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RESEARCH ARTICLE

ASSESSING THE EFFECTS OF APPLIED POTASSIUM ON SELECTED *VIGNA RADIATA* L. GENOTYPES UNDER WATER DEFICIT

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Abstract

Vigna radiata L. (Mungbean) is one of the most important pulse crops for protein supplement in a subtropical zone of the world, as it is the best alternative to meet the food needs of the large population of developing countries due to its nutritional superiority. The performance of two mungbean genotypes SML-668 and MH-318 to potassium fertilization 0.00, 1.54, 2.31and 3.08 mmol dm^{-3} in addition to the existing level of 1.32 mmol dm^{-3} in the soil medium was investigated under water deficit. Water stress (Soil Moisture Contents 4.5 ± 0.5 %) was created by withholding irrigation at different growth stage. Water stress at flowering stage caused highest reduction in leaf area (36.4%), photosynthetic rate (71.4%), total chlorophyll contents (45.2%) and dry weights of various plant parts. Dry weights of various plant parts, leaf area, photosynthetic rate, stomatal conductance and chlorophyll contents at all sampling stages were enhanced by potassium application under control as well as stress conditions. Cultivar SML-668 proved more tolerant to water stress as compared to MH-318. This study provides direct evidence of the beneficial physiological functions of potassium fertilization in mitigating the adverse effects of water stress.

Introduction

Abiotic stresses negatively influence the yield of crops up to seventy per cent (Kaur et al., 2008; Thakur et al., 2010). Tolerance to abiotic stresses is very complex, due to the intricate of interactions between stress factors and various molecular, biochemical and physiological phenomena affecting plant growth and development (Razmjoo et al., 2008; Zhu, 2001). Water stress is the most prevalent abiotic stress that limits global plant growth and productivity more severely than that caused by any other environmental stresses (Vorasoot et al., 2003; Jaleel et al., 2009). Water deficit occurs when the availability of water is insufficient to maintain plant growth, photosynthesis and transpiration (Fan et al., 2006), often stunting vegetative growth, inducing flower abortion and promoting leaf senescence (Pinheiro et al., 2004; Farouk and Amany, 2012). It has been found that nutrient status plays a vital role in improving the resistance of plants to stress conditions (Yadov, 2006). Potassium is the third macronutrient required for plant growth, after nitrogen and phosphorus (Abbas et al., 2011) and also plays a vital role in plant growth and sustainable crop production (Baligar et al., 2001). Application of potassium fertilizer could be considered a significant factor in overcoming soil moisture stress. In legumes, devastating effects of drought can be alleviated by rich potassium supply (Sangakkara et al., 2000). Yield limiting effects of water deficit could be overcome by increasing potassium supply (Damon and Rengel, 2007). However, the work done on legumes with potassium application is not well recognized in comparison to cereals and other crops (Tandon, 1992). Moreover, work done on legumes with potassium is not systematic and less conclusive.

Mungbean (*Vigna radiata* L. Wilczek), grown mainly in the central and southern regions of Asia, is one of the important and the most underexploited grain legume crop (De Costa et al., 1999). Among the various pulses grown in India, Mungbean accounts 11 per cent to the total production of pulses. It is an important crop, as it is the best alternative to meet the food needs of the large population of developing countries due to its nutritional superiority and nitrogen fixing characters (Parida and Das, 2005; Raza et al., 2012). The reactions of plants to water stress differ significantly at various levels depending upon intensity and duration of stress as well as plant species and its stage of growth (Chaves et al., 2002; Jaleel et al., 2008). Potassium has an important role either direct or indirect, under different environments, in major plant processes such as photosynthesis, respiration, protein synthesis, enzyme activation and yield of plant (Zaidi et al., 1994, Singh et al., 1997, Waraich et al., 2011). Numerous studies have shown that the application of potassium fertilizer mitigates the adverse effects of drought stress on growth of different crops such as barley (*Hordeum vulgare* L.) (Andersen et al., 1992), faba beans (*Vicia faba* L.) (Abdelvahab and Abdalla, 1995). The present study aims to investigate the effect of induced water stress on growth of mungbean plants and also aims to determine, if added potassium ameliorates the negative effect of water deficit on mungbean plants at different stages.

Materials and methods

The present study was carried out for three consecutive years (2010-11, 2011-12 and 2012-13) during summer season under net house conditions at Botany Department, Kurukshetra University, Kurukshetra. Kurukshetra, stands in the plains of North Eastern part of Haryana State, in India, between latitude (29^o-52' to 30^o- 12') and longitude (76^o-26' to 77^o-04') with an altitude of 258.4 meters above sea level. The climate of the district is of pronounced character with a summer maximum temperature as high as 45^{o}C and a winter temperature of as low as 3^{0}C. The average yearly rainfall lies between 400-500 mm. The experiment was conducted in net house in order to avoid any birds attack on the plants and interruption by rainfall. The later was done by covering the net house structure with polyethylene plastic sheet at the time of rainfall.

