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Suhana Rao
 Department of Botany,
 Kurukshetra University,
 Kurukshetra, Haryana, India

Rameshwar Groach
 Department of Botany,
 Kurukshetra University,
 Kurukshetra, Haryana, India

Sombir Singh
 Department of Botany,
 Kurukshetra University,
 Kurukshetra Haryana,
 India

Correspondence
Suhana Rao
 Department of Botany,
 Kurukshetra University,
 Kurukshetra, Haryana, India

A review on potassium mediated drought alleviation

Suhana Rao, Rameshwar Groach and Sombir Singh

Abstract

Water stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Water stress has deleterious effects on plant growth and development. Potassium improved the water status and relative water content of the plants, gas exchange capacity, nitrogen fixation and overall yield. A reduction in photosynthetic rate, respiration rate, total chlorophyll content, starch content and total soluble carbohydrates is observed under water stress. Application of potassium improved the overall grain yield of crop plant.

Keywords: Potassium mediated drought alleviation

Introduction

Drought Stress

The increase in world population at rapid rate has resulted in global climate changes leading to an overall decline in crop production (Lobell *et al.*, 2008)^[19]. According to an estimate, one-third of the world's population lives in areas where water is very scarce (FAO 2003)^[11]. Drought frequency and severity is expected to increase in the future because of climate change, mainly as a consequence of decreases in regional precipitation and increase in evaporation driven by global warming (Lobell *et al.*, 2008)^[19]. More than 10 % of arable land, mostly in arid and semi-arid areas is affected by drought resulting in desertification and salinization ultimately declining average yields for major crops on the global scale (Bray *et al.*, 2000)^[4]. Plant growth, development, germination, vegetative, flowering and seed filling stages of crop plants are sensitive to water deficit. All the mentioned developmental stages are influenced by a number of physiological responses, which may suppress plant growth and crop yield under drought. The severity of the drought is unpredictable as it depends on many factors such as occurrence and distribution of rainfall, evaporative demands and moisture storing capacity of soils (Wery *et al.*, 1994)^[39]. Effects of drought range from morphological, physiological and biochemical to molecular levels and are evident at all phenological stages of plant growth at whatever stage the water deficit takes place. The impaired germination, as well as poor stand establishment, is one of an important effect of drought (Harris *et al.*, 2002)^[15]. There have been reports of drought stress severely reducing germination, yield and seedling stand (Kaya *et al.*, 2006)^[16]. In a study on the pea, drought stress impaired the germination process and early seedling growth of five cultivars tested (Okcu *et al.*, 2005)^[27]. Moreover, Zeid and Shedeed (2006)^[41] reported reduction in germination potential, hypocotyl length, shoot and root fresh and dry weights in alfalfa (*Medicago sativa*), by polyethylene glycol (6000)-induced water deficit condition with an increase in the root length.

Growth is accomplished through cell division, cell enlargement, cell differentiation and involves genetic, physiological, ecological and morphological events. Cell growth is one of the most drought sensitive physiological processes due to the overall reduction in turgor pressure (Taiz and Zeiger, 2006)^[32]. Cell elongation of higher plants is inhibited by interruption of water flow from the xylem to the surrounding elongating cells under severe water deficiency (Nonami, 1998)^[26]. Drought conditions result in impaired mitosis, cell elongation and expansion ultimately leading to the reduction of plant height, leaf area and crop growth (Nonami, 1998)^[26]. Frederick *et al.* (2001) reported reduction of total seed yield and the branch seed yield in soybean under drought stress. The process of starch biosynthesis from simple carbohydrates is known as Grain filling in cereals. It is believed that four enzymes play key roles in this process: sucrose synthase, adenosine diphosphate-glucose-

