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Techniques of Growing Crops under Water Logging Conditions

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Flooding is one of the abiotic stressors that can be observed worldwide and has a significant impact on plant productivity and biodiversity. The frequency of floods has increased by about 65% in the last 25 years and causes greater climatic adversity worldwide than other severe climatic events. Increasing flood events due to global warming are detrimental to plant communities and affect the distribution of plants in natural ecosystems. In addition, one-tenth (about 12 mln ha) of flooded cropland loses its productivity during each flood event. Long-term waterlogging has negative effects on all growth stages of the plant throughout its life cycle and ultimately leads to productivity losses.

Morphological and anatomical adaptations in crop plants

The high photosynthetic rate as well as the persistence of plants in waterlogged soil are often associated with a number of anatomical and morphological changes, including the production of aerenchyma in root tissues, the appearance of adventitious roots, and the development of a barrier to root radial O_2 loss. To adapt to waterlogging, various morphological as well as anatomical adaptations have been reported in plants, e.g., the formation of thick Casparian strips and the formation of aerenchyma in the taproot of wheat, barley, and rice and the formation of adventitious roots (ARs) in bitter sweet (*Solanum dulcamara*), were observed under waterlogging conditions.

Roots are highly sensitive organs of plants in flooded soils. In roots, some morphological and anatomical changes are perceived that are important for the maintenance of root function under a hypoxic condition. The formation of aerenchymatous tissue facilitates roots to maintain aerobic respiration by initiating the distribution of various gases from the aboveground shoot to the waterlogged roots of plants. The waterlogging resistance responses in woody plants are the formation of new adventitious roots, the development of parenchymatous cells and the hypertrophy of lenticels (Kreuzwieser, Rennenberg, 2014).

Aerenchymatous tissue development in various plant parts

Aerenchyma can provide a complete aeration channel for the transport of oxygen from leaves to plant roots; it can also remove other gases such as methane, carbon dioxide, nitrogen, and ethylene, allowing plant roots to grow normally even in waterlogged soil. Two categories of aerenchyma are found in taproots of waterlogging-tolerant plants: primary aerenchyma (in wheat, maize, and rice, formed by schizogenic and lysogenic cell disruption), present in primary tissues, and secondary aerenchyma, formed in secondary tissues (in roots of soybean). The development of secondary aerenchymatous tissue (spongy tissue with many gas spaces formed in the phellem) in plant roots, stems, root nodules, and hypocotyls of some plants (legumes) increases the exchange of gases between submerged soil tissues and the atmosphere. The two types of aerenchyma give enlarged spaces for gas dispersion.

Development of novel adventitious roots (ARs) as an alternative of primary root

Adventitious root production is an adaptation to waterlogging stress that increases the dispersion of gasses and decreases separation for oxygen dispersal (Sauter 2013). To survive in waterlogged soil, the development of ARs is a significant change for plants to continue the normal function of primary roots as these roots are damaged by waterlogging. Recently, they formed adventitious roots with aerenchyma, are developed from the stem to restore root work in plant species, such as water and supplement uptake, and adhere to the surface. Adventitious roots (ARs) are connected to the stem by aerenchyma, which facilitates oxygen diffusion from floodwater to aerial shoots. The adventitious roots originate from the basal region of the stem or the waterlogged part of the hypostyle. These roots generally transform into basal roots when the primary root structure is no longer able to supply water and minerals to the shoot. Adventitious roots regularly emerge from the basal part of the stem or in the area where lenticels are abundant, and their development is lateral and parallel to the water-soil surface in Sedum spectabile cultivars. In sesame (*Sesamum indicum*), adventitious roots represent a tolerance strategy to waterlogging. Adventitious root development is constrained by complex genetic events at each developmental stage, such as during root primordia development, root emergence, and continuous growth.

