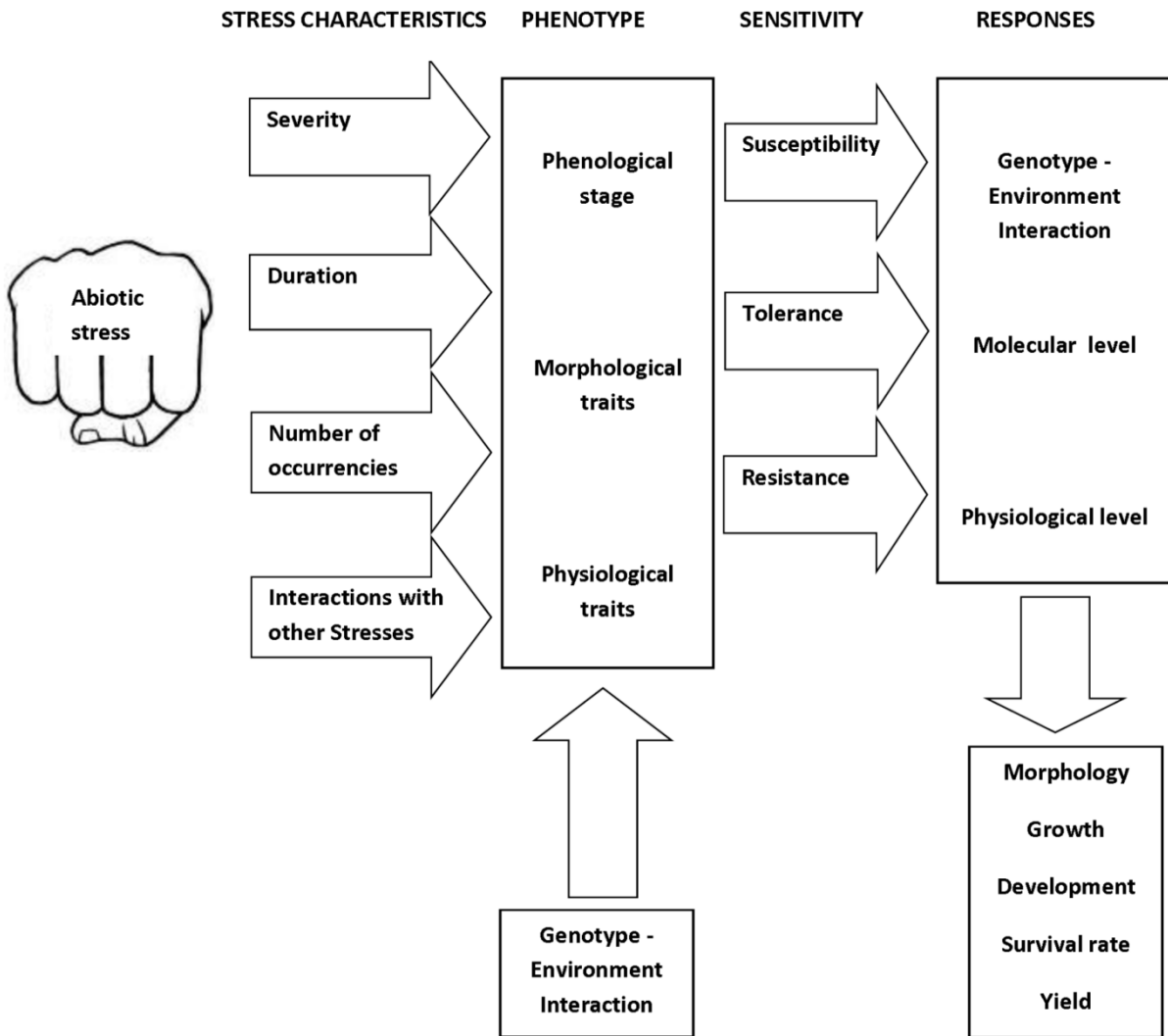


Fig. 3. Scheme of factors that determines the crop responses to abiotic stress.

Secondary effects of abiotic stress

Abiotic stress conditions such as drought, high and low temperature and salinity are known to influence the occurrence and spread of pathogens, insects, and weeds. They can also result in minor pests to become potential threats in future. Additionally, abiotic stress conditions such as drought enhance competitive interactions of weeds on crops as several weeds exhibit enhanced water use efficiency than crops.

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Stress combination

Plants tailor their responses to combined stress factors and exhibit several unique responses, along with other common responses. Therefore, to fully recognize the impact of combined abiotic and biotic stresses on plants, it is important to understand the nature of such interactions. Mittler and colleagues (2006) developed a “stress matrix” to compile the interactions among various abiotic and biotic stresses on plant growth and productivity (Fig. 4). This matrix illustrates that the stress combinations can have negative as well as positive effects on plants. Therefore, development of plants with enhanced tolerance to combined abiotic and biotic stresses involves identification of physiological traits that are affected by combined stresses.