Experimental design:

Two genotypes of *Vigna radiata* i.e. SML-668 and MH-318 were selected for the present study.

(Figure 1)

The seeds were sterilized and inoculated with standard *Bradyrhizobium sp.* S-24 before sowing. The crop was raised in earthen pots (30 cm in diameter) lined with polythene bags and filled with 7.0 kg of dune sand. Five seeds were sown in each pot at uniform depth and distance. Thinning was done after one week of germination and only two plants of uniform size were retained in each pot. These pots were placed in the net house under natural conditions and the soil was saturated with water. Sowing was carried out at field capacity of soil. The experiment was laid out in factorial complete randomized design (CRD) with three replications.

Level of potassium: After germination (7 days after sowing), potassium was supplied in the soil in the form of muriate of potash in the following concentration in addition to the existing level (1.32 mmol dm^{-3}) in the soil medium.

a) 0
b) 1.54 mmol
c) 2.31 mmol
d) 3.08 mmol

Level of stress: Water stress was created by withholding irrigation at different sampling stages:

Treatments	Soil Moisture Content (%)
a) Control	12.0 ± 0.5
b) Stress	4.5 ± 0.5

The pots were weighed daily and depletion in soil moisture content (SMC %) was maintained gravimetrically.

SAMPLING STAGES: The plants were sampled at following stages:

i) Vegetative: 20±2 days after sowing (DAS)
ii) Flowering: 35±2 DAS
iii) 50% pod formation: 47±2 DAS

Each pot was supplied with equal quantity of nitrogen free nutrient solution (Wilson and Reisenauer, 1963) at a regular interval of 7-10 days.

Leaf area, Stomatal conductance and Growth analysis

For dry weight(g) analysis, the plants under each treatment and at different stages were removed and separated into their components i.e. leaves, stem and root and then oven dried at 70˚C until a constant weight was obtained and weighed again. Leaf area was measured using a portable leaf area meter (Systronics 211, Ahmedabad, India), as per the manufacturer's instructions. The stomatal conductance ($mmol^{-2}sec^{-2}$) was measured using porometer (AP_4- DELTA- T DEVICES- Cambridge, U.K.).

Gaseous exchange

Rate of photosynthesis and respiration were measured using infra-red gas analyser (IRGA-Model MK 225-ADC England). Photosynthesis was measured between 10.00 and 11.00 A.M. While respiration was measured during night at 9.00 P.M.

Chlorophyll content

Leaf chlorophyll contents were measured and calculated following Arnon (1949). Total chlorophyll was determined using the following equation:

Total chlorophyll (mg/l) = (20.2 x A645) + (8.02 x B663)

Statistical analysis

The data collected was analysed statistically by online Statistical Analysis (OPSTAT, CCS Haryana Agriculture University, Hisar). The significance of data obtained was judged from the critical difference at 5 % level of significance.

Result and Discussion

i. **Leaf dry weight:** Water stress significantly decreased the dry weight of leaves during all the stages and in both the cultivars. Water stress decreased the translocation of assimilates to the leaf, which lowered the amount of leaf dry weight (Gupta et al., 2005). The decrease in dry weight of leaves also occurs due to reduced rate of current photosynthesis and lower leaf turgor potential under stressed environment, which restricted the cell enlargement and division and hence reduction in expansion of leaf area, and it ultimately affected the active sink at the time of reproductive phase (Burman et al., 2002). At all the sampling stages, dry weight of leaves in cv. SML 668 was significantly higher than cv. MH-318. Dry weight of leaves reached their maximum at flowering stage after which there was a reduction. The reduced contribution of leaves to total biomass after flowering was because of the shift of active sink due to development and filling of pods and leaf abscission. Maximum reduction of 14.9%, 33.5%, and 19.4% in dry weight of leaves/plant was observed in the cv. MH-318 at vegetative, flowering and pod formation stages under stress conditions. Significant increase in dry weights in response to applied potassium under stress as well as under normal condition was observed in both the cultivars. Response to applied K was also higher in genotype SML-668 at flowering stage with a maximum increase of 37.6% in control plants at 3.08 mmol of potassium concentration. The per cent increase in dry weights of leaves was more (35.5%) at 2.31 mmol over control, but there was less increase when the concentration of potassium was further increased to 3.08 mmol. These results are in agreement with the findings of other workers who also observed the reduction in leaf dry weight under water stress in mungbean (Tawfik, 2008), mothbean (Sharma et al., 2007), groundnut (Madhusudan et al., 2002). The increase in 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 dry weight of leaves. Stimulating effect of potassium on dry matter accumulation was reported by (Sharma et al., 1992; Umar et al., 1993).

