Chapter

Protagonist of Mineral Nutrients in Drought Stress Tolerance of Field Crops

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Abstract

The food demand is increasing hastily, that is inducing continuous pressure on agriculture sector and industries to fulfill rising dietary needs. To meet with increasing demand, the food production must be elevated up to 70% until the year 2050. On the other hand, changing climate is disturbing crop production around the World. Crops grown under field conditions are affected by more than one abiotic stress. It is continuous task and challenge for agronomists to make crops environment hardy to obtain maximum yield. It is considered that different agronomic managements, if done appropriately, could be beneficial for increasing crop production. The optimal provision of plant nutrients can assist the crops to fight in better way with environmental stress like drought; it can help them to continue their normal metabolism even under hostile abiotic circumstances. The regions that have reduced availability of water for crop production, a balanced nutrient management can assist crops to give adequate production. Some of nutrients have potential of not only maintaining plant metabolism but also to enhance the quality of product. This chapter highlights the protagonist of plant nutrients in alleviation of drought stress in field crops.

Keywords: drought, physiology, consequences, alleviation, macronutrients, micronutrients, mechanisms

1. Introduction

Water shortage is an emerging limitation to crop production due to climate change. It critically influences development and growth of crops and results in significant production loss. It is important to recognize morphological, physiological and bio-chemical effects of drought in relation to nutrient uptake in crops [1]. Drought impairs mineral transport and effects stomatal conductance. By considering nutrients role in plants growth, negative consequences of drought can be avoided by management strategies [2, 3]. Previously, many scientists have worked to understand the role of mineral nutrients in alleviation of drought stress, but more is to be done. Among minerals that are essential for plant growth, macronutrients has significant importance because their shortage lead to quick response and plants become more susceptible to other abiotic and biotic stresses. On the other hand, micronutrients deficiency effect at molecular level and results in altered enzymatic activity and blockage in signal transduction pathways [4]. Those plants that have capability to attain and retain water in large amount, as well as better water usage efficiency, are more tolerant to drought stress. Response in the direction of water stress depends upon crop growth stage, intensity and severity of drought [5, 6].

There are many reports available previously that addresses the consequences of drought on different physiological parameters like photosynthesis, respiration, homeostasis and assimilates transportation but very few discourses the drought effects on mineral in crops. Albeit, if crops are grown on mineral-rich soils, water limitations can be the reason of disruption in nutrient uptake. Minerals are taken up by plants in inorganic ionic forms. When a plant is subject to drought, due to low soil moisture, the diffusion of minerals is disrupted and ultimately transport is affected [3, 7, 8].

2. Effect of drought stress in crops

Field crops are simultaneously subjected to more than one abiotic stress during their complete life cycle. Drought and high temperature are the most detrimental abiotic stresses. It is continuous task for scientists to make crops hardy against biotic and more importantly abiotic stresses to increase food productivity. The simulation model predicts that to cope with rising food demand, supply must be increased to 70% till the year 2050 [9–12].

Drought stress influences crops by disturbing their physiological and biochemical functioning [13–16]. Previously, work is done making crops vigorous to deal with climatic challenges [9, 16–18] but more is still to be done.

Early droughts due to changing climate can reduce crop productivity [19]. The struggle of water use among domestic, industrial and agricultural sector is making situation worse for irrigated agriculture [20]. This problematic situation is shifting agriculture from irrigated to rainfed areas where periodic drought events are occurring due to disturbed rainfall pattern [21, 22].

2.1 Impact of drought on morphological traits

Crops when subjected to drought stress show different behavior. Some crops are resistant to drought while others are susceptible [23]. Those crops that have taproot system are more tolerant to short term drought events. They can stand with mild to moderate drought condition. On the other hand, prolonged drought can affect all crops likewise and can cause significant yield loss [24].

2.1.1 Effect of drought on seedling emergence

Seed germination is the most critical stage in complete life cycle; it is influenced by water availability for imbibition [25]. Drought stress at this stage can results in irregular germination and deprived seedlings [26, 27]. In rainfed areas, absence of shower at seedling establishment stage critically reduces field emergence [28, 29].

2.1.2 Growth phase affected by drought

Water shortage at vegetative stage disturbs growth and development through impaired turgor and stomatal conductance [30]. The reduction of water potential inside cytosol increases solute level. This leads to damage of cell structure and functioning. Cell division and expansion is also inhibited [31]. Under drought stress, nutrient uptake is also exaggerated that primes to reduction in leaf area and photosynthesis [32, 33]. Several traits of crops that are affected by drought at vegetative stage include leaf area, assimilation rate, total dry matter and chlorophyll [34, 35]. Root length and dry weight of leaves and stem is also reduced [36].

