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Managing Water Stress by Potassium Fertilizer in Legumes for Sustainable Agricultural Intensification: A Review

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ABSTRACT

Water stress has become the most uncontrolled and unpredictable factor, which is continuously limiting production in crops. Legumes are the major source of protein and are well-recognized for their nutritional benefits as well as their impact on the sustainability of agricultural systems are well known. Leguminous crops are severely affected by water stress causing alterations in various development processes. Proper nutrient management helps in attaining economical legume yields from drought-prone lands. The protective role of potassium in plants suffering from water stress has been documented and it positively influences plant capacity to adjust water stress conditions. This review compromises the information on the water stress-induced harmful effects on legumes growth, nitrogen fixation, gaseous exchange and mineral uptake parameters and proposes appropriate management by potassium application to alleviate the severity of water stres on above mentioned parameters. Application of potassium proved to meet higher yield from legume on cultivation under low/residual soil moisture availability conditions.

Key words: Legumes, Nitrogen fixation, Nutrient uptake, Photosynthesis, Potassium, Water stress.

An expansion in the aggregate food production for ever-increasing world population is the key difficulty in the 21st century. Drought is a major and the most unpredictable constraint, with adverse effects on crop production worldwide (Hussain *et al*. 2018). The occurrence of drought at any growth stage has a potential to decrease crop yield by inducing deleterious effects on plant physiological and biochemical processes. Majority of leguminous crop area is under rain fed conditions hence, the production of these crops has declined in India. Application of potassium improved the ability of plant to tolerate osmotic stress in drought by minimizing its negative effects and enhancing the uptake and translocation of water to maintain a balance in plants (Adhikari *et al*. 2019).

Effect of water stress on legumes

Drought frequency and severity limit grain yield, plant biomass and related components of legumes (Ghassemi-Golezani *et al*. 2013). Under terminal drought, grain yield in chickpea can decreased upto 70%, mainly due to reduced pod production (Behboudian *et al.* 2001) and increased pod abortion (Leport *et al.* 2006; Guneri *et al.* 2018). Moreover, declining soil moisture and increasing temperature in these periods (Ganjeali *et al*. 2011) also cause a reduction in yield for chickpea. In cowpea and pigeon pea, water stress during flowering and pod formation stages cause senescence and abscission of leaves and hence the yield (Lopez *et al.* 1997). Li *et al.* (2018) stated that drought occurring at the seedling stage reduce yield in faba bean. Table 1 defines some observations on water stress induced harmful effects in legumes.

Potassium management under water stress

Potassium is the third macronutrient required for plant growth, after nitrogen and phosphorus and carries out vital functions in metabolism, growth and stress adaptations (Krauss and Johnston, 2002). The important functions in which potassium is involved with the plant are enzyme activation, cation/anion balance, stomatal movement, phloem loading, assimilate translocation and turgor regulation (Zorb *et al*. 2014; Erel *et al*. 2015).

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Potassium fertilizers

Potassium chloride all together (KCl or muriate of potash) accounts for approximately 95% of all potassium fertilizers used, mainly because of its lower cost. Potassium chloride in the form of granular material is best suited for direct application and dry blending because it contains a uniform particle size (Kafkafi *et al*. 2001).

Potassium-magnesium sulfate ($K_2SO_4 2MgSO_4$ or K-Mag) is an excellent source when magnesium or sulfur in addition to potassium is required. Potassium sulfate (K_2SO_4, or sulfate of potash) is preferred for chloride-sensitive crops. Potassium nitrate (KNO_3 or saltpeter) is an excellent source of potassium and nitrogen, both are not commonly used because of their higher cost.

Table 1: Effect of water stress on various parameters of legume species.