(Table 1)

ii. **Stem dry weight:** Water stress caused a significant decline in dry weight of stem at all the stages in both the cultivars. Dry weight of stem increased with the progression of growth stages as secondary branches continued to emerge out. Water stress lowers the cell turgor and causes slower cell expansion, consequently growth and development of a plant decreased that leads to a lower plant dry weights (Plaut et al., 2000). Highest reduction i.e. 15.5%, 32.3% & 15.8% in dry weight of stem was noticed in the genotype MH-318 at different growth stage. Similar findings were noticed by (Ranawake et al., 2011) who reported similar progressively reduced stem dry matter with progressive increase on moisture stress in mungbean and also by Patel *et al.*, (2003) in groundnut. Dry weight of stem increased by application of potassium in both the cultivars and at all the stages under stress as well as control conditions. Application of potassium proved to be the most effective at flowering stage in genotype SML-668 for stem dry weight with an increase of 68.0% over control.

(Table 2)

iii. **Root dry weight:** Water stress caused a significant decline in dry weight of roots/plant of both genotypes. The dry weight of root increases with the progression of growth stages, due to production of lateral and secondary branches. Highest decrease 14.2%, 24.7% and 17.6% was observed in the genotype MH-318 under water stress over control at vegetative, flowering and pod formation stage of growth. (Dhole and Reddy, 2010) found that the numbers of roots per plant decreased with decrease in water potential. Similar findings were reported by (Sharma et al., 2007). There was increase in root dry weights with increasing concentration of potassium under stress as well as control conditions. Root growth promotion by increased potassium supply was found to increase the root surface (Romheld and Kirkby, 2010).

(Table 3)

(Figure 2)

iv. **Nodules dry weight:** Water stress caused a significant decline in dry weight of nodules /plant in both the cultivars. Dry weight of nodules reached their maximum at flowering stage under control as well as stress conditions, after which there was a reduction in dry weight of nodules. This reduction was due to severe senescence and an arrest in the development of new nodules under the imposed stressful conditions and decaying of nodule. Maximum decrease in dry weight of nodules was observed in genotype MH-318 with 15.5%, 23.1% and 20.5% for all the stages under moisture stress. Water stress delays nodule formation in leguminous crops (Reddi and Reddy, 1995; Sharma et al., 2007; Sangakkara et al., 1996). When legumes are subjected to water stress, following functions of the stressed plant affect the nodule (Streeter, 1993), (1) reduced photosynthesis and therefore reduced availability of carbohydrate (2) less water for the transport of N-products away from the nodule (3) some direct effect on nodule gas permeability (4) the alteration of nodule metabolic activity. In the present study, dry weights of nodules increased with the increase in concentration of potassium. Response to applied K was also higher in SML-668 at flowering stage with a maximum increase of 25.1% at 3.08 mmol of potassium concentration, but maximum percentage increase was observed at 2.31 mmol of potassium concentration.

(Table 4)

v. **Leaf area:** Maximum leaf area was recorded at flowering stage in both the cultivars and then showed sharp decline at pod formation stage. Leaf area decreased continuously with an increase in soil moisture stress as observed by (Umar et al., 1993). (Ranawake et al., 2011) found that water stress affect the crop phenology and leaf area development. (Yadav et al., 2005) also reported the reduction in total leaf area of the sorghum under drought conditions. Significant decrease in leaf area under water stress was observed in both the cultivars which were mainly due to the decrease in relative water content (data not given). Water deficit mostly reduced leaf growth and in turn the leaf areas in many plants like soybean (Zhang et al., 2004), maize (Sacks et al., 1997); cowpea (Manivannan et al., 2007). Cultivar SML-668 had higher leaf area than cv. MH-318 at all the stages. Maximum increase in leaf area was observed with the increasing potassium concentrations at flowering stage. Potassium brought a significant expansion of leaf area under control as well as stress conditions at all the stage but the per cent improvement was more in SML-668. More leaf area formation and its retention during drought period resulted in higher yields by potassium application (Sinha and Nair, 1971).

(Table 5)

vi. **Stomatal conductance:** Significant decrease in stomatal conductance under water stress was observed in both the cultivars irrespective of sampling stages. Stomatal conductance decreased with age of plants i.e. it was higher at vegetative stage and decreased progressively. The decrease in stomatal conductance was more in cv. SML-668, this occurs for minimization of water loss by stomatal closure and to maintain a more favourable internal water status. The first response of all plants to acute water deficit is the closure of their stomata to prevent the transpirational water loss (Mansfield and Atkinson, 1990). Stomatal conductance at vegetative stage showed a reduction of 26.3% in cv. SML-668 under stress, whereas potassium treatment ameliorated the effect of stress on plants and increased the conductance by 4.0%. Maximum increase with potassium concentration was observed under control conditions with an increase of 16.0%, 35.9% and 37.7% at flowering stage in cv. SML-668. There was an increase in percentage of stomatal conductance in stressed plants with increasing potassium concentration. Minimum stomatal conductance was observed under highest drought level without potassium application (Muhammad et al., 2013). Ashraf and Ibram (2005) also reported that stomatal conductance decreased significantly under water deficit conditions. Closure of stomata may result from direct evaporation of water from the guard cells (hydropassive closure) or may also be metabolically dependent and involve processes that result in reversal of the ion fluxes that cause stomatal opening (hydroactive closure). Environmental conditions that increase the rate of transpiration promote ABA accumulation and lead to reduction in stomatal conductance (Wilkinson and Davies, 2002).