2.1.3 Effect of drought on crop yield

The loss of crop yield due to drought stress is decided by many factors like intensity, duration and ability of crop to tolerate drought stress. In higher plants, anthesis is the most drought susceptible stage [37]. Water shortage at that stage can results in substantial yield loss [30].

In oilseed crops, almost all yield related traits are affected by drought [38–40]. Severity of drought is also an important aspect; it distresses all growth stages regardless of crop, eventually results in considerable yield loss [41–44].

2.1.4 Effect of drought on crop quality

Among oilseed crops, sunflower has significant importance because it is rich in linoleic acid. Drought stress at reproductive stage reduces oil quality in oilseed crops and deteriorates its texture [45]. Drought stress also reduces quality of end products. It disturbs biochemical enzymes [46] and gene regulation that are responsible for oil constituents in sunflower [47].

2.2 Effect of drought on physio-biochemical traits

Crops are responsive to abiotic stresses from molecular to morphological level. Those crops that are tolerant to drought stress modify their cells at molecular level like increasing concentration of osmolytes in cytosol under harsh environment [48–52]. However, in susceptible crops, drought can affect at biochemical level [53–56].

2.2.1 Water relation disturbance

The key phenotypic adoption in drought tolerant crops is tap root system. They can extract water from deeper soil layer even under severe environment. Those plants that have shallow root system, when subjected to drought, it affects their water potential inside cell [57]. The low water potential leads to turgor loss and interrupted stomatal conductance [36, 41]. Transport of nutrients through xylem is concerned under drought [58, 59].

2.2.2 Photosynthesis reduction

The metabolic process of carbon fixation that occurs in leaves in the presence of light is called as photosynthesis. This is the main energy harvesting phenomenon that is accountable for growth and development. It is affected by different environmental factors like, availability of moisture, sunshine, humidity and temperature [60].

The plants that have C4 carbon fixation pathway are more efficient in carbon harvesting [61], but under drought, they perform in the same way as C_3 plants. Stomatal closure is triggered by water deficit condition that eventually restricts CO_2 diffusion [62], thus diminishes photosynthesis [36]. Ribulose bisphosphate is a vital enzyme in carbon fixation. The activity of RuBP is affected under drought stress. Those crops that can maintain RuBP production are more resistant to drought stress [63–68].

2.2.3 Disrupted uptake of nutrients

Under drought, absorption capacity of roots is affected that condenses nutrient uptake. Nitrogen, being a vital constituent of plants, is required in high quantity. The reduction of soil moisture reduces ability of roots to absorb adequate moisture. Phosphorus uptake, transport and translocation are also affected in drought conditions [6]. It lessens NPK uptake in sunflower [41].

2.2.4 Drought induced oxidative stress

Free radicals of oxygen, that are also known as reactive oxygen species has significant role in cell signaling. Their production remains continue unceasingly inside cell in controlled amount. When a plant is subjected to any environmental stress, its production increases. This augmented concentration induces oxidative stress to crops. They are highly reactive in action; they can cause injury to cellular structure [69]. In oilseeds like sunflower, drought overproduces ROS [70]. Malondialdehyde is an indicator of cell membrane damage in plants. Water deficiency increases MDA production that specifies increment in cellular injury [71–73].

3. Role of nutrients in drought stress alleviation

Optimum nutrient supply not only improves growth of crops but is also helpful for plants under adversative climatic conditions. There are seventeen nutrients that are crucial for plant growth [74]. Upon their requirement, these are grouped as macronutrient and micronutrient. This review deals with role of essential nutrients in drought stress mitigation.

3.1 Macronutrients

3.1.1 Nitrogen

Under dry climatic conditions, water use efficiency and growth of crops is restricted due to less accessibility of water. Efficient nitrogen application can serve the purpose under drought stress [75, 76]. Plants facing drought stress are more susceptible to heat tremors as well. Nitrogen deficiency in drought stress outcomes as biomass reduction in crops [77, 78]. Previous studies have suggested that shoot biomass is more affected under drought-cum-nitrogen stress, while root biomass is not much exaggerated primarily [79]. On the other hand, plants become drought hardy under sufficient soil nitrogen availability [75, 80, 81]. Increasing nitrogen significantly improved crop performance under drought stress. Nitrogen also play significant role in prevention of plasma membrane damage and osmotic adjustment. Application of N under water deficiency also enhances other major nutrient uptake like potassium and calcium [82].

Nitrogen availability diminishes malondialdehyde content that alleviates in drought stress [80]. It recovers photosynthetic contents and improves cell division that lead to leaf area increment [83]. At molecular level, drought stress greatly influences photosystem-II efficiency that is recovered by optimum nitrogen accessibility [51, 84–93].