Legume	Drought dose	Reduced parameters	Reference
Cowpea	Water applied in 20 day interval at vegetative and reproductive stages	Pods and seed yield	Ahmed and Suliman 2010
Chickpea	Early pod stage	Stomatal conductance, transpiration rate and seed yield	Pang *et al.* 2017
Soybean	Reproductive stage	Reproductive structures and dry matter	Andriani *et al.* 1991
Drybean	End of the vegetative stage to physiological maturity	Leaf area, number of flowers and pod	Barrios *et al.* 2005
Soybean	At six stages	Shoot biomass and seed yield	Demirta *et al.* 2010
Soybean	Reproductive stage	Ground cover, plant biomass, yield parameter and grain yield	Ghassemi-Golezani and Lotfi, 2012
Chickpea	During flowering and grain filling stages	Plant height, chlorophyll content and yield components	Pasandi *et al.* 2014
Commonbean	Vegetative and reproductive stage	Nodulation, N_2 fixation and grain yield	Pena-Cabriales and Castellanos, 1993
Mungbean	At different time intervals	Yield components	Sadeghipour, 2008
Mungbean	At different time intervals	Yield components	Baloch *et al.* 2012

The application strategy for potassium application depends on type of soil, crop selection and seedling equipment design. Soil test results, decides or helps in choosing the best application procedure and need for additional potassium.

Potassium application methods

Soil/Basal application

Seed-placement of potassium fertilizers is usually the most effective method of application for lower rates requirements of K, provided the rate of application is not greater than the seed can tolerate. However, pulses have a fairly low tolerance to seed placed potassium and seedling damage from the salt-effect can result from over application. Side-band placement is an efficient means of applying potassium and much safer than seed placement, particularly when higher rates of potassium must be applied. Banding, also referred to as deep banding, places the potassium into the soil in a concentrated band prior to seeding. Broadcasting application of potassium fertilizer helps in building up soils extremely deficient in potassium or for use with forage crops. In situations where banding equipment is not readily available and seed placement is too risky, broadcast incorporation proves to be useful.

Foliar application

This application of potassium proved to be more proficient to minimize drought stressed injuries (Hu *et al.* 2005). In some cases *e.g.*, sandy soil, waterlogged conditions, potassium is applied as a foliar spray (Sarkar and Malik, 2001). However, the effectiveness of the foliar spray is dependent on the absorption capacity and penetration into leaves therefore, it can only partially compensate for insufficient uptake by the roots. Foliar application of potassium not only increases the tolerance of plants to drought stress but also helpful in maintaining the osmotic potential and water uptake and has a positive effect on stomatal closure. Moreover a large variety of enzymes which are concerned in photosynthesis, water use efficiency, nitrogen uptake and protein building are also activated by foliar application of potassium (Nguyen *et al.* 2002).

Observations on potassium application as foliar/basal/in both combinations under water stress in legumes (Table 2).

A. Effects of water stress on growth and development in legumes and its amelioration by potassium application

Fresh and dry weight/Leaf area/Nodule number

Decrease in growth occurs due to reduced production of photosynthates and increase osmotic pressure in the root medium, which tend to decrease synthesis of metabolites, reduce translocation of nutrient from the soil to the plant as well as decrease division and elongation of the cells under water stress. Water deficit reduce the individual leaf size and leaf longevity by decreasing the soil's water potential, relative water content and photosynthesis. Leaf injury during water deficit is a common phenomenon and correlated with vulnerability to oxidative stress, accompanied by chlorophyll loss, decreased soluble protein content and changes in the ratio of chlorophylls and it is related to an increase in reactive oxygen species, lipid peroxidation and membrane leakage (Navabpour *et al.* 2003). When legumes are subjected to water stress, there is reduced availability of carbohydrate to nodules, less water for the transport of N-products away from the nodule, some direct effect on nodule gas permeability or the alteration of nodule metabolic activity. Nodules developed under limited water availability showed decreased branching, a breakdown of endodermis, greater compactness and decreased vacuolation of cells in the central tissue as compared to the control. Drought during flowering stages affected primarily nodule formation, as nodule number decreased in drought compared to control

Table 2: Legume response to potassium application under water stress.