(Table 6)

vii. **Photosynthesis:** Photosynthetic rate decreased in both the cultivars under water stress at all stages but treatment with potassium reduced the effect of water deficit. Reduction in photosynthesis occurs due to decreased water potential and RWC under water stress which led to loss of leaf turgor and ultimately decreased stomatal conductance of leaves. The results further indicate that reduction in photosynthesis seems to be due to a decrease in chlorophyll content under water stress. The highest rates of photosynthesis were observed at flowering stage in both the cultivars. The maximum decrease of 71.4% in photosynthetic rate was observed in cv. MH-318 under water stress at flowering stage, while there was a increase in rate of photosynthesis by 18.7% in plants treated with potassium under stress. It was reported that accumulation of potassium in guard cells provides the necessary amount of solute, for developing water potential gradient required for water movement into guard cells for stomatal opening and gas exchange necessary for photosynthesis (Jensen and Tophoj, 1985). Potassium takes part in many essential processes in plants (Marschner, 1995) and enhances photosynthetic rates, plant growth and yield under stress conditions (Egila et al., 2001; Sharma et al., 1996; Tiwari et al., 1998; Umar and Moinuddin, 2002). The enhancing effect of applied potassium on photosynthesis could be ascribed to its role in stomatal activity responsible for exchange of CO_2, water vapour and O_2, production of ATP regulating the rate of photosynthesis (Pervez et al., 2004). The maximum photosynthesis rate was recorded in cv SML-668 as compared to cv. MH-318 at all stages under stress as well as under normal conditions.

(Table 7)

viii. **Respiration:** The rate of respiration declined at pod formation stage. The rates of dark respiration were highest in young actively growing plant parts and it decline as soon as these plant parts mature (Luthra et. al., 1983). Water stress increased the rate of respiration at all stages of growth. Nir and Poljakoff-Mayber (1967) suggested that functional and structural components of mitochondria were affected under stress condition due to which respiration rate declined. Increased level of potassium resulted in a progressive decrease in rate of respiration in both the cultivars under stress as well as control conditions at all the stages. MH-318 showed higher respiration under water deficit conditions. It may be attributed to improved water status in plants. Similar type of results was reported by Sharma et al., (l992) in *Brassica* and Singh et al., 1997 in *Cicer arietinum.*

(Table 8)

ix. **Total chlorophyll content:** Total chlorophyll content of leaves increased up to flowering stage and then it got declined in both the cultivars. Chlorophyll content of leaves reduced significantly under water stress. The highest reduction (45.2%) was noticed at flowering stage in MH-318. Decrease in chlorophyll content in the leaves of plant may be attributed to high rate of degradation of chlorophyll more than its biosynthesis under water stress. Furthermore, Schtz and Fangmeier (2001) and Bano and Aziz (2003) reported that water stress accelerate chlorophyll break down. Increase in chlorophyll content was observed with the increasing potassium concentrations under control as well as stress conditions in both the genotypes. Potassium involves in increasing chlorophyll amount in leaf, thereby delaying leaf senescence and also involve in prevention of the decomposition of chlorophyll.

(Table 9)

Table: 1.Interaction of water stress and applied potassium on dry weight of leaves (g)/Plant of Mungbean cultivars at different growth stage