3.1.2 Phosphorus

Previously, many researchers have testified that phosphorus application under water deficiency in many crops significantly enhance their water usage ability and helps in drought resistance [74, 94, 95]. It is also well known that optimum phosphorus in crops improves root growth and stomatal activity [96, 97]. Phosphorus availability also optimizes leaf area [98], plasma membrane stability and water use efficiency [99–102]. It was observed that phosphorus in leaves was relatively higher under drought condition as compared to optimum water availability which suggests that phosphorus has contribution in drought tolerance [94, 96].

Phosphorus also improves nitrogen mobility under water deficiency [103]. Morphological and physiological parameters were also improved when phosphorus was applied at high rate in drought such as, plant height, leaf area, dry weight and water use efficiency [102, 104]. Application method of phosphorus also influences crop growth in drought, deep phosphorus placement (DPP) method works excellently for drought affected areas that ultimately promotes root growth [101, 105].

3.1.3 Potassium

Potassium is well-known for its osmoregulatory functions in crops. It regulates stomatal conductance and water uptake; the optimum K application increases WUE [106, 107]. Potassium soothes aquaporins and osmotic pressure that regulates water uptake, stomatal regulation, carbon intake, cell elongation and ROS detoxification [108, 109]. In grasses like sorghum, K application under drought improves photosynthesis which leads to growth and yield [106, 110]. In maize, potassium plays role photosynthates assimilation [111]. Potassium availability is correlated with aquaporins activity and stem cell expansion [112].

The hydraulic conductivity of root and anatomical traits has great influence on crop performance. The increment in hydraulic conductivity is associated with drought tolerance [113]. In higher plants, reduction in K influences aforementioned traits, hence compromised yield. Drought simulates ethylene production that in return hinders abscisic acid activity. The starvation of K further worsen the situation, it delays stomatal conductance [109]. Potassium also play role in ROS detoxification and promotes photosynthesis process [114, 115].

3.1.4 Magnesium

Magnesium has central place in chlorophyll molecule, thus has significant importance. It has great role in dry matter partitioning from sink to source. Passable Mg is required at reproductive stage to avoid flower sterility. Foliage application also improves nutrient mobility and helps in growth maintenance under stressful environment [116, 117]. Magnesium is highly mobile nutrient. It has positive correlation with nitrogen and potassium. Adequate magnesium increases their mobility; they are helpful in stress tolerance [118].

Drought stress in field crops affects magnesium uptake from soil. This deficiency can be fulfilled by foliar Mg application [119]. Earlier, it is known that foliage applied Mg can satisfy plant's need [120]. The mechanisms of Mg that are responsible for drought stress induction include growth of root, NPK uptake and improvement of WUE [74].

3.1.5 Calcium

Drought stress leads to overgeneration of ROS that result in cell damage [121–124]. Calcium has its role in detoxification of ROS [125]. It is known that in the activity of aquaporins, pH and calcium are of significance importance [126, 127]. Exogenous application of Ca induces drought resistance in wheat cultivars. Calcium has cell signaling mechanism, which simulates proline accumulation.

Calcium, when it is applied under drought stress, it improves chlorophyll and catalase activity and decreases plasma membrane damage. It also maintains osmolytes like proline and other soluble antioxidants [128, 129]. Foliage applied Ca under drought stress helps to improves drought stress alleviation by refining catalase, peroxidase and superoxide dismutase activity [130].

3.1.6 Sulfur

The role of sulfur application in mitigation of drought stress is very little known previously. It has a substantial role in stress signaling pathway. It improves crop growth, morphological parameters and nutrient contents [131]. In counter stress mechanism, increment in glutathione also has significant importance. It aids in ROS detoxification [132]. The uptake of sulfur in adequate amount helps crops to stand with drought events. Its transport and assimilation is among one of the drought stress responses [133, 134].

3.2 Micronutrients

3.2.1 Zinc

Zinc has role in various physiological processes like activity of catalytic, carboxypeptidase, superoxide dismutase, RNA polymerase and alkaline phosphates [4, 118, 135, 136]. Under water shortage, zinc has been known to improve drought resistance by improving WUE and water activity [4, 137, 138]. The reduction in zinc uptake, that is caused by water shortage, leads plants toward stress condition. Under limited soil moisture, zinc is immobile [118].

In cereals like wheat, when drought is subjected at anthesis and grain filling, it constrains nutrient uptake which become cause of stunted growth [139]. The process of photosynthesis and water activity is affected under zinc-cum-drought stress, however, when zinc is present in optimum amount, it helps crop to stand with drought. It aids in deactivation of ROS [4, 140]. At reproductive stage, plants are highly susceptible to Zn shortage [141]. When plants are subjected to prolonged drought, it impairs activity of different cell metabolic contents like NADPH. Zinc application inhibits photooxidative damage, reduces ROS generation, and promoting osmolytes concentration like SOD [74, 142–145].

