The Journal of Animal & Plant Sciences, 24(5): 2014, Page: 1452-1465
ISSN: 1018-7081

ROLE OF POTASSIUM IN PHYSIOLOGICAL FUNCTIONS OF SPRING MAIZE (*Zea mays* L.) GROWN UNDER DROUGHT STRESS

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ABSTRACT

Drought stress leaves deleterious effects on growth of maize plant while potassium plays an important role in reducing such deleterious effects. To study the role of potassium on maize plant grown under drought stress an experiment was conducted at Postgraduate Agricultural Research Station, Faisalabad, Pakistan. Maize hybrids 32-F-10 (drought tolerant) and YH-1898 (drought sensitive) were grown on February 25, 2010 and in next year on February 21, 2011. Drought treatments were imposed on growth stages such as; no drought, at five-leaf stage, at ten-leaf stage, at anthesis and at grain formation while two potassium treatments were such as; no potassium and 100 mg/kg of soil application. The design of experiment was RCBD with split-split arrangement. The field capacity was determined by gravimetric method while application of water in drought treatment was maintained by using a formula. It was found that application of potassium had significant effects on relative water contents, leaf water potential, turgor potential, photosynthetic rate, transpiration rate, grain weight per cob, biological yield and grain yield during both the years 2010 and 2011 when drought was imposed at critical growth stages. However, potassium effect on osmotic potential was only significant during 2010. Thus, potassium could be helpful in drought stress mitigation as well to improve produce quality.

Key words: Potassium, water relation, gas exchange, spring maize and water deficit.

INTRODUCTION

The demand for maize grains is increasing with the passage of time due to the current flood of increasing population especially in developing world. The use of meat and poultry is also being increased and this increased consumption of meat and poultry will enhance the demand of maize kernels as feed. However, forecasts indicate that in coming few decades by 2020 the developing nations demand for maize will increase due to the huge population growth and urbanization. It is predicted that global demand of maize will increase by 45% in 2020 (James, 2003).

Compared to other cereals maize also faces many biotic and abiotic constraints during production. These include weeds, insect pest infestation, diseases, drought, water logging, and nutrient deficiency (Joshi *et al.,* 2005). Among these constraints drought stress is deleterious which reduces the crop growth and development (Jaleel *et al.,* 2009). In the life span of maize crop, there are several stages when drought stress disturbs growth and reduces yield of maize. These stages include seedling establishment, vegetative growth or post-emergence growth, flowering or reproduction and grain filling. It has been concluded that grain yield is affected severely if drought stress occurs at bracketing flowering (Abo-El-Kheir and Mekki, 2007).

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. Water is considered as an important input to crop plant in the form of solvent, as a cooling agent, as a reagent and is important for maintaining the body structure by keeping it turgid. Turgor pressure reaches to zero when plant wilts and at this time cells start to collapse, damage to plasma membrane and enzyme protein starts to denature. After drought stress, cells may be repaired if damage is removed. However, it will take 0.5 to 7 days. In case damage is too huge, cells will die (Banziger *et al*., 2000). Low turgor pressure suppresses cell expansion and cell growth. However, osmotic regulation can maintain turgor pressure for plant survival or during severe drought conditions helps the plant growth as it was studied in pearl millet crop plant (Shao *et al.*, 2008).

It has been studied that more leaf water potential, osmotic adjustment and cool leaves are responsible for higher yield under drought stress situation (Nilson and Orcutt, 1996). Other scientists also found that short duration response of plants to the variation in water status including physiological, biochemical, and molecular changes interrelated with desiccation tolerance could not be the desirable attribute for improved yield potential of plant in drought stress condition (Blum, 1996; Passioura, 1996). Stomatal closure and restriction of gas exchange are very important effects of drought in crop plants (Jaleel *et al.*, 2009) including restriction of water supply, losing leaf water potential and turgor. Rigorous drought stress diminishes photosynthesis, produce disturbance in metabolism and leads to plant death (Farooq *et al.*, 2008; Jaleel *et al.*, 2009).

The low quantity of potassium in the plant body decreases the photosynthetic carbon metabolism and the consumption of fixed carbon resources (Mengel and Kirkby, 2001) as a result of this huge deposition of carbohydrates take place in the source leaves. Because of these changes of photosynthetic C metabolism excess of non-utilized light energy and photoelectrons are there in the plant bodies, which create photo oxidative damage to plant body. The plants with potassium 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 potassium deficiency.

Potassium has greater ability to produce tolerance in plant body. Hence, potassium can improve production and quality (Cakmak, 2010) to fulfill the current food requirements under ever reducing irrigation water scenario. This study was conducted to investigate the effect of drought imposed at different growth stages on maize hybrids and to inquire the promoting effect of potassium on physiological functions and yield related parameters of maize hybrids under drought stress.