Values represent means, n=3;
Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mea n	
Vegetative Stage	0	0.165	0.144 (12.7) *	0.154	0.114	0.097 (14.9) *	0.10 5	V = 0.017 S = 0.015 K = N/A V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.174 (5.4)	0.150 (4.1)	0.162	0.117 (2.6)	0.099 (2.0)	0.10 8	
	2.31	0.186 (12.7)	0.156 (8.3)	0.171	0.124 (8.7)	0.100 (3.0)	0.11 2	
	3.08	0.188 (13.9)	0.158 (9.7)	0.173	0.126 (10.5)	0.102 (5.1)	0.11 4	
	Mean	0.178	0.152		0.120	0.099		
Flowering Stage	0	0.276	0.197 (28.6) *	0.236	0.188	0.125 (33.5) *	0.15 6	V = 0.021 S = 0.020 K = 0.030 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.328 (18.8)	0.229 (16.1)	0.278	0.211 (12.2)	0.134 (7.2)	0.17 2	
	2.31	0.374 (35.5)	0.261 (32.4)	0.317	0.228 (21.2)	0.144 (15.2)	0.18 6	
	3.08	0.380 (37.6)	0.263 (33.5)	0.321	0.229 (21.8)	0.146 (16.8)	0.18 7	
	Mean	0.339	0.237		0.214	0.137		
Pod formation stage	0	0.227	0.189 (16.7) *	0.208	0.154	0.124 (19.4) *	0.13 9	V = 0.024 S = 0.022 K = N/A V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.255 (12.3)	0.201 (6.3)	0.228	0.169 (9.7)	0.129 (4.0)	0.14 9	
	2.31	0.267 (17.6)	0.209 (10.5)	0.238	0.175 (13.6)	0.133 (7.2)	0.15 4	
	3.08	0.270 (18.0)	0.211 (11.6)	0.240	0.177 (14.9)	0.135 (8.8)	0.15 6	
	Mean	0.254	0.202		0.168	0.130		

Table: 2.Interaction of water stress and applied potassium on dry weight of stem (g)/plant of Mungbean cultivars at different growth stage

Values represent means, n=3;

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	0.171	0.154 (9.9)*	0.162	0.135	0.114 (15.5)*	0.124	V = 0.018 S = 0.017 K = 0.025 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.194 (13.4)	0.167 (8.4)	0.180	0.148 (9.6)	0.120 (5.2)	0.134	
	2.31	0.257 (50.2)	0.200 (29.8)	0.228	0.168 (24.4)	0.127 (11.4)	0.147	
	3.08	0.260 (52.0)	0.203 (31.8)	0.231	0.172 (27.4)	0.129 (13.1)	0.150	
	Mean	0.220	0.181		0.155	0.122		
Flowering Stage	0	0.252	0.219 (13.1)*	0.235	0.201	0.136 (32.3)*	0.168	V = 0.024 S = 0.021 K = 0.034 V×S = N/A V×K = 0.048 S×K = N/A V×S×K= N/A
	1.54	0.315 (25)	0.253 (15.5)	0.284	0.234 (16.4)	0.153 (12.5)	0.193	
	2.31	0.422 (67.4)	0.315 (43.8)	0.368	0.274 (36.3)	0.163 (19.8)	0.218	
	3.08	0.427 (69.4)	0.317 (44.7)	0.372	0.279 (38.8)	0.165 (21.3)	0.222	
	Mean	0.354	0.276		0.247	0.154		
Pod formation stage	0	0.310	0.275 (11.2)*	0.292	0.246	0.207 (15.8)*	0.226	V = 0.028 S = 0.028 K = 0.039 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.368 (18.7)	0.305 (10.9)	0.336	0.280 (13.8)	0.226 (9.1)	0.253	
	2.31	0.479 (54.5)	0.375 (36.3)	0.427	0.321 (30.4)	0.238 (14.9)	0.279	
	3.08	0.483 (55.8)	0.379 (37.8)	0.431	0.326 (32.5)	0.240 (15.9)	0.283	
	Mean	0.410	0.333		0.293	0.227		

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Table: 3.Interaction of water stress and applied potassium on dry weight of root (g)/plant of Mungbean cultivars at different growth stage

Values represent means, n=3;

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	0.077	0.068 (11.6)*	0.072	0.063	0.054 (14.2)*	0.058	V = 0.015 S = 0.018 K = N/A V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.088 (14.2)	0.072 (5.8)	0.080	0.070 (11.1)	0.056 (3.7)	0.063	
	2.31	0.111 (44.1)	0.078 (14.7)	0.094	0.084 (33.3)	0.060 (11.1)	0.072	
	3.08	0.114 (48.0)	0.080 (17.6)	0.097	0.086 (36.5)	0.061 (12.9)	0.073	
	Mean	0.097	0.074		0.075	0.057		
Flowering Stage	0	0.114	0.092 (19.3)*	0.103	0.085	0.064 (24.7)*	0.074	V = 0.016 S = 0.016 K = 0.022 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.149 (30.7)	0.100 (8.7)	0.124	0.107 (25.8)	0.068 (6.2)	0.087	
	2.31	0.190 (66.6)	0.120 (30.4)	0.155	0.131 (54.1)	0.078 (21.8)	0.104	
	3.08	0.193 (69.3)	0.123 (33.7)	0.158	0.134 (57.6)	0.080 (25)	0.107	
	Mean	0.161	0.108		0.114	0.072		
Pod formation stage	0	0.140	0.120 (14.2)*	0.130	0.102	0.084 (17.6)*	0.093	V = 0.018 S = 0.017 K = 0.026 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	0.167 (19.2)	0.129 (7.5)	0.148	0.118 (15.6)	0.089 (5.9)	0.103	
	2.31	0.215 (53.5)	0.147 (22.5)	0.181	0.144 (41.1)	0.098 (16.6)	0.121	
	3.08	0.218 (55.7)	0.150 (25)	0.184	0.146 (43.1)	0.100 (19.0)	0.123	
	Mean	0.185	0.136		0.127	0.092		

