The Relationship Between Climate and Root Systems

Climate change is having an ever-increasing impact on crop production, from increases in heatwaves, to fewer days of frost and less rainfall that comes in heavy bursts. This presentation delves into the effects of heat stress and flooding on plant root systems.

The Effects of Heat Stress

Roots require an optimal temperature range for proper growth and function which tends to be lower than the above ground parts. As the heat of the roots becomes higher than the plant likes, hormonal and metabolic changes are triggered as the plant tries to overcome the stress.

Plant Compounds Affected by Heat Stress

The following compounds are currently the most commonly identified primary contributors affected by this response:

Salicylic Acid - Improves heat tolerance and mitigates damage in some crops.

Ethylene - Reduces oxidative damage and supports maintenance of chlorophyll content.

Abscisic Acid - Controls tolerance to abiotic stress by increasing photochemical efficiency and membrane stability.

Cytokinin - A key regulator of the root system architecture. Decreased levels of this hormone lead to an enlarged root system, thereby increasing heat tolerance but decreasing surface area for nutrient cycling and microbial activity.

Carbohydrates - Carbohydrate concentrations (i.e., glucose, fructose, galactose and sucrose/xylose) are typically lower after roots experience high temperatures.

Temperature Sensing and Signaling in Roots

Warmer temperatures alter stability of membranes, cytoskeleton components, proteins and nucleic acids. Increased temperatures will also affect a plant’s metabolism which impacts carbohydrate structures, amino acid balance, lipid metabolism and the activation of heat and oxidative pathways to prevent disruption of root growth. Heat also affects hormone levels which trigger transduction pathways that prepare the plant to overcome the stress. Extreme heat at the roots is often accompanied by abiotic and biotic stresses such as drought, salinity, nutrient deficiencies and pathogenic infections.

Endoplasmic Reticulum Stress

Heat stress creates an accumulation of unfolded proteins that are potentially toxic, and this process is known as endoplasmic reticulum stress. The endoplasmic reticulum (ER) is responsible for protein and lipid synthesis, folding, and transport, and plants react to this ER stress by forming heat shock proteins and brassinosteroids. These compounds help the plant improve membrane stability and aid in the creation of antioxidant enzymes.

Temperature Effects on Plant Roots

High soil temperatures will alter root structure and limit root growth, reducing root: shoot ratio due to the plant prioritizing shoot growth to increase transpiration. Increased soil temperatures typically reduce the surface area between root and soil due to root enlargement (to mitigate lower photosynthesis and increased transpiration) and reduction of root mass, thereby decreasing nutrient and water uptake.

How Roots Cope with Heat Stress

Researchers have found that plants may increase the length of root hairs as a coping strategy to help with nutrient and water uptake via rhizophagy. During extreme heat, the root's membranes will become rigid, thereby heavily decreasing the root's ability for water uptake. This is the plant's defense mechanism to protect root cells from dying.

The Effects of Flooding

Not only does flooding hurt plant roots, the re-oxygenation following flooding does as well. The following slides discuss how flooding impacts root systems on various levels.

What Happens When Roots Become Flooded?

Plants will downregulate photosynthesis in favour of survival, leading to overall poorer health of the plant.

Gas diffusion of soil is reduced, preventing oxygen from entering the soil and CO_2 from getting out. Microbes will compete with roots for oxygen. Once oxygen is gone, the roots and microbes will die due to anaerobic conditions.

The plant will do everything it can to maintain aerobic metabolism in the root, such as forming aerenchyma (air-filled cell tissues that transport oxygen from the shoots to the roots) and/or shift metabolism to ferment carbohydrates to produce ATP (adenosine triphosphate) for plant energy.

Starch reserves in the root will be rapidly used up. Energy supply, membrane integrity and ion transport become impaired, resulting in nutrient deficiency in the root and shoot. Plants will downregulate photosynthesis in favor of survival leading to overall poorer health of the plant.

Reactive Oxygen Species (ROS)

Reactive Oxygen Species (ROS) are produced in hypoxic (low oxygen) environments and are a result of oxidative metabolism imbalance. ROS can cause oxidative damage and degrade cell membranes, proteins and lipids. When roots become flooded with water, the lack of oxygen triggers the production of ROS and can lead to lipid peroxidation, which causes membrane damage, enzyme inactivation and eventually cell death. This all leads to a weaker plant that will have reduced productivity.

Plant Defense Mechanisms Against Root Flooding

A plant will activate antioxidant defense systems and increase accumulation of potential osmolytes (small organic molecules that protect cells from stress) to fight against root flooding.
- Superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR) all work together to scavenge flooding-induced ROS, helping the plant to survive. These compounds already exist in plants and increase during a flooding event.
- Glutathione (GSH), ascorbic acid, carotenoids and tocopherols work to protect membranes and photosynthetic apparatus by scavenging ROS.
- Proline, sugars, soluble proteins and free amino acids will accumulate to counter toxic effects of flooding.

Conclusion

Weather and climatic events can have devastating effects upon crops. By understanding plant root responses to these effects, you can be better situated to create management practices to mitigate these dangers and create resiliency in your cropping systems.

Thank you for reading!