3.2.2 Manganese

It is vital micronutrient that has several functions in plants. It assists in activation of various metabolic enzymes of tricarboxylic cycle. It is the part of photosystem-II, also aids in ATP synthesis and RuBP carboxylase activity. It helps to maintain balance among superoxide dismutase activity and chlorophyll contents, even under water stress [130].

The role of manganese is well known for detoxification of ROS like superoxide and hydrogen peroxide [146]. On the other hand, manganese shortage leads to oxidative stress in plants that causes chlorophyll damage thus stunted photosynthetic activity [4]. Water shortage can also be responsible for manganese deficiency. Low soil availability of manganese as it occurs under dry conditions makes it unavailable for plants [147]. The starvation of manganese leads to WUE reduction. In cereals like barley, lower WUE is correlated with abrupt stomatal control during the day and imperfection in stomatal closure during night. This leads to degradation of waxy layer of plasma membrane that is consequence of ROS activity [148].

3.2.3 Iron

It is involved in chlorophyll pigments production. It is the part of enzymes that are involved in transfer of energy, reduction of nitrogen and formation of lignin. It creates compounds along with sulfur that are the catalysts for other vital biochemical procedures in plants. The iron deficiency results in chlorosis which is the consequent of low chlorophyll concentration. Severe deficiency of iron turns leaf color from yellow to white that is sign of leaf death. Under high soil pH, iron uptake is affected. It also has antagonistic effects with phosphorus and manganese [149].

The moisture in soil greatly inhibits iron uptake [150]. The iron has vital protagonist in oxidative damage protection of leaves under stress. Its deficiency is highly dreadful for plants growth [4]. Sufficient iron amount in plant is essential for activities of antioxidants [151].

3.2.4 Boron

Boron is unavailable in soil barring basic pH and low moisture. It is highly immobile in pedosphere as well as plant. The continuous supply of boron can prevent crops from its deficiency and detrimental effects [152].

Low soil moisture greatly hampers boron uptake from rhizosphere. Its uptake via roots involve passive uptake frequently that is maintained by water uptake. As the water decreases in soil, its uptake is compromised [153]. Main function of boron is to take part in synthesis of cell wall and its extension. It also recovers biosynthesis of lignin and differentiation of xylem. It increases photosynthetic activity and plasma-membrane integrity. It facilitates assimilate transportation [4, 74].

It is necessarily required for H-ATPase activity and the coding involved for it. It also influences uptake of other nutrients like K and deteriorate cell expansion [4]. Boron is also involved in lessening of photochemical damage of cell. Among reasons for low photoinhibition, boron deficiency and drought are well known [153].

3.2.5 Copper

Among micronutrients, copper is essential for growth of plants. It has vital role in electron transport chain and cell wall loosening. It also involves in sensing ethylene, metabolism of cell wall and oxidative stress protection [154, 155]. The well-known function of copper is its involvement in formation of pollens and upholding their viability [4, 155].

There are many enzymes in which this metal acts as cofactor like ascorbic oxidase, laccase, amino oxidase and polyphenols. At molecular level, copper is also involved in cell signaling, trafficking of proteins, mobilization of iron and oxidative phosphorylation. The reproductive parts of plants are more susceptible to cooper deficiency [155, 156].

4. Conclusion

The changing climate is making situation worse for field crop production. Abrupt variations in rainfall and temperature is limiting crop yield. Under field condition, more than one abiotic stresses are disturbing plant growth simultaneously. Drought stress is among the major agricultural yield limiting factor worldwide. Different agronomic practices like optimum plant nutrition management are greatly obliging for crops under drought stress. It can alleviate drought consequences affectively. Drought stress greatly inhibits different physiological functions and biochemical processes. It leads to ROS over-generation that significantly damages cell structure. Optimal nutrients supply like NPK and Ca be accommodating for ROS detoxification and maintenance of cell functions. Under drought stress, they also facilitate in antioxidant generation like catalase, superoxide dismutase and peroxidase. They inhibit photooxidation of vital cell molecules and maintain cell membrane integrity. Likewise, micronutrients such as Zn and Mg also play role in antioxidant generation. Other mechanisms that are maintained by nutrients to induce drought stress are water uptake and stomatal conduction regulation. Optimum supply of K and Ca helps to regulate water activity and aquaporin function. In a nutshell, efficient nutrient management will be helpful in mitigation of drought stress in field crops. The best practice should be adopted to increase their availability to plants. Effective nutrient utilization cultivars need to be focused on.

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