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Abiotic Heat Stress in Crops

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When temperatures start creeping above 85 degrees, you are not the only one who is stressed. Most plants suffer when the weather turns hot enough for a period of time. It causes irreversible damage by way of plant function or development. Abiotic stresses due to environmental factors could adversely affect the growth and development of crops. Among the abiotic stresses, drought and heat stress are two critical threats to crop growth in the San Joaquin Valley and worldwide. This is not merely droopy leaves in the heat of the afternoon; it's things like stunted growth, leaf drop, leaf scald, fruit scald, failure to flower, or failure to produce seeds.

Crops grow best at temperatures of 68-86°F. Growth slows down significantly beyond 86°F and stops roughly above 104°F. As temperatures increase the effect of excessive heat begins. The growth, development, biomass accumulation, and yield will all be adversely affected by heat stress, although the damage depends on the crop's ability to withstand, acclimate to, or recover from the stress. Heat stress is also strongly associated with drought stress. The combination of heat/drought stresses kills or will kill a plant quickly.

As an example, for tomato plants, when sufficient water is available in soil, visual symptoms of heat stress include reduced plant size, low number of leaves, small and curling leaves, and dry flowers. Fruit set is poor and pollen and stigma viability, anthesis, pollination, pollen tube growth, fertilization, and early embryo development are all highly susceptible to heat stress. Typically, we would see a gap of fruit set along the plant. Crops with some heat tolerance may set fruit, but fruit will be small and ripen as early-cell expansion is inhibited but more plant hormone ethylene (responsible for fruit ripening) is released.

High temperatures boost the rate of development, which reduces the time needed to add photosynthesis to the production of fruit or seed. Also, high temperatures can cause drought stress due to increased water loss by transpiration or evaporation. During the vegetative growth, high day temperatures can cause damage to components of leaf photosynthesis, reducing carbon dioxide assimilation rates compared with environments having more optimal temperatures.

Temperature stress wreaks havoc on a plant. As with any living organism, a plant has an optimal temperature range at which it grows and performs best. If the temperature is too cold for the plant, it can lead to cold stress. Hot weather too can affect plants adversely. Intense heat can cause plant cell proteins to break down, a process called denaturation. Cell walls and membranes can also "melt" under extremely high temperatures and the permeability of the membranes is affected.

When plants are subjected to high temperatures (increases of 10-20°F) , we see deeper modification of growth (without being necessarily lethal), protein denaturation, enzyme inactivation and reduction in chloroplast's photosynthetic activity.

Heat Stress on Growth and Development

- Pollen development is affected
- Alteration of the Ca/K balance in stomata function
- Swelling of mitochondria thereby resulting in decreased respiration and oxidative phosphorylation
- Disruption of cytoskeleton and microtubules
- Disappearance of polysomes
- Disruption of normal protein synthesis
- transcription by RNA polymerase
- Decline in DNA synthesis
- Seedling establishment is hampered
- Grain and fruit development and quality is affected
- The cellular changes due to alterations of enzymes and various protein molecules
- Fragmentation of Golgi complex
- Disruption of splicing of mRNA precursors
- Increase in number of lysosomes
- Inhibition of chromatin assembly
- Decline in Cessation of pre-RNA processing

Extreme heat stress reduces plant photosynthetic and transpiration efficiencies and negatively impact plant root development, which collectively negatively impact yield. The decline in the photosynthetic rate under both heat and water stresses are frequently attributed to:

- lowered internal plant CO_2,
- inhibition of photosynthetic enzymes (e.g., Rubisco) and
- synthesis of ATP (adenosine triphosphate), which produces chemical energy that is needed for regulating plant biochemical reactions.

The coupled effect of both heat and water stress on yield of many crops is much stronger than the effect(s) of individual stress alone. Heat stress is a complex function of intensity, duration, and the rate of the increase in air temperature. In addition, the effect of an increase in soil temperature (because of increase in air temperature) may be even stronger when accompanied by a decline in soil water content. Therefore, during extreme heat periods, soil water content must be kept at an adequate level 1) to provide for plant uptake and 2) to minimize the impact of higher soil temperature caused by higher air temperature.

Extreme air and soil temperature can alter the water transport rate from the soil into the root and plant system, which can reduce plant transpiration rate where plant transpiration cannot keep pace with high atmospheric evaporative demand. Extreme heat stress (even in the presence of adequate soil moisture) can cause a reduction in plant stomatal conductance, which reduces plant transpiration rate, causing reductions in plant productivity and yield. If extreme heat stress is coupled with dry wind over the plant canopies, the magnitude of stomatal closure and the reduction in rate of transpiration is great. If the heat stress is coupled with water stress, this would cause a multiplication, which will decrease the efficiency of plant water uptake.

While options are limited for mitigating the negative impact(s) of extreme heat stress on crops, there are several practical options:

1. Monitoring soil moisture during heat wave periods is critical. Maintaining adequate moisture in the soil profile is crucial to reducing the impact of heat stress on crops.
2. Soil fertility can also impact the degree to which heat and water stress affect plants. Plant stomatal conductance and the transpiration rate under water stress conditions were observed to be lower under good conditions compared to low fertility conditions. Also, under heat stress soil fertility improved by applying macronutrients such as potassium and calcium and micronutrients such as boron, manganese, and selenium. These applications modified stomatal function and activated physiological and metabolic processes that helped in upholding high tissue water potential and increasing heat stress tolerance.

Proteins are major workhorses in all cells. They help capture light for photosynthesis or act as enzymes to produce the sugars in fruits or the components of wood. In unfavorable environments, whole new sets of proteins can be made that provide plants with the ability to counteract stress. One interesting fact is that stressed plants not only need to produce new proteins to survive the stress, but they also need to make them right away. A delay of even six hours of new protein translation will inhibit optimal growth and reproduction. The plants might not outright die, but they are severely impaired without the rapid synthesis of these new proteins. As plant leaf temperatures approach 104°F, the plant shuts down and is unable to function normally. For each hour that the plant shuts down, it takes two hours for the plant to recover and begin to function normally.