Development of barrier for radial root oxygen loss (ROL)

Some marsh plants form a structural boundary that blocks the escape of oxygen from apical root regions, termed the barrier to radial oxygen loss. Environmental signals activate the induction of the ROL barrier in the root, a factor that, together with the gas filled porosity of the tissue, promotes internal air circulation. Induction of the radial O_2 loss barrier promotes longitudinal O_2 dispersion and may also prevent phytotoxin invasion. Induction of the ROL barrier lowers the level of oxygen transported through aerenchymatous tissues to the root tip and allows root development in anoxic soil. Plant roots of some species establish a ROL barrier under waterlogged conditions (inducible ROL barrier), while the remaining species allow oxygen to escape under aerated conditions (constitutive ROL barrier). A larger percentage (approximately 55%) of root exodermis cells not formed by suberin lamellae was observed in this plant. These results suggested that suberin is an important component in the formation of the constitutive ROL barrier.

Physiological reactions of crop plants under waterlogging

Physiological disorders caused by waterlogging include impaired hormonal balance, photosynthetic rate, and lack of nutrients, minerals, and water uptake, which cause poor development when flooded. Waterlogging causes stomata closure associated with photosynthetic efficiency of plants, disrupting gas exchange and ultimately reducing yield and productivity.

Plants also show a decrease in stomatal conductance under waterlogging, often caused by reduced assimilation of net CO_2 and chlorosis of the leaf. Reduced net CO_2 accumulation is caused by restricted uptake of water (H_2O) and nutrients (P, Ca, Mg, Fe, Mn, Mo, etc.), which reduce plant development, growth and organic matter accumulation.

Waterlogging induced anaerobic respiration and alteration of cellular metabolites

Waterlogging stress represents a hypoxic state (below 21% O_2) in which a shift from the oxygenated to the low energy anaerobic state occurs to support plant growth. It involves various biochemical adaptations, the pathways of anaerobic digestion, and the formation of defensive compounds for the removal of phytotoxic products which are important for plant persistence under waterlogged conditions.

There are two types of anaerobic respiration, one is ethanolic fermentation and the other is lactate fermentation. In ethanolic fermentation, a two-step process is involved in which first pyruvate decarboxylase (PDC) decarboxylates pyruvate to acetaldehyde and then alcohol dehydrogenase (ADH) converts acetaldehyde to ethanol by producing oxidised nicotinamide adenine dinucleotide (NAD^+). In lactate fermentation, lactate dehydrogenase (LDH) catalyzed pyruvate to lactate using reduced nicotinamide adenine dinucleotide (NADH).

Antioxidant mechanism to defense against waterlogging induced stress

A high level of formation of reactive oxygen species is an important phenomenon in hypoxia or anoxia and especially in oxygenation. In this situation, an imbalance of redox potential can generally trigger oxidative damage to various cellular metabolites. It leads to changes in membrane fluidity, peroxidation of unsaturated fatty acids of the cell membrane, denaturation of proteins, inactivation of enzymes, genomic damage, and irreversible metabolic changes leading to cell apoptosis.

To survive under oxidative stress, plants generate an antioxidant defence system by increasing the activity of ROS and ROS through the enzymatic and non-enzymatic antioxidant mechanism to eliminate oxidative damage under hypoxic conditions.

Changes in photosynthetic parameters to waterlogging responses

Dynamic monitoring of various photosynthetic and chlorophyll fluorescence parameters studied under waterlogging conditions; it reveals the growth strategies of plants. The maximum quantum efficiency (Fv/Fm) of photosystem II and plant phenotyping studies are evaluated using chlorophyll fluorescence under abiotic stress. Chlorophyll fluorescence and chlorophyll content were reduced in blackgrass (*Alopecurus myosuroides*) genotypes during waterlogging stress and light-harvesting complex (LHC) was damaged in blackgrass and tomato during waterlogging situation. In barley, photosynthesis was reduced under early waterlogging conditions due to stomatal and non-stomatal constraints.