Legume	Drought type	Potassium applied	Reference	Response to potassium application
Chickpea	100%, 50% and 25% field capacity	Foliar	Sattar *et al.* 2017	Increase in fresh and dry biomass
Mungbean	Intermittent stress	Foliar	Thalooth *et al.* 2006 Majeed *et al.* 2016	Improves growth and yield
Lentil	Terminal stress	Foliar	yadav *et al.* 2019	Improves yield parameters
Mungbean	Terminal stress	Soil	Fooladivanda *et al.* 2014	Enhancement in yield and yield components
Maize	Limited irrigation	Foliar and Soil	Amanullah *et al.* 2016	Higher yield and yield components

(Miao *et al*. 2012). Oxidative damage has been proposed by several authors as one of the most important mechanisms mediating nodule senescence in stressed nodules, due to the high content of oxygen-labile proteins, leghemoglobin and catalytic Fe (Becana *et al*. 2000) in nodules. This in turn can damage biomolecules, such as lipids and proteins, thus contributing to nodule senescence. Observations by several authors on water stress induced effects on legume *spp*. (Table 3).

Potassium promotes root growth of legumes under water stress and mitigates the adverse effects of moisture stress by increasing translocation and maintaining water balance within plants (Walker *et al*. 1998). In addition, the increase in the rate of photosynthesis, leaf area, accumulation of sugar and decreased rate of respiration under the influence of potassium may be the reason of increase in fresh weight of different plant parts. Potassium affects photosynthetic capacity positively because of the dependence of protein synthesis and developmental processes on potassium. Thus, the carbon exchange rates of an expending leaf are restricted rapidly after the onset of potassium deficiency. Application of potassium sulfate increased stem fresh weight and total fresh weight at physiological maturity (Almodares *et al*. 2008). The exogenous application of potassium significantly increased total plant fresh weight dry weight, leaf area and nodule number under all levels of water stress in various legume (Table 4). In potassium deficient plants, sclerenchyma fiber cell and woody parenchyma cells become thin and poorly lignified cell walls result into reduced shoot weight. The loading of potassium ion into the xylem most likely mediated the xylem hydraulic conductance that aided plants in maintaining cell turgor, stomatal aperture and gas exchange rates as part of their drought adaptations (Oddo *et al*. 2011). Potassium increases total leaf area and hence, photosynthesis, this further increases progressive translocation of photosynthates towards roots system for use by nodules and hence improves root nodules, both in size and number. Potassium also serves as a cofactor that is required for the action of the enzyme needed to transport carbohydrates across cell membranes and into the phloem. Once in the phloem, these sugars can move quickly into the root system to stimulate the growth of new root hairs as well as nodule development and function.

Table 3: Decrease in potential traits in legumes under drought.

Traits	Leguminous crops	Reference
Fresh and dry weight	Common bean	Ashraf and Ibram, 2005
	Mungbean	Tawfik, 2008
	Fababean	Al-Amri, 2019
	Common bean	Amede and Schubert, 2005
	Chickpea	Abdela *et al.* 2020
Leaf area	Cowpea	Manivannan *et al.* 2007
	Fababean	Ali *et al.* 2013
	Soybean	Shawquat *et al.* 2014
	Maize	Martineau *et al.* 2017
Nodule mass and number	Soybean	Marquez-Garcia *et al.* 2015
	Chickpea	Kurdali *et al.* 2002
	Mungbean	Farooq and Bano, 2006
	Common bean	El-Enany *et al.* 2013
	Peanut	Pimratch *et al.* 2008

B. Effects of water stress on nitrogen fixation and nitrate reduction in legumes and its amelioration by potassium application

Nitrogenase activity/Leghemoglobin content/Nitrate reduction

The inhibitory effects of water stress on nitrogen fixation caused by several factors including impairment in the nitrogenase activity, decrease in the supply of photosynthate to the nodules to drive symbiotic nitrogen fixation, breakdown of the oxygen diffusion barrier and loss of leghemoglobin (Arrese-Igor *et al*. 2011). The limitation of nitrogen fixation by inadequate supply of photosynthate to nodules has been reported in pea nodules (Galevz *et al*. 2005). Moreover, the impairment of sucrose metabolism within the nodule could be responsible for the nitrogen fixation decline by limiting the carbon flux for bacteroid respiration. The main carbon source transported from the shoot into the nodules is sucrose, which may be hydrolysed by either sucrose synthase (SS) or alkaline invertase (AI). Hydrolysis by SS produces fructose and UDP-glucose, whilst AI hydrolysis produces glucose and fructose. It has been suggested that the decline in SS activity in the nodules during water-deficit may be responsible for the reduced metabolic potential.

