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DROUGHT STRESS, ITS EFFECT ON MAIZE PRODUCTION AND DEVELOPMENT OF DROUGHT TOLERANCE THROUGH POTASSIUM APPLICATION

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ABSTRACT. Today, the world is facing many problems for crop production among them drought is the most dangerous. Here in this paper we have reviewed the threat of drought to food security in future especially related to maize production. Water is a cooling agent plays an important role in the functioning of plant body. Drought stress have deleterious effects on the seedling establishment, vegetative growth, photosynthesis, root growth, anthesis, anthesis-silking interval, pollination and grain formation in maize crop. The deleterious effects of drought can be mediated by application of nutrients which may enhance tolerance to drought stress. Among the nutrients potassium can enhance the tolerance in maize plant for drought stress. The application of potassium enhanced root growth and stem elongation. Similarly, potassium increased leaf water potential, osmotic potential and turgor potential under drought stress. Likewise, gas exchange parameters are improved by potassium. Application of potassium enhanced the photosynthetic rate and has better effect on other attributes. Most importantly potassium is greatly helpful in transport of sugars prepared in leaves to fruit. Potassium enhanced the yield and yield related parameters of maize crop. It seems quite important to study the role of potassium for increasing the plant tolerance to drought stress and to increase yield of crop under drought stress.

Key words: Drought stress; Maize; Growth; Drought tolerance; Potassium.

Globally, crop yield decreased by biotic or abiotic stresses. Drought, flooding, heat, wind and cold are the abiotic stresses. Agriculture scientists are facing the challenge of drought in the current situation of water shortage

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which may affect negatively the arable area. Drought is a meteorological term and takes place when there is more moisture loss from soil surface and fewer water supplies to soil in the form of rainfall or other sources of precipitation. Drought is a serious threat for crop production and food security. During the drought conditions water potential and turgor are decreased and this situation disturbs the normal functioning of plant body (Hsiao, 1973).

Drought is a worldwide problem and dangerous for arable field crops growth and subsequently for food security (Jaleel *et al.,* 2009). Currently selection criteria are applied for good variety selection as compare to breeding techniques which are time consuming (Zhu, 2002). Drought stress or water deficit stress is globally renowned feature of climate, also an alarming threat to our agriculture which could be unavoidable. Kramer (1980) studied that one third part of arable land of the world faces the water shortage which also disturb the crop production. Water is an integral part of plant body plays an important role in growth initiation, maintenance of developmental process of plant life and hence has pivotal function in crop production. Grzesiak (2001) reported the soil drought effect on growth in experiment done in glass house and concluded that genetic makeup of maize show variation in drought tolerance and is better manipulated under severe conditions of drought.

Potassium is a macro-nutrient and plays an important role in crop growth and development (Marschner, 1986). It has great role in cell expansion and maintain the turgor pressure of plant. Potassium assists in osmoregulation of cell, help in opening and closing of stomata (Hsiao, 1973). Potassium activates more than 60 enzymes (Tisdale *et al*., 1990). Potassium has promoter effect on the growth, development and grain yield in maize plant (Davis *et al*., 1996). The maize crop requires potassium as much as that of nitrogen for six metric tons grain production while maize removes 120 kg N, 50 Kg P and K per hectare from soil (Bajwa and Rehman, 1996). Potassium is being decreased in soils of Pakistan rapidly. It is due to the low application (0.8 kg/ha/year) of potassium in Pakistan as compare to global average use of K (15.1 kg/ha/year) (Ahmad and Rashid, 2003).