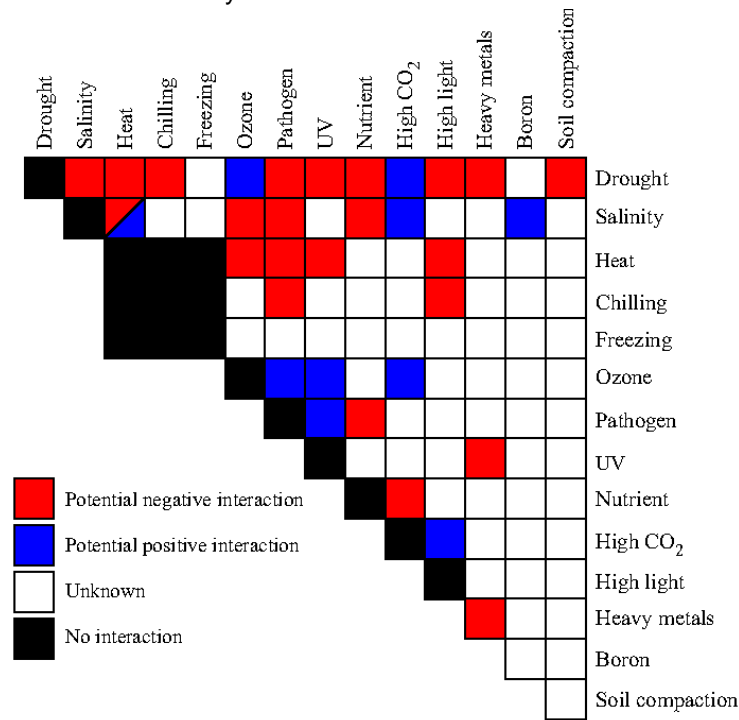


Fig. 4 The stress matrix. Different combinations of potential environmental stresses that can affect crops in the field are shown in the form of a matrix. The matrix is color-coded to indicate stress combinations that were studied with a range of crops and their overall effect on plant growth and yield.

Stress tolerance

In the literature the term *stress resistance* is often used interchangeably with *stress tolerance*, although the latter term is preferred. If tolerance increases as a result of exposure to prior stress, the plant is said to be acclimated (or hardened). Acclimation can be distinguished from *adaptation*, which usually refers to a *genetically* determined level of resistance acquired by a process of selection over many generations. Unfortunately, the term *adaptation* is sometimes used in the literature to indicate acclimation. And to add to the complexity, we will see later that gene expression plays an important role in acclimation.

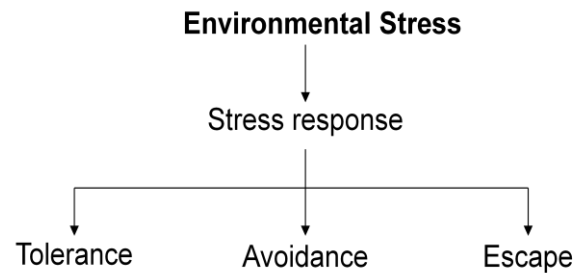
Adaptation and acclimation to environmental stresses result from integrated events occurring at all levels of organization, from the anatomical and morphological level to the cellular, biochemical, and molecular level. For example, the wilting of leaves in response to water deficit reduces both water loss from the leaf and exposure to incident light, thereby reducing heat stress on leaves.

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Cellular responses to stress include changes in the cell cycle and cell division, changes in the endomembrane system and vacuolization of cells, and changes in cell wall architecture, all leading to enhanced stress tolerance of cells. At the biochemical level, plants alter metabolism in various ways to accommodate environmental stresses.

Plants Adaptation to Stress



Stress Escape

Plant avoid the injury of stress by regulating its life cycle to avoid meeting with stress. e.g. some short-lived, desert ephemeral plants germinate, grow and flower very quickly following seasonal rains. They thus complete their life cycle during a period of adequate moisture and form dormant seeds before the onset of dry season.

Stress avoidance

Plants avoid the injury of stress by building up a barrier to prevent stress factors entering the plant. e.g. alfafa survive dry habitats by sending down deep root systems that penetrate the water table. Salt-secretion halophytes secrete the salts out from the leaf thus reduce salt content in the leaf.

Stress tolerance

Plants adapt to the stress environment by regulating their metabolism and repair the damage caused by stress. e.g. Highly salt tolerant halophytes such as *Suaeda salsa* survive salty habitat by many strategies such as high ROS scavenging ability, high osmotic adjustment ability, high ion compartmentalization ability and so on.

Adaptation vs. Acclimation

- Adaptation and acclimation both are means of achieving tolerance to a particular stress.
- Adaptation refers to heritable modifications in structure or function that increase the fitness of the organism in the stressful environment. e.g. CAM plants to desert.
- Acclimation refers to nonheritable physiological modifications that occur over the life of an individual. These modifications are induced by gradual exposure to the stress. E.g. slow drying increases the drought resistance of plants. The process of acclimation is known as hardening.