Table 4: Observations on exogenously applied potassium in legume growth and development under water stress.

Traits	K fertilizer	*Legume sp.*	Reference
Fresh and dry weight	Potassium oxide	*Glycine max.*	Hatami *et al.* 2010
	Potassium sulfate	*Vigna radiate*	Fooladivanda *et al.* 2014
	Potassium chloride	*Vicia faba*	Abdelwahab and Abdalla, 1995
Leaf area	Potassium sulfate	*Cyamopsis tetragonolobus*	Ayub *et al.* 2012
	Potassium sulfate	*Glycine max*	Ohashi *et al.* 1999
	Potassium thiosulfate	*Vicia faba*	Emam and Semida 2020
Nodule mass and number	Potassium oxide	*Glycine max*	Abdelhamid *et al.* (2011);
	Potassium chloride	*Vicia faba*	Abbasi *et al.* (2012)
			Abdelwahab and Abdalla, 1995

Gonzalez *et al*. (1995) found a rapid decline of both sucrose synthase (SS) activity and protein content in soybean plants subjected to a moderate water stress. Contrary to these reports, depression of nitrogen-fixation during reproductive period has been attributed to some factors other than photosynthesis. Djekoun and Planchon (1991) showed that nitrogen fixation was more sensitive than photosynthesis to moderate water deprivation thus SS decline does not seem to be triggered by photosynthate shortage. Steeter (2003) reported that the major decrease in N_2 fixation activity was due to the lower demand for fixed N to support growth, not due to carbon supply to bacteriods. Guerin *et al*. (1990) suggested that metabolic potential, defined as the sum of the nodule biochemical machinery and its capacity to support nitrogen fixation at maximum rates, may also be reduced, since they were unable to overcome the inhibition by raising the concentration of oxygen. Drought might finally also affect expression of nodule specific cysteine-rich antimicrobial peptides (NCR AMPs) essential for bacteroid development and found in legumes with indeterminate nodules (Mergaert *et al*. 2003; Horvath *et al*. 2015). Such inhibitory effects have been reported in legumes such as broad bean (Plies-Blazer *et al*. 1995), common bean (Ramos *et al*. 2003) and soybean (Kunert *et al*. 2016). Nitrogenase activity was significantly decreased as a result of imposed water deficit levels (75% and 50% FC) in cowpea (El-Enany *et al*. 2013). With progressive soil drying, nitrogenase activity of the nodulated roots of soybean significantly decreased by 17.73 per cent as compared to control (Tint *et al*. 2011). Specific nitrogenase activity was severely depressed even under a slight soil-water deficit (Abd-Alla and Abdel-Wahab, 1995). Leghaemoglobin considered to be an index to nitrogen fixing efficiency and their total content is known to decrease under different stress conditions (Muneer *et al*. 2012). The degradation of leghemoglobin during water stress may contribute to the loss of C_2H_2 reduction and may affect the pattern of recovery upon rewatering (Guerin *et al*. 2006). It has been reported that leghaemoglobin content declined in dehydrated nodules subjected to severe drought (Figueiredo *et al*. 2008). The leghemoglobin content decreased significantly with an increase in water stress in chickpea (Swaraj *et al*. 1995), faba bean (Abd-alla and Abdel-Wahab, 1995) and in cowpea (Lobato *et al*. 2009). Nitrate reductase plays a key role in nitrate assimilation. The nitrate reductase is an efficient indicator because it is the first enzyme involved in the nitrogen metabolism, moreover, this enzyme shows a quick response under inadequate conditions for the plant; it is also extremely sensitive to the biotic and abiotic changes (Lobato *et al*. 2008). Previously, it has been shown that changes in NRA under drought were dependent on the inherent capability of a given cultivar to respond to drought, potassium supplies and growth stage (Zhang *et al*. 2011). Water stress may decrease nitrate reductase activity either by inhibiting nitrate uptake or protein synthesis. In an intact plant, reduced transpiration pull during water stress may cause a decline in nitrate flux into the tissue. Drought was found to induce a greater reduction in NRA of the drought-sensitive cultivar S911 than of the drought-tolerant S9 of *Zea mays* at different growth stages (Zhang *et al*. 2014). A decrease in nitrate reductase activity of leaves under moisture stress condition has been reported in pigeonpea (Mukane *et al*. 1993) and chickpea (Singh *et al*. 1993).