Drought stress effects on maize plant

Effect of drought on seedling establishment

It was studied that maize seedlings adapt to low water potential by making the walls in the apical part of root further extensible. This is due to the increase in expansion activity and some other complex phenomenon. If drought occurs at seedling stage, it enhanced root growth and adaptation of maize hybrids to drought stress. Sacks *et al.* (1997) studied the effect of drought stress on the cell division in the meristem of primary root of maize plant seedlings and concluded that drought stress resulted meristematic cells to be long and cell division reduced along with per unit length of tissues and cell in all the meristem. Ţerbea and Ciocăzanu (1999) reported the response of some maize crop inbred lines seedlings sown under limited water availability. Such kind of evaluation declared that under normal supply of soil moisture, the variability of maize genetics for above given parameters was less marked than under limited moisture supply. Grzesiak (2001) reported the effects of soil water deficit conditions on growth in a glasshouse experiment and found that in maize different varieties have different potential for drought tolerance against drought and salinity. Early stage of seedling growth and establishment is very sensitive to drought. Thus cessation of elongation and expansion of cell stops growth of seedling (Anjum *et al.,* 2003a; Bhatt and Rao, 2005; Kusaka *et al.,* 2005; Shao *et al.,* 2008).

Effect of drought on vegetative growth

Growth of cell is severely sensitive to water deficit conditions. Sharma and Bhalla (1990) made diallel crosses of six drought tolerant lines of maize crop with one drought sensitive variety under rain fed situations in which dominance gene action could be important for number of stomata and number of leaves. Following parameters such as: root length, fresh root weight and root shoot ratios were taken. Elongation of stem in maize under drought stress was reduced during vegetative stage. It was studied that drought tolerant varieties generate more fresh and dry weights of stem as compared to sensitive one (Ashraf, 1989). Drought tolerant maize hybrids attained larger leaf area under drought stress as compare to drought sensitive maize hybrids.

Effect of drought on root growth

Research work showed that root weight increased while shoot weight decreased with the application of water deficit stress (Morizet *et al.*, 1983). It was found that drought reduced fresh and dry shoot and root weight by 40 and 58 %, respectively. Drought stress decreased the length and fresh weight of shoot in maize (Thakur and Rai, 1984). It was found that the most drought resistant varieties had maximum root fresh weight that was the best symptoms and characteristics for identification of drought resistance of crop plants such as maize. It was also observed that drought resistant varieties De Kalb C42y and M351 had greater root weight and volume along with longer roots as compare to less drought resistant varieties.

The experiments conducted in green house to study the effect of drought stress on the vegetative and root growth of maize and it was found that drought stress reduced shoots and root growth (Ramadan *et al*., 1985). Wu and Cosgrove (2000) observed that the root-shoot ratio of plants enhanced under limiting availability of water. The increase in ratio was due to the reason that roots are comparatively less susceptible to water deficit condition than shoots growth. It was screened out that this adaptation to low water potential was due to the role of xyloglucan endotransglcosylase, peroxidase and some other wall enzymes in roots of plants. Hu *et al.* (2007) reported that drought and salinity stress decreased the seedling fresh weight and these results were also same for maize crop plants. Benett and Hammond (1983) verified that only minimal saving of irrigation water could be attained by applying normal water stress at the time of vegetative growth of maize. Betran *et al.* (2003) studied in maize plant that variation in yield among the hybrids and inbred lines increases with the intensity of water deficit stress. Dass *et al.* (2001) screened 166 genetically differ lines of maize under different artificially provided stress conditions such as control, mild stress, intermediate stress and severe stress and found that plant height was severely affected when irrigation water was stopped at knee height and maximum genotypes were screened out.

A developed root system is constitutive feature in many environments. The roots help the plants to absorb water and minerals for their better use. Roots are also important component of drought tolerance at the various growth stages of plant (Blum, 1996; Weerathaworn *et al.*, 1992). The maximum accumulated water in the root zone depends on the anchorage of roots in the soil volume. Under the limited supply of water resource allocation pattern changes; root tissues gain more assimilates as compare to leaf tissues. If drought stress prevails at the early seedling stage the root-shoot changes (Nielson and Hinkle, 1996a) and commonly increases (Sharp and Davies, 1989). The long life span of plant helps to gain more biomass and hence high productive (Blum, 1996). Studies of Anderson (1987) clarify that rapid development of root occurs during the first eight weeks after planting. He also found that under the adequate rainfall the root system of maize plant that has established during the first 60 days can assist the plant till maturity. While in the moisture limited situation root growth may continue during the whole life span of maize plant. The current research work done by CIMMYT has inquired the prolific area of roots to absorb water in the root zone and this parameter may be used as selection criterion for improving drought tolerance. In the research the greater emphasis has been made on the point whether the more number of brace roots and extensible development of fine roots allow the formation of shoot biomass (Edmeades *et al.*, 2000).