pyrophosphorylase, starch synthase and starch branching enzyme (Taiz and Zeiger, 2006) [32]. The decline in the rate of grain growth resulted from reduced sucrose synthase activity, while cessation of growth resulted from inactivation of adenosine diphosphate-glucose-pyrophosphorylase in the water stressed wheat (Ahmadi and Baker, 2001) [2]. The prevailing drought reduces plant growth and development, leading to hampered flower production and grain filling. Thus, smaller and fewer grains. The reduction in grain filling occurs because of the lower assimilate partitioning and activities of sucrose and starch synthesis enzymes. The important feature that influence plant water relations are relative water content, leaf water potential, stomatal resistance, rate of transpiration, leaf temperature and canopy temperature. Siddique *et al.* (2001) [35] reported the relative higher water content of leaves during leaf development and decreased in the dry matter accumulation in matured leaf in wheat. Obviously, wheat and rice plants which are water-stressed are having lower relative water content as compared with non-stressed ones. Exposure of water stress to plants results in the decrease in the leaf water potential, relative water content and transpiration rate, with a concomitant increase in leaf temperature (Siddique *et al.*, 2001) [31]. Nerd and Nobel (1991) [25] reported that during drought stress, total water contents of *Opuntia ficus-indica* cladode were decreased by 57%. The lower turgor potential is observed in the water-storage parenchyma of the cladodes because of loss of a greater amount of water than the chlorenchyma. Egilla *et al.* (2005) [9] reported decrease in the relative water content, turgor potential, transpiration, stomatal conductance and water-use efficiency under drought stress in *Hibiscus rosa-sinensis*. Drought results in lowering the water availability along with limited total nutrient uptake. Water deficiency results in the acquisition of nutrients by the root and their transport to shoots. The decreased absorption of the inorganic nutrients because of interference in nutrient uptake and the unloading mechanism along with reduced transpirational flow (Garg, 2003) [13]. However, plant species and genotypes of a species may vary in their response to mineral uptake under water stress. In general, moisture stress induces an increase in N, a definitive decline in P and no definitive effects on K (Garg, 2003) [13]. Grossman and Takahashi (2001) have reported that limited availability of energy for assimilation of PO_3^{4-} and SO_2^{4-} because of water stress in the plant it may be converted in energy-dependent processes ultimately resulting into the less availability of energy for growth and development of plant. McWilliams (2003) [23] reported hampered uptake of that N and K under drought stress in cotton. Peuke and Rennenberg (2004) [28] reported decreased P and PO_3^{4-} contents in the plant tissues under drought, possibly because of lowered PO_3^{4-} mobility as a result of low moisture availability. The drought stress reduces the availability, uptake, translocation and metabolism of nutrients. A reduced transpiration rate due to water deficit reduces the nutrient absorption and efficiency of their utilization. Drought results in reduction of photosynthesis because of the decrease in leaf expansion, impaired photosynthetic machinery, premature leaf senescence and an associated reduction in food production (Wahid and Rasul, 2005) [38]. When stomatal and non-stomatal limitations to photosynthesis are compared, the former can be quite small. This implies that other processes besides CO_2 uptake are being damaged. The role of stomatal closure in leaves is very important which limits CO_2 uptake in by water stress. In such

events, restricted CO_2 availability could possibly lead to increased susceptibility to photo-damage (Cornic and Massacci, 1996) [7]. The stomata closure is the important first response of all plants to acute water deficit conditions to check the transpirational water loss (Mansfield and Atkinson, 1990) [20]. The decrease in leaf turgor and/or water potential or to a low-humidity atmosphere is the other responses associated with water stress (Maroco *et al.*, 1997) [21]. The discussion on drought limiting photosynthesis through stomatal closure and metabolic impairment has been continued for a long time (Tezara *et al.*, 1999) [33]. In the last decade, It was widely accepted that stomatal closure is the main determinant for the decrease in photosynthesis under mild to moderate drought conditions (Cornic and Massacci, 1996) [7]. This decreases in the inflow of CO_2 into the leaves and spares more electrons for the formation of active oxygen species. As the rate of transpiration decreases, the amount of heat that can be dissipated increases (Yokota *et al.*, 2002) [40]. Many researchers had reported that stomatal responses are closely linked to soil moisture content than to leaf water status. This suggested that stomata respond to chemical signals e.g. abscisic acid, produced by dehydrating roots when leaf water status is kept constant (Turner *et al.*, 2001) [35]. Environmental conditions that result increase in the rate of transpiration also increase the pH of leaf sap ultimately promoting abscisic acid accumulation and concomitantly diminish stomatal conductance.