MATERIALS AND METHODS

Site Geography: The research was conducted at Postgraduate Agricultural Research Station, University of Agriculture, Faisalabad, Pakistan. The station is located between longitude 73°74 East, latitude 30°31.5 North, at an elevation of 184 meters above sea level.

Table 1. Monthly average weather data for the experimental duration.

	Rainfall (mm)		Temperature (ºC)		R. Humidity (%)		Potential ET (mm)	
Months	2010	2011	2010	2011	2010	2011	2010	2011
February	11.9	20.6	15.7	14.4	62.7	73.0	2.5	1.2
March	8.8	6.8	23.3	19.8	57.5	59.8	3.4	2.5
April	1.3	20.9	29.9	24.8	36.8	47.0	6.0	4.2
May	11.2	14.6	33.1	32.8	31.7	43.0	5.7	6.1
June	1.0	78.3	33.9	32.3	40.0	55.0	6.3	5.5

Field Capacity Determination: The field capacity was determined on gravimetric basis (Nachabe, 1998). Gravimetric procedure of direct soil water measurement was applied to determine the water contents in the soil. Soil sampling for soil moisture measurement was carried out regularly on alternate days keeping in view the weather conditions. Composite soil samples at the depth intervals of 30 cm up to 100 cm were taken on taking into consideration of maize growth stage from randomly located sites in each plot for moisture determination, as the maximum moisture extraction depth of root zone of maize crop was taken as 100 cm.

Depth of irrigation water: Irrigation was applied to respective plots as soon as the desired available soil moisture depletion level reached in the soil of crop root zone. Depth of irrigation for each field capacity levels was predetermined by adopting the direct measurement or field sampling method of crop water requirement as reported by Mujumdar (2002):

$$d = \frac{(Fc - M_b) \qquad (Bd) \times D}{100}$$

Here;
d = Depth of water to be applied in (cm)
D = Depth of root zone (cm)
F_c = Field capacity in percent by weight
Bd= Bulk density of soil g/cm^3
M_b= Water contents in soil before irrigation by weight

Discharge of water applied to each treatment was determined with the help of a cut-throat flume (3' x 8"). The time required to supply the required depth of irrigation water to each plot was calculated according to following equation (Rafiq, 2001);

$$t = \frac{d \times a}{q}$$

Where;
t = time in hours
d = depth of water in inches
a = area in acres
q = discharge of irrigation water in ft^3/s

Table 2. Physio-chemical properties of soil

Parameter	Units	2010		2011	
		0-15 (cm)	16-30 (cm)	0-15 (cm)	16-30 (cm)
Texture	--	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	--	8.0	8.1	8.3	8.0
EC	(dSm^{-1})	0.72	0.53	0.69	0.52
O. M.	(%)	0.38	0.38	0.39	0.37
Nitrogen	(%)	0.044	0.036	0.042	0.037
Available P	(ppm)	7.5	5.5	7.1	5.2
Extractable K	(ppm)	135.5	121.1	132.5	122.7
Sand	(%)	55	48	54	49
Silt	(%)	22	28	22	26
Clay	(%)	23	24	24	25
Field capacity	(%)	26.10	25.4	25.5	26.2
Wilting point	(%)	8.5	7.8	8.2	8.1
SAR	--	09	11	08	10

Experimental Details: The soil was analyzed before application of treatments. The experimental design was RCBD with split-split arrangement and replicated thrice. The treatments were as following; Factor A: Maize hybrids (32-F-10 and YH-1898), Factor B: Growth stages to impose drought (no drought, at five leaf stage, at ten leaf stage, at anthesis and at grain formation) Factor C: Potassium levels (0 and 100 mg/kg of soil).

The previously grown crop was wheat. The field was ploughed with moldboard plough once and then cultivated two times with cultivator. It was then planked and leveled with laser land leveler. The recommended fertilizers (NP: 250 kg/ha and 125 kg/ha) and K @ 100 kg/ha was applied. All the phosphorus, potash and 1/3 of nitrogenous fertilizer were applied at the time of sowing while the rest of nitrogen was applied at knee height of maize crop. The ridges were made with the help of tractor-mounted ridger at the distance of 2.5 foot apart. The sowing of this experiment was done on February 25, 2010 and on February 21, 2011. The screened hybrids; drought tolerant (32-F-10) and sensitive (YH-1898), were sown manually.

The drought was imposed at different growth stages by maintaining 70% FC after 30% depletion in it. A flume was installed at the start of field channel to measure the quantity of water. Quantity of water was measured that was applied to control plot (Full irrigation application) with flume while to drought stressed plots water was applied to maintain the required field capacity. To control the broad-leaved weeds atrazine was applied after the germination of weeds while the narrow leaved weeds were controlled with hoeing. After that Furadon was applied twice to control the stem borer with fortnightly interval.