Effect of drought on photosynthetic activity

It was studied that drought diminished the photosynthesis and it was also found that grain growth during endosperm cell division was more sensitive to drought as compare to deposition of starch in the seed. In the photosynthetic mechanism drought affects photo-system-II more severely as compare to photo-system-I. In this way free high energy electrons are produced in the leaf. These uncoupled electrons transport results to photo-oxidation of chlorophyll and loss of photosynthetic ability occurs. Activity of enzymes reduces under drought stress. For instance formation of starch from sucrose in grain decreases as the ability of acid invertase diminishes.

Optimal leaf area establishment is vital criterion for photosynthesis maintenance and dry matter production. Photosynthetic pigments are used specially for capturing light and reducing powers production. Dryness of soil affects the chlorophyll a and b activity (Farooq *et al.,* 2009) while carotenoids are the compounds which support the plants to withstand against drought stress. Photosynthesis directly depends on relative water contents and leaf water potential. Decrease in relative water contents and leaf water potential decreases the speed of photosynthesis (Lawlor and Cornic, 2002). Meanwhile the discussion among the plant scientist continues whether photosynthesis decline is due to stomatal closure or due to metabolism destruction (Lawson *et al.,* 2003; Anjum *et al.,* 2003b). However, stomatal closure or other reasons which slow down photosynthesis has been considered the main reason of drought stress (Farooq *et al.,* 2009).

Effect of drought on reactive oxygen species (ROS)

Drought disturbs the series of developmental processes such as growth, organ development, flower production and then grain filling. As the drought situation prevails stomata closes progressively as a result of which photosynthesis and water use efficiency terminated to decline. The enzyme activity is also dependent on moisture availability. This decrease in photosynthetic CO_2 fixation activates the molecular O_2 for extensive production of reactive oxygen species (ROS). These reactive oxygen species (ROS) damage the chloroplast and cell membrane. ROS are mainly produce in chloroplast which are; superoxide radical (O^-_2), hydrogen peroxide (H_2O_2) and singlet oxygen ($1O_2$) during the process of photosynthesis (Asada, 2000). Chloroplast produce high amount of ROS, when plants are under environmental stresses like drought, chilling, deficiency of fertilizer nutrients and salinity (Foyer *et al.,* 1994; Asada, 2000; Vranova *et al.,* 2002). These reactive oxygen species (ROS) are extremely harmful causes membrane damage, damage chlorophyll then leads to necrosis and chlorosis development. In the normal situation, 20% of electron flux in the photosynthesis is transferred to molecular O_2, which results to form O_2^- and other reactive oxygen species (Biehler and Fock, 1996; Cakmak, 2000). The consumption of light energy during CO_2 fixation diminishes due to the influences of biotic or abiotic stresses. Under this condition electron flux to O_2 increases which increases the addition of ROS in the chloroplast under such condition of low consumption of light energy, excitation energy also transfer to O_2 which create highly toxic ROS. ROS production in chloroplast under environmental stress increases when plants are exposed to high light intensity under such kinds of conditions prevail in Pakistan. These ROS also provide photo-oxydative damage to chloroplast. Many examples have been observed that if plants are exposed to high light intensity and environmental stress at same time produce quickly chlorosis and necrosis (Cakmak and Marschner, 1992; Foyer *et al.,* 1994; Wise, 1995; Huner *et al.,* 1998; Cakmak, 2000; Choi *et al.,* 2002). One of the main factors that are responsible for the reduction of growth and yield of crop plant is the production of ROS in the cell organelles like chloroplast, mitochondria and peroxisomes (Asada, 2000). The ROS destroy membrane lipids, enzyme proteins and nucleic acids (Cakmak, 2000).