Application of potassium helped in offsetting the decrease in various parameters associated with N_2 fixation (Table 5).

C. Effects of water stress on gaseous exchange parameters in legumes and its amelioration by potassium application

Photosynthesis/Respiration

The net photosynthetic rate was significantly affected under water stress (Zareian *et al*. 2013). The first response of plants to acute water deficit is the closure of their stomata to prevent the transpirational water loss which is the major reason for reduced rates of leaf photosynthetic activity. However, some of the physiologists claim that impaired ATP is an explanation for this reduction of photosynthesis under water stress (Lawlor and Cornic, 2002). Moreover, Water stress affects various events of photosynthetic processes such as CO_2 assimilation, photosynthetic transport system and photophosphorylation and activity of a number of enzymes associated with photosynthesis. Water stress also inhibits the photosynthesis of plants by causing changes in chlorophyll content, damage the photosynthetic apparatus and decreases the activities of Calvin cycle enzymes (Monakhova and Chernyadev, 2002). The reduction of relative water content strongly reduced photosynthesis and

Table 5: Observations on potassium induced N_2 fixation parameters.

Legume	Enhanced factors	Reference
Broad bean	Carbohydrate turnover in the nodules and ATP	Mengel *et al.* 1974
Bean	Partitioning of above ground N to the seeds	Thomas and Hungria, 1988
Fababean	Nodulation, nitogenase activity and leghemoglobin content	Abdalla and Abdelwahab, 1995
Common bean, faba bean	Nodulation and symbiotic N_2 fixation	Sangakkara *et al.* 1996
Soybean	Nitrogenase activity	Abdelhamid *et al.* 2011
Chickpea	Leghemoglobin, nitrogenase, nitrate reductase activity and nitrate content	Singh and Kataria, 2012
Maize	Nitrate reductase activity	Zhang *et al.* 2014
Mungbean	Nodulation, nitrogenase and nitrate reductase activity	Kataria and Singh, 2020

stomatal conductance. Previous studies indicating decreased rate of photosynthesis under soil water deficits in mungbean (Sangakkara *et al.* 2001), in soybean (Atti *et al.* 2004), in chickpea (Mafakheri *et al.* 2010) and in Fababean (Siddiqui *et al.* 2015). The rates of dark respiration are known to be highest in actively growing plant parts and it declined as soon as plant parts mature. Dark respiration declines moderately as water potential fall and stress is not too severe. A strong correlation exist between respiration rates and water content, the decreased respiration rate showed positively correlated to decrease of relative water content. Water stress led to a decline in respiration of leaves as compared to control and drastic reduction observed at soil water potential of -1.34 MPa in *Cajanus cajan* (Nandwal *et al.* 1991). Water stress affects the rate of dark respiration, but considerable respiration occurs when no net photosynthesis occur the reason for this is starting of senescence in leaves. The rate of respiration decreases during water stress due to reduced assimilation of photosynthate and growth needs. However, this behaviour may be somewhat species dependent and the rate of respiration can also increase, particularly under severe water stress (Flexas *et al.* 2005). Nevertheless, during the development of water stress, total respiration rates are usually kept within a smaller range than those of photosynthesis, resulting in a gradually increased ratio of respiration to photosynthesis ratio, *i.e.* a decreased carbon balance. Plants possess two respiratory pathways: the energy-conserving, cyanide-sensitive, cytochrome pathway and the energy-wasteful, cyanide-resistant, alternative pathway (Lambers *et al.* 2005). In soybean, water stress induces a sharp decrease in the cytochrome respiration rate concomitant with a similar increase in the alternative respiration rate, so that total respiration rate remains quite constant (Ribas-Carbo *et al.* 2005). Moreover, these changes are not accompanied by increases in alternative oxidase protein content, indicating that these changes may be regarded as a biochemical regulation. The change in respiratory rate result from damage to the mitochondria which altered substrate availability due to inhibition of photosynthesis. Moreover, this decrease creates a risk of secondary oxidative stress (Flexas *et al.* 2006). Among the studies, several described a water-stress-induced decreased respiration rate in leaves or in different plant organs (Ghashghaire *et al.* 2001; Haupt-Herting *et al.* 2001; Mohammadkhani *et al.* 2007) others showed almost unaffected (Ribas-Carbo *et al.* 2005) or even increased respiration rates in water-stressed plants (Zagdanska, 1995). The reason for increase in respiration could be ascribed to continued increase in substrate import and carbohydrate content during stress.