To determine the relative water contents fresh weight of 0.5 g excised leaf fully expanded from the top was measured and put into test tube full of water so that the leaf portion could be fully soaked into water. Leaf was taken out of the test tube after 16 hours. Water on the surface of leaf was swiped out with the help of tissue paper and weight of leaf was recorded. The samples were then dried in an oven at 65 ± 2°C for 24 hours and weighed to measure the dry weight. The relative water contents were measured by using the following formula (Karrou and Maranville, 1995) given below;

RWC = (FW-DW)/ (TW-DW) x 100

Where FW is the fresh weight of sample, DW is the dry weight of sample and TW is the turgid/soaked weight of sample.

The third leaf from the top (fully expanded youngest leaf) of maize stem was excised between 6:30 am to 8:30 am for the determination of leaf water potential (ψ_w) by using Scholander type pressure chamber. The leaf that was used for the determination of leaf water potential (ψw) was frozen in a freezer below -20ºC for more than 7 days. Afterwards, the frozen leaf material was thawed and sap from the material was extracted by pressing with the help of glass rod. This sap was directly used for the determination of osmotic potential (ψ_s) by using vapor pressure osmometer. The turgor potential (ψ_p) was measured by determination of difference between water potential (ψ_w) and osmotic potential (ψ_s) values.

$\psi_p = \psi_w - \psi_s$

Photosynthesis (A) and transpiration rate were measured with infrared gas analyzer (Analytical Development Company, Hoddesdon, England) from top of 3rd leaf of each plant. This kind of measurements were done from 10:00 am to 2:00 pm with the following type of adjustments such as; leaf surface area 11.35 cm^2, ambient CO_2 concentration 342.12 micromole mol^{-1}, leaf chamber temperature varies from 36.2 to 42.9 ºC, gas flow rate of leaf chamber volume 396 mL min^{-1}, molar gas flow rate of leaf chamber 251 µmole s^{-1}, ambient pressure 99.95 KPa, molar flow of air per unit of area of leaf 221.06 mol m^{-2} s^{-1}, PAR on the leaf surface was highest up to 1030 µmole m^{-2} s^{-1}. All the above physiological parameters were taken twice 40 and 60 days after sowing during whole the experimental duration while all the yield and yield related parameters were recorded at maturity.

Statistical Analysis: Data collected were analyzed statistically using Fisher' analysis of variance technique. Difference among the treatments means was compared using Least Significant Difference Test at 5 % probability level (Steel *et al.*, 1997) using the MSTAT C computer software (MSTAT Development Team, 1989).

RESULTS AND DISCUSSION

Relative Water Contents (%): The effect of potassium on relative water contents of maize hybrids grown under drought was found statistically significant during both the years 2010 ($p \le 0.05$) and 2011 ($p \le 0.01$). The data (Table 3) in both the years indicated that potassium application significantly enhanced relative water contents. The minimum relative water contents were observed when drought was imposed from five-leaf stage. The graphical representation shows the relative water contents developed by maize hybrids during drought stress imposed at different growth stages (Fig.1). Maize hybrid 32-F-10 had more relative water contents as compared to YH-1898 as per treatments. Improving the plant internal status of potassium seems to be very important for improving the yield under water deficit conditions. Such kind of studies were conducted by Waraich *et al*. (2011) that under moisture deficit conditions potassium application to crop plant enhanced the crop tolerance to drought stress by utilizing the soil moisture more efficiently as compare to potassium deficient plants. Accordingly, it was reported by Lindhauer (1985) that potassium application increased dry matter production and leaf area development greatly by retention of more water under drought conditions. Similarly, root growth was enhanced by potassium application. Potassium acts as an osmolyte in plant body hence; potassium enhanced relative water contents under well water as well as drought conditions.

Table 3. Effect of potassium on relative water contents (%) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	70.72 cd	77.25 a	72.70 d	79.62 a
	Five leaf stage	47.35 k	43.48 l	49.64 m	46.14 n
	Ten leaf stage	59.54 h	59.51h	61.66 j	61.71 j
	Anthesis	65.23 fg	69.20 de	68.36 h	71.65 e
	Grain Formation	66.13 f	73.35 b	69.15 g	75.84 b
YH-1898	No drought	67.38 ef	72.63 bc	69.68 f	75.14 c
	Five leaf stage	42.58 l	42.82 l	44.78 p	45.22 o
	Ten leaf stage	54.37 i	50.07 j	56.61 k	56.13 l
	Anthesis	63.56 g	65.39 fg	65.66 h	68.16 h
	Grain formation	65.18 fg	73.23 b	68.22 h	75.92 b

LSD ($P \le 0.05$) = 1.63 LSD ($P \le 0.05$) = 0.24

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