Effect on reproductive growth

The period from one week before silking to two weeks after silking is quite important because abortion of ovules, kernels and ears may occur. Drought stress during this period initiates this process (Uhart and Andrade, 1995). Andrade *et al*. (2000) studied that water deficit stress decrease the carbon availability and dry matter partitioning to ear at the critical stages and these factors determine the number of grains. It is a fact that when drought stress starts to affect the plant during the reproductive stage the plant reduces the demand of carbon by decreasing the size of sink. As a result of it tillers degenerate, flower may drop, pollen may die and ovule may abort (Blum, 1996). The inherently characters of maize may have more potentials for ears, ovules and kernels as compare to produce at the time of maturity (Tollenaar, 1977). The abortion of ovule may take place if silks fail to extrude because of slow growth. The abortion of kernels takes place after proceeding of pollination. Westgate and Boyer (1986) has studied that low water potential at the time of pollen shedding does not restrict the pollination but due to the lack of photosynthesis it prevents the development of embryo. During the supply of assimilates to ear when it drops below to threshold that is compulsory to ovule development, abortion of the entire kernels take place resulted to barren cob (Edmeades *et al*., 1993). To study the factors affecting kernels development and grain yield, the number and size of kernels are important to understand (Bänziger *et al*., 1999).

a. Effect on pre-anthesis stage

In maize plant any kind of stress decreased number of grain per plant. Number of pollen could be decreased with increasing drought stress (Hall *et al*., 1981). Drought stress before one week to silking and two weeks after silking decreased the grain yield (53% of the non-drought stressed) (Denmead and Shaw 1960; Claassen and Shaw 1970). Limited supply of moisture to plant at vegetative growth stage make the final leaf area of plant smaller hence utilization of carbon will be less in the whole growing season of plant (Nilson and Orcutt, 1996). The storage of reserves in the ear shank and stem are dependent of the situations under which the assimilation takes place before the initiation of flowering. It has been studied that prolonged drought conditions during the vegetative stage affect the length of internodes by disturbing cell size development and assimilate storage (Denmead and Shaw, 1960). It is a matter of great concern that under the normal conditions (no drought) stored reserve has little role in the success of reproductive process (Schussler and Westgate, 1995), but when photosynthesis is limited at the grain filling stage the stored reserves are reutilized to fill grains (Blum, 1996). The effects of water deficit stress on the leaf area decrease the assimilation and extent of it (Blum, 1997). The important strategy to overcome the water use of drought stressed plant is the plasticity in leaf area (Blum, 1996).

b. Effect of drought on anthesis-silking interval

It has been studied that water deficit stress increase the interval between silking and anthesis resulted to reduced grain filling duration of all the hybrids, however drought stress had little effect on the physiological maturity of maize crop (Fiedrick *et al.*, 1989). In maize plant flowering, silking, pollination and grain formation are the sensitive stages of vegetative and reproductive growth. Continuance of drought stress during flowering leads to ear growth and silk appearance reduction. This results to expansion of gap between anthesis and silking.

At the time of reproductive stage of maize if drought occurs it delayed the silking however anthesis is delayed little bit. In this way anthesis-silking interval (days from anthesis to silking) gap increased which could be important reason for the failure of crop under drought stress or this may be directly correlated to kernel set (Byrne *et al.*, 1995). The studies on the maize hybrids show that effect of reduced number of pollen grains on the number of grain occur when pollen quantity reduced to 80% or more or when anthesis silking interval reached to 8 days or more (Bassetti and Westgate, 1994). Edmeades *et al.* (2000) found that anthesis-silking interval is a good indicator of movement of recently produced assimilated to the ear, cob growth, number of grains and also the water potential of plant.

Effect of drought on grain yield

Due to shortage of water to maize crop grain yield reduced if water deficit occurs during the critical growth stages from tasseling to grain filling. Bergamaschi *et al*. (2004) studied that during 1998/'99 a long period drought, 48.8 mm rainfall produces 4.8 t/ha of grain yield. On the other hand during the year 2002/2003 a short duration drought that occurred during critical growth period reduced the grain yield up to 2 t/ha. Dai *et al.* (1990) reported that mild water stress inhibited the growth and development of all the hybrids at different growth stages maize crop and also had effect on yield.