Potassium enhanced the rate of photosynthesis irrespective of stress level because it helps in maintaining the rate by improving relative water content and leaf water potential through osmotic adjustment under stress. Adequate potassium concentration has been shown to enhance photosynthetic rate in different legumes under water stress conditions (Sangakkara *et al.* 2001). Conversely, many studies suggest that potassium had no effect on photosynthetic rates under well-watered conditions, but potassium starvation could favor stomatal opening and promote transpiration, compared with potassium sufficiency in several plants under drought stress (Benlloch-Gonzalez *et al.* 2010). Moreover, potassium starvation increases the transcription of genes involved in ethylene production and signaling and stimulates ethylene production. The increased ethylene could inhibit the action of abscisic acid (ABA) on stomata and delay stomata closure (Tanaka *et al.* 2005, 2006). A strong relationship between potassium content in leaves and intensity of photosynthesis was observed, which was attributed to the active diffusion of potassium in guard cell thus providing necessary amount of solutes to favor movement of water into those cell so as to open up the stomata, which increase the intake of CO_2 necessary for photosynthesis. Increased level of potassium resulted in a progressive decrease in the rate of respiration under stress as well as control conditions at all the stages in *Cicer arietinum* (Singh *et al.* 1997) and *Vigna radiata* (Kataria and Singh, 2014).

D. Effects of water stress on mineral uptake in legumes and its amelioration by potassium application

Phosphorus/Potassium/Nitrogen uptake

Water deficit has strong damaging effects on the legumes uptake of minerals. Reduction in phosphorus concentration may be due to the dieback of the absorbing roots during the exposure of plants to drought. Phosphorus uptake decreased with decreasing soil moisture (Ashraf *et al.* 1998).

More reduced phosphorus uptake was recorded in the plants where drought was created at flower initiation stage (Samar *et al*. 2013). Nandwal *et al*. (1998) stated that the highest nitrogen and potassium percentage were observed in leaves of stressed mungbean plants. Phosphorus content was higher in plants irrigated every five days than plants irrigated every two and ten days in mungbean (Tawfik, 2008). In stressed plants, large numbers of organic and inorganic ions were accumulated which provide resistance against drought (Hoekstra *et al*. 2001). The increase in uptake of phosphorus at low potassium level can be explained on the basis of higher dry matter yield and their concentration in the plant at this level of potassium application (Yadav *et al*. 1991).

Potassium Uptake declined with the rise in moisture stress. Kusvuran *et al*. (2011) and Zadehbagheri *et al*. (2012) observed accumulation of potassium under drought stress in common bean. Application of potassium improved the uptake of phosphorus in plants under water deficit at all the growing stages. The nitrogen uptake increased with increasing K_2O levels as well as farmyard manure, because of increased availability of nitrogen in the soil with farm yard manure (Singh and Tomar, 1991). Nitrogen contents of the plant increased under the influence of potassium (Sarma and Ramana, 1993). The reduction in potassium uptake by the crop due to water stress could be compensated by raising the level of potassium application and improving the water use efficiency. Anderson *et al*. (1992) reported that uptake of potassium was especially high during the early vegetative stages in the period when leaf area rapidly expanded resulting in maximum accumulation of potassium and this depends upon the level of potassium application. The enhanced content of nutrients in plants treated with potassium was also observed by Patnaik (2003).