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Table:4. Interaction of water stress and applied potassium on dry weight of nodules (mg)/ Plant of Mungbean cultivars at different growth stage

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	21.5	18.6 (13.4)*	20.0	16.1	13.6 (15.5)*	14.8	V = 0.001 S = 0.001 K = N/A V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	23.5 (9.3)	19.1 (2.6)	21.3	17.3 (7.4)	13.8 (1.4)	15.5	
	2.31	24.2 (12.5)	19.5 (4.8)	21.8	17.6 (9.3)	14.1 (3.6)	15.8	
	3.08	24.4 (13.4)	19.7 (5.6)	22.0	17.8 (10.5)	14.2 (4.4)	16.0	
	Mean	23.4	19.2		17.2	13.9		
Flowering Stage	0	29.8	23.8 (20.1)*	26.8	21.6	16.6 (23.1)*	19.1	V = 0.001 S = 0.001 K = 0.001 V×S = 0.001 V×K = N/A S×K = 0.002 V×S×K= N/A
	1.54	34.3 (15.1)	24.9 (4.6)	29.6	24.5 (13.4)	17.2 (3.6)	20.8	
	2.31	37.0 (24.1)	26.3 (10.5)	31.6	26.0 (20.3)	17.8 (7.2)	21.9	
	3.08	37.3 (25.1)	26.5 (11.3)	31.9	26.4 (22.2)	18.0 (8.4)	22.2	
	Mean	34.6	25.3		24.6	17.4		
Pod formation stage	0	26.5	21.8 (17.7)*	24.1	19.5	15.5 (20.5)*	17.5	V = 0.001 S = 0.001 K = 0.001 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	29.2 (10.1)	22.6 (3.6)	25.9	21.5 (10.2)	15.9 (2.5)	18.7	
	2.31	30.8 (16.2)	23.5 (7.8)	27.1	22.3 (14.3)	16.4 (5.8)	19.3	
	3.08	31.1 (17.3)	23.7 (8.7)	27.4	22.7 (16.4)	16.5 (6.4)	19.6	
	Mean	29.4	22.9		21.5	16.0		

Values represent means, n=3;

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Table: 5.Interaction of water stress and applied potassium on leaf area (sq.cm.)/plant of Mungbean cultivars at different growth stage

Values represent means, n=3;

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	98.4	80.2 (18.5)*	89.3	81.6	61.5 (24.6)*	71.5	V = 2.40 S = 2.40 K = 3.40 V×S = N/A V×K = N/A S×K = 4.80 V×S×K= N/A
	1.54	112.6 (14.4)	85.0 (5.9)	98.8	90.8 (11.2)	63.8 (3.7)	77.3	
	2.31	125.6 (27.6)	89.2 (11.2)	107.4	99.2 (21.5)	66.7 (8.4)	82.9	
	3.08	128.1 (30.1)	91.3 (13.8)	109.7	101.4 (24.2)	68.0 (10.5)	84.7	
	Mean	116.1	86.4		93.2	65.0		
Flowering Stage	0	184	126.0 (31.5)*	155	145.0	91.9 (36.4)*	118.4	V = 3.63 S = 3.63 K = 5.14 V×S = 5.14 V×K = 7.27 S×K = 7.27 V×S×K= N/A
	1.54	249.0 (35.3)	144.0 (14.2)	196.5	190.0 (31.0)	101.3 (10.2)	145.6	
	2.31	295.0 (60.3)	171.1 (35.7)	233.0	215.6 (48.5)	114.5 (24.5)	165.0	
	3.08	301.9 (64.0)	173.7 (37.8)	237.8	219.3 (51.2)	117.5 (27.8)	168.4	
	Mean	257.4	153.7		192.4	106.3		
Pod formation stage	0	82.0	61.1 (25.4)*	71.5	71.2	49.6 (30.3)*	60.4	V = 3.04 S = 3.04 K = 4.30 V×S = N/A V×K = N/A S×K = 6.08 V×S×K= N/A
	1.54	102.4 (24.8)	69.9 (14.4)	86.1	84.8 (19.1)	53.9 (8.6)	69.3	
	2.31	115.3 (40.6)	77.2 (26.3)	96.20	94.2 (32.3)	58.2 (17.3)	76.2	
	3.08	117.7 (43.5)	78.9 (29.1)	98.30	96.3 (35.2)	59.6 (20.1)	77.9	
	Mean	104.3	71.7		86.6	55.3		