Maize production in drought stress environment

Among the three major cereal-grain crops (maize, sorghum and pearl millet) growing in sub-humid to semi-arid regions, maize crop produces the maximum yield as compare to others when water is applied in excess quantity and soil is fertile enough but the maize crop is least tolerance to drought stress (Muchow, 1989). Maize is being removed by sorghum and pearl millet when average rainfall decreased to 600 mm. But due to its socio-economics importance, development of short duration varieties and because maize grain is the most protected from bird it is also being grown even in semiarid tropics (Carberry *et al*., 1989).

Maize is being grown in drought prone and marginal lands having low fertility level in South East Asia. Approximately 50% tropical low land maize grown in South East Asia is considered to facing the grain yield because of drought stress and also due to low nitrogen supply (CIMMYT, 1994). According to estimates done by International Maize and Wheat Improvement Centre (CIMMYT) related to abiotic stresses the most important reason for low yield on farmer fields are low fertility and drought conditions (Edmeades and Deutsch, 1994). As the mineral and organic fertilizers are the most expensive similarly irrigation water is becoming scarce in maize fields. Farmer should adopt the maize production strategies to decrease the yield losses in semi-arid tropics are to select short duration varieties and sowing at proper time when drought stress may occur at late vegetative, flowering and rain filling stages (Abrecht and Carberry, 1993). CIMMYT has made a reality check to determine the potential of maize varieties for yield in drought-prone areas. Approximately 20% of yield gap between actual yields in drought conditions and yield potential can be achieved by breeding (Muchow, 2000). Further 20% can be achieved by doing water conservation practices and remaining 60% yield gap may be achieved by additional water supply.

Induction of drought tolerance in maize

Plants tolerance to abiotic stresses is very complex mechanism as various molecular, biochemical and physiological phenomenon are required to understand which disturb growth and development of crop plants (Razmjoo *et al.,* 2008). Crop with utmost yield potential could perform well even under moderate drought stress (Smirnoff, 1993; Jaleel *et al.,* 2009). Drought is the most important environmental agent which decreases growth and development of plants among all the environmental stresses (Shaw, 1988; Sadras and Milroy, 1996; Aslam *et al.,* 2006). It has been considered a serious yield limiting factor in developing countries (Ceccarelli and Grando, 1996). Hence this water shortage in Pakistan fabricate the varieties of maize crop which are drought tolerant and are able to provide high yield under drought by the provision of fertilizer nutrients, especially potassium (Kitchen *et al.,* 1999). The current water shortage may be devastating quandary for food assembly in future, hence could put human being under alarming state of life and death.

The mechanism of drought tolerance involves many physiological and biochemical processes. These include reduction of water loss by enhancing stomatal resistance, developing deeper root system and more uptake of water, deposition of osmolytes and production of osmoprotectant. Detoxification of ROS by enzymatic and non-enzymatic ways stability of plasma membrane, synthesis of aquaporins and stress proteins are the special mechanisms of drought tolerance (Farooq *et al.,* 2008).

Use of potassium (K) for drought tolerance

It is estimated that the share of environmental stresses to our global losses of crop production is becoming very alarming (Bray *et al*., 2000), if we did a comparison of losses done by biotic and abiotic stresses, the losses done by abiotic stresses are very high. It was reported that 60% of soils of the world have nutrients deficiency or toxicity problem for crop production (Cakmak, 2002). Addition of drought stress with nutrient deficiency and toxicity is responsible for severe losses of crop production in the entire globe. However, the survival and productivity of crop plants exposed to environmental stress are dependent on the ability of crop plant tolerance against the drought stress. In this way mineral nutrients in plant body can enhance its tolerance to drought stress. Among these nutrients K is important nutrient to develop tolerance in the plant body. Under the limited supply of K, leaf chlorosis and necrosis develop and disturbance of growth takes when plants exposed to high light intensity. The low quantity of K in the plant body decreases the photosynthetic, carbon metabolism and also the consumption of fixed carbon resources (Cakmak and Engels, 1999; Mengel and Kirkby, 2001), as a result of this huge deposition of carbohydrates take place in the source leaves. As a result of these changes of photosynthetic carbon (C) metabolism excess of non-utilized light energy and photoelectron are there in the plant bodies which create photo oxidative damage to plant body.