E. Redox mediated mechanism by potassiamin legumes under stress conditions

Exposure to various environmental stresses increases the development of ROS, triggering protein oxidation, chlorophylls, lipids, nucleic acids, carbohydrates and impairment of enzyme activity (Ahmad *et al*., 2010; Demidchik, 2015), causing anomalies in several essential cellular biochemical pathways. Continued photosynthetic light reactions during drought under minimal intercellular CO_2 concentration result in the accumulation of reduced photosynthetic electron transport components that could potentially reduce molecular oxygen, resulting in the development of reactive oxygen species (ROS), this leads to leaf damage and decreased photosynthesis. The reduced rate of photosynthesis is mainly due to stomatal closure. Phytohormone, abscisic acid is considered as one of the major signals of root-to-shoot stress (Jiang and Hartung, 2007), triggering stomatal closure and shifting the plant towards a water-saving strategy. Thus, by adjusting the stomatal opening, plants can control water loss by reducing transpiration flux, but at the same time limit CO_2 intake. Abid *et al*. (2016) also reported increased accumulation of ROS and oxidative stress during drought. Restricting CO_2 fixation will reduce $NADP^+$ regeneration through the Calvin cycle, hence allowing the photosynthetic electron transport chain to be over-reduced. In addition, the photorespiratory pathway is also enhanced under drought, when there is maximum oxygenation of RuBP due to limitation of CO_2 fixation. Photorespiration is likely to account for over 70% of total H_2O_2 production under drought stress conditions, showing the predominance of photorespiration on oxidative load (Noctor *et al*. 2002). Under drought pressure, the development of hydroxyl radical in thylakoids by “iron-catalyzed” reduction of H_2O_2 by both SOD and ascorbate is one of the real threats to the chloroplast. In addition, there is no known enzymatic reaction to remove the highly reactive hydroxyl radical and its accumulation will inevitably result in deleterious reactions that damage the thylakoidal membranes and the photosynthetic system. Early regulation of stomatal actions without complete stomatal closure is a characteristic technique of dry plants such as cowpea (Cruz *et al*. 1998). Plants up-regulate the activity of antioxidant enzymes and the production of non-enzymatic antioxidants during stress (Lee *et al*. 2015).

Potassium role in enhancing transport of photosynthates into sink organs, maintenance of tissue water content, photosynthetic CO_2 fixation and inhibiting the transfer of photosynthetic electrons to O_2 helps in reducing ROS production (Cakmak, 2005). Moreover, by reducing NADPH oxidase activity and maintaining photosynthetic electron transport, potassium concentration in plants inhibits ROS development under drought. Deficiency of potassium increases stress susceptibility (Jatav *et al*. 2014). Potassium can restore the growth of plants under stress by altering antioxidant metabolism, nitrogen assimilation and accumulating the osmotica. Due to potassium treatment, reduced lipid peroxidation is indicative of reduced ROS accumulation in potassium-treated plants, resulting in increased membrane stability for optimal cell function. Siddiqui *et al*. (2012) have shown reduced oxidative stress in plants treated with potassium in *Vicia faba*. Adding K salts promotes growth by providing membranes with stability by up-regulating the antioxidant defense system (enzymatic as well as non-enzymatic) and retaining tissue water content (Ahanger *et al*. 2015). Improving the activity of antioxidant enzymes due to potassium supplementation can help protect the photosynthetic apparatus by reducing toxic ROS production. Role of potassium in the modulation of antioxidant defense system are corroborative with the results of Manivannan *et al*. (2007), Alam *et al*. (2014) and Shafiq *et al*. (2015).

CONCLUSION

Based on the literature, it is clear that water stress adversely affects leguminous crops. Decrease in growth occurs due to impaired cell division and elongation because of limited turgor. Application of potassium helps plants to enhance their growth, nitrogen fixation, gas exchange capacity and nutrient uptake under water stress. Photosynthetic rate and nutrient uptake were considerably improved in potassium treated plants than stressed ones. The rate of respiration and ROS production decreased with potassium application. Thus, application of potassium has beneficial effects in overcoming soil moisture stress in food legumes. All these findings lead us to recommend that under water deficit conditions, farmers should apply potassium to minimize the negative effect of water stress.

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