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Table: 6.Interaction of water stress and applied potassium on Stomatal Conductance of leaves ($mmol^{-2}sec^{-2}$) of Mungbean cultivars at different growth stage

Values represent means, n=3;

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	402	296 (26.3) *	349	343	269 (21.5) *	306	V = 16.5 S = 16.5 K = 23.4 V×S = 23.4 V×K = N/A S×K = N/A V×S×K= N/A
	1.54	441 (9.7)	308 (4.0)	374	362 (5.5)	276 (2.6)	319	
	2.31	490 (21.8)	327 (10.4)	408	391 (13.9)	291 (8.4)	341	
	3.08	500 (24.3)	332 (12.1)	416	396 (15.4)	294 (9.3)	345	
	Mean	458	315		373	282		
Flowering Stage	0	281	110 (60.8) *	195	240	112 (53.3) *	176	V = 15.9 S = 15.9 K = 22.5 V×S = 22.5 V×K = N/A S×K = 31.9 V×S×K= N/A
	1.54	326 (16.0)	120 (9.0)	223	272 (13.3)	120 (7.4)	196	
	2.31	382 (35.9)	132.2 (20.1)	257	301 (25.4)	130 (16.6)	215	
	3.08	387 (37.7)	134.4 (22.1)	260	305 (27.0)	133 (18.7)	219	
	Mean	344	124		279	123		
Pod formation stage	0	103	29.4 (71.4) *	66.2	91.0	32.5 (64.2) *	61.7	V = N/A S = 11.0 K = N/A V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	117 (13.5)	31.4 (6.8)	74.2	101 (10.9)	34.3 (5.5)	67.6	
	2.31	127 (23.3)	33.8 (14.9)	80.4	108 (18.6)	36.5 (12.3)	72.2	
	3.08	129 (25.2)	34.3 (16.6)	81.6	110 (20.8)	37.2 (14.4)	73.6	
	Mean	119	32.2		102	35.1		

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Table: 7. Interaction of water stress and applied potassium on rate of Photosynthesis (mg CO_2 fixed plant^{-1}h^{-1}) of Mungbean

Values represent means, n=3;

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	17.13	6.96 (59.3)*	12.04	16.91	5.94 (*64.8)	11.42	V = 0.034 S = 0.034 K = 0.048 V×S = N/A V×K = 0.068 S×K = 0.068 V×S×K= 0.096
	1.54	22.06 (28.7)	7.78 (11.7)	14.92	20.85 (23.3)	6.51 (9.6)	13.68	
	2.31	25.72 (50.1)	9.18 (31.9)	17.45	23.89 (41.2)	7.67 (29.1)	15.78	
	3.08	26.02 (51.9)	9.23 (32.6)	17.62	24.31 (43.7)	7.80 (31.3)	16.05	
	Mean	22.73	8.28		21.49	6.98		
Flowering Stage	0	33.05	10.83 (67.2)*	21.94	32.05	9.14 (71.4)*	20.59	V = 0.037 S = 0.037 K = 0.052 V×S = 0.052 V×K = 0.073 S×K = 0.073 V×S×K= 0.104
	1.54	43.46 (31.5)	13.07 (20.6)	28.26	43.46 (29.3)	10.85 (18.7)	27.15	
	2.31	49.86 (50.8)	14.78 (36.4)	32.32	46.84 (46.1)	12.22 (33.7)	29.53	
	3.08	50.26 (52.0)	15.02 (38.6)	32.64	47.44 (48.0)	12.44 (36.1)	29.94	
	Mean	44.15	13.42		42.44	11.16		
Pod formation stage	0	10.25	4.05 (60.4)*	7.15	6.43	2.42 (62.3)*	4.42	V = 0.041 S = 0.041 K = 0.058 V×S = 0.058 V×K = 0.081 S×K = 0.083 V×S×K= 0.117
	1.54	13.25 (29.2)	5.06 (24.9)	9.15	8.21 (27.6)	2.74 (13.2)	5.47	
	2.31	15.40 (50.2)	5.94 (46.6)	10.67	9.26 (44.0)	3.18 (31.4)	6.22	
	3.08	15.62 (52.3)	6.03 (48.8)	10.82	9.36 (45.5)	3.54 (33.4)	6.45	
	Mean	13.63	5.27		8.31	2.97		

Table: 8. Interaction of water stress and applied potassium on rate of respiration (mg CO_2 evolved plant^{-1}h^{-1}) of Mungbean

Values represent means, n=3;

Values in parentheses are: (i) * Percent increase under stress and (ii) Percent decrease with K