The potassium present in cytosol could not be replaced by any other cation hence any decrease of cytosolic K concentration will affect the potassium specified functions in plant body especially the large number of reactions are dependent on the potassium (Marschner, 1995). It is of quite important to note that deficiency of potassium may be appeared on the plant leaves but this deficiency could not be fulfilled at later stages of growth (Bergmann, 1992). Application of potassium may increase the yield, 1000 grain weight and shelling percentage over control. Application of potassium can enhance the uptake of it and also the available potassium contents in soil (Roy and Kumar, 1990).

Potassium is an important element required for plant growth and development that is involved in activation of more than sixty enzymes. Potassium creates immunity in plants body against drought and high temperature as well as diseases. Potassium helps the plant body to produce starches, enhance root growth, control stomatal conductance for better water use efficiency. All plants require potassium but those plants require more which are high in carbohydrates. Studies on crop plants shows that potassium enhances the shelf life of fruit, enhances the length of stem along with root length (Maser *et al.*, 2002).

In the earth crust potassium is the seventh most abundant element even then only one to two percent can be taken up by plants while other is fixed. Hence potassium is applied to crop plant to fulfill its requirement. Potassium is obtained from mining or from evaporation of solution pumped out from below the soil surface or from natural salt lakes like Great Salt Lake in USA and Dead Sea on the western border of Jordan. The deficiency of potassium is a big nutritional disorder. It is essential for crop production and quality improvement. The plants with K paucity under drought are highly susceptible to light with high intensity and become necrotic and chlorotic quickly. Impairment in stomatal regulation, transfer of light energy into chemical energy, transport of assimilates from source to sink and disturbance in photosynthetic CO_2 fixation are the main disorders of K deficiency. Plants exposed to high light intensity are more sensitive to it if K supply is limited. Plants develop rapidly chlorosis and necrosis if exposed to high light intensity and are K deficient (Marschner and Cakmak, 1989; Marschner *et al.,* 1996).

Potassium has major role in maintenance of photosynthesis and other related mechanisms. Different studies show that K deficiency decreases the photosynthesis severely. This decrease of photosynthesis by low K status in plant becomes more prominent when plants are provided with high concentration of CO_2 and O_3. This clarify that CO_2 enrich environment around plants enhance the plants requirement for K. Due to the current increase in the global CO_2 requires further investigation about the supply of K in the recent passing century. Photosynthesis in the K deficient plants also decreases due to restricted stomatal conductance, enhancing mesophyll resistance and diminished ribulose bisphosphate carboxylase activity (Cakmak and Engels, 1999; Zhao *et al.,* 2001). For the continuation of photosynthesis at high speed it is obligatory for photosynthates to be exported from source to sink. Under high K application the concentration of sucrose in source leaves increases many folds (Marschner *et al.,* 1996; Bednarz and Oosterhuis, 1999; Zhao *et al.,* 2001). All above conclusions are related to the results that K deficiency disturb the export of assimilates from source to sink (Cakmak *et al*., 1994). The field experiments conducted in Egypt shows that reduction in yield by restriction of irrigation may be eliminated by K application (Abd El-Hadi *et al.,* 1997). Under such kind of considerations in our mind, it can be clarify that enhancing the concentration of K in plants body parts could be of significant importance for obtaining high sustainable yield under drought situation (Valadabadi and Farahani, 2009).

Abortion of kernels at the top of cob and smaller grain size may be resulted due to the deficiency of potassium (Bly *et. al* 2002). Morphology of cell on leaf surface of maize plant is greatly affected by K nutrition. Alongside the roles of potassium on plant body it also increase efficient use of other fertilizer nutrients. The accumulation of potassium in plant body is depended on for what purpose crop has been sown. At the early stage of crop growth the concentration of potassium changes rapidly due to the difference in K uptake and dry matter production. Hence for the maximum uptake of potassium rapidly available supply of potassium is required in the soil. However this supply of potassium depends on many factors such as length of growing period and period of rapid uptake. On the one side soil profile may contain sufficient potassium to fulfill the crop requirement however during the peak growing periods this supply may be disturbed. Plants absorb potassium from the soil solution which is minute quantity to fulfill the needs of plant.

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