Alleviating Effects of Potassium

Potassium (K) plays a major role in plant metabolism, growth, development, and yield. Deficiencies of K result in perturbations of numerous physiological functions, including water relations, enzyme activation, charge balance, poor growth, reduced yield, and decreased resistance to stress. Further, K is also involved in numerous physiological functions related to plant health and tolerance to biotic and abiotic stress. Under water-deficit conditions, K nutrition increases crop tolerance to water stress by utilizing the soil-moisture more efficiently than in K-deficient plants. The positive effects of K on water stress tolerance may be through the promotion of root growth accompanied by greater uptake of nutrients and water by plants (Rama Rao, 1986) [29] and through the reduction of transpirational water loss (Berlinger & Trolldenier, 1978) [3]. K maintains the osmotic potential and turgor of the cells (Lindhauer, 1985) [18] and regulates the stomatal functioning under water stress conditions which is reflected in improved crop yield in drought conditions (Umar & Bansal, 1997) [36]. Besides, it takes part in many essential processes in plants (Marschner, 2011) [22] and enhances photosynthetic rate, plant growth and yield under stress conditions (Tiwari *et al.*, 1998) [34]. The protective role of K in plants suffering from drought stress has been attributed to the maintenance of a high pH in the stroma and against the photo-oxidative damage to chloroplasts (Cakmak, 1997) [6]. There is increasing evidence that plants suffering from environmental stresses like drought have a larger internal requirement for K. The K acquisition is limited because of the rates of K^+ diffusion towards roots in the soil as well as root growth is restricted in water stress. This results in lowering the K concentrations. Thus, further depress the plant resistance to drought stress, as well as K absorption. Maintaining adequate plant K is, therefore, critical for plant drought resistance. There is a close relationship between K nutritional status and plant drought resistance. So, for

improved crop tolerance to stress, deeper rooting along with larger absorption surfaces, greater water retention in plant tissues be tried. Deep rooting in crop plants be attained by deeply placing K fertilizer associated with other P and N, which are having root signalling functions (Kirkby *et al.*, 2009) [17]. Further, K is also essential for the translocation of photoassimilates in root growth (Romheld and Kerkby, 2010) [30]. Root growth promotion by increased appropriate K supply under K-deficient soil was found to increase the root surface that was exposed to the soil as a result of increased root water uptake (Romheld and Kerkby, 2010) [30]. Lindhauer (1985) [18] reported that fine K nutrition increased plant total dry mass, leaf area along with improved water retention in plant tissues under drought stress.

Stomatal closing in response to drought stress leads to a reduction in photosynthetic efficiency as a consequence of chloroplast dehydration (Cakmak, 2005) [5]. Photosynthesis inhibition can further disturb the balance between ROS production and antioxidant defence resulting in ROS accumulation. The ROS has a dual action in biotic and abiotic stresses that depends on their cellular concentration. Low levels of ROS could be involved in the stress-signalling pathway by triggering stress defence/acclimation responses (Dat *et al.*, 2000). However, ROS became extremely injurious to cellular membranes and other cellular components when its concentrations reached the point of phytotoxicity, resulting in oxidative stress and eventually cell death (Mittler, 2002). Drought stress-induced ROS production can additionally be enhanced in K-deficient plants (Cakmak, 2005) [5]. Under drought stress, photosynthetic CO₂ fixation in K-deficient plants is substantially limited by impairment in stomata regulation, conversion of light energy into chemical energy and phloem export of photosynthates from source leaves into sink organs (Egilla, 2001) [10]. The maintenance of adequate K nutrition is critical for mitigating or preventing damage by drought stress and controlling the water balance (Abdel-Wahab *et al.*, 1995). Egilla (2005) [9] suggested that increasing extra chloroplastic K⁺ concentrations in plant cells with an excess K⁺ supply could prevent photosynthesis inhibition under drought stress. Cakmak (2005) [5] reported the requirement of K for water-stressed plants in increasing photosynthetic CO₂ fixation and transport of photosynthates into sink organs. It inhibits the transfer of photosynthetic electrons to O₂ reducing ROS production. Beside the photosynthetic electron transport, nicotinamide adenine dinucleotide phosphate (NADPH)-dependent oxidase activation represents another major source for the production of ROS in plant cells by a number of biotic and abiotic stress factors (Vranova *et al.*, 2002). NADPH-oxidizing enzymes catalyze the one-electron reduction of O₂ to O₂^{•-} by using NADPH as an electron donor (Cakmak, 2005) [5]. Cakmak (2005) [5] reported that the activity of NADPH oxidase was increased in cytosolic fractions of bean roots with increasing severity of K deficiency, resulting in an increase in NADPH-dependent O₂^{•-} generation. An improvement in the plant K supply can inhibit ROS production under drought stress by reducing NADPH oxidase activity and maintaining photosynthetic electron transport (Cakmak, 2005) [5].

In brief, K increases the cell membrane stability, root growth, leaf area and total dry mass for plants living under water stress conditions. It improves water uptake and water conservation. Thus, an adequate K is critical for plant osmotic adjustment and mitigating ROS damage originated by drought stress in plants.

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