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	4.11	5.75 (37.4)*	4.93	5.35	7.75 (42)*	6.55	V = 0.349 S = 0.349 K = 0.493 V×S = N/A V×K = N/A S×K = N/A V×S×K= N/A
	1.54	3.55 (13.6)	4.84 (15.8)	4.19	4.60 (14.0)	6.39 (17.5)	5.49	
	2.31	2.45 (40.3)	3.35 (41.7)	2.90	3.16 (40.9)	4.44 (42.7)	3.80	
	3.08	2.37 (42.3)	3.24 (43.6)	2.80	3.05 (42.9)	4.32 (44.2)	3.68	
	Mean	3.12	4.29		4.04	5.72		
Flowering Stage	0	5.79	8.30 (43.3)*	7.04	7.20	10.46 (45.2)*	8.83	V = 0.344 S = 0.344 K = 0.487 V×S = N/A V×K = N/A S×K = 0.688 V×S×K= N/A
	1.54	4.87 (15.8)	6.90 (16.8)	5.88	6.00 (16.6)	8.64 (17.4)	7.32	
	2.31	3.21 (44.5)	4.47 (46.1)	3.84	3.90 (45.8)	5.48 (47.6)	4.69	
	3.08	3.14 (45.7)	4.35 (47.5)	3.74	3.87 (46.2)	5.36 (48.7)	4.61	
	Mean	4.25	6.00		5.24	7.48		
Pod formation stage	0	4.65	6.51 (40)*	5.58	6.14	8.78 (43)*	7.46	V = 0.322 S = 0.322 K = 0.455 V×S = N/A V×K = N/A S×K = 0.644 V×S×K= N/A
	1.54	3.98 (14.4)	5.44 (16.4)	4.71	5.50 (15.6)	7.28 (17.0)	6.39	
	2.31	2.70 (41.9)	3.59 (44.8)	3.14	3.75 (42.4)	4.69 (46.5)	4.22	
	3.08	2.62 (43.6)	3.56 (45.3)	3.09	3.61 (44.6)	4.63 (47.2)	4.12	
	Mean	3.48	4.77		4.75	6.34		

Table.9. Interaction of water stress and applied potassium on total chlorophyll content (mg g^{-1} FW) of leaves of Mungbean

Values represent means, n=3;

Values in parentheses are: (i) * Percent decrease under stress and (ii) Percent increase with K

Sampling Stages	K (mM)	Varieties						C.D. at 5% level
		SML-668			MH-318			
		Control	Stress	Mean	Control	Stress	Mean	
Vegetative Stage	0	9.28	6.52 (29.7)*	7.90	8.85	5.96 (32.6)*	7.40	V = 0.064 S = 0.064 K = 0.091 V×S = 0.091 V×K = 0.129 S×K = 0.129 V×S×K= 0.182
	1.54	12.47 (34.3)	7.41 (13.6)	9.94	11.70 (32.2)	6.60 (10.7)	9.15	
	2.31	14.86 (60.1)	8.86 (35.8)	11.86	13.47 (52.2)	7.96 (33.5)	10.71	
	3.08	15.11 (62.8)	8.96 (37.4)	12.03	13.70 (54.8)	8.06 (35.2)	10.88	
	Mean	12.93	7.93		11.93	7.14		
Flowering Stage	0	11.79	7.34 (37.7)*	9.56	10.83	6.35 (41.3)*	8.59	V = 0.072 S = 0.072 K = 0.102 V×S = 0.102 V×K = 0.145 S×K = 0.145 V×S×K= N/A
	1.54	16.35 (38.6)	8.62 (17.4)	12.48	14.64 (35.1)	7.28 (14.6)	10.96	
	2.31	19.28 (63.5)	10.26 (39.7)	14.77	17.27 (59.4)	8.58 (35.1)	12.92	
	3.08	19.48 (65.2)	10.43 (42.1)	14.95	17.45 (61.1)	8.90 (40.1)	13.17	
	Mean	16.72	9.16		15.04	7.77		
Pod formation stage	0	6.28	4.17 (33.6)*	5.22	5.69	3.63 (36.2)*	4.66	V = 0.077 S = 0.077 K = 0.109 V×S = 0.109 V×K = 0.154 S×K = 0.152 V×S×K= N/A
	1.54	8.59 (36.7)	4.83 (15.8)	6.71	7.61 (33.7)	4.07 (12.1)	5.84	
	2.31	10.15 (61.6)	5.75 (37.8)	7.95	8.86 (55.7)	4.87 (34.1)	6.86	
	3.08	10.31 (64.1)	5.82 (39.5)	8.06	8.96 (57.4)	4.96 (36.6)	6.96	
	Mean	8.83	5.14		7.78	4.38		

CONCLUSION

The results of this study demonstrated that water deficit at any critical crop growth stage severely affected the plant growth and gaseous exchange parameters of mungbean. Application of potassium on water stressed plants at all the growth stages improved the physiological performance and gaseous exchange parameters. All these findings lead us to recommend that for mungbean crop under water stress should be supplied with potassium to minimize the negative effect of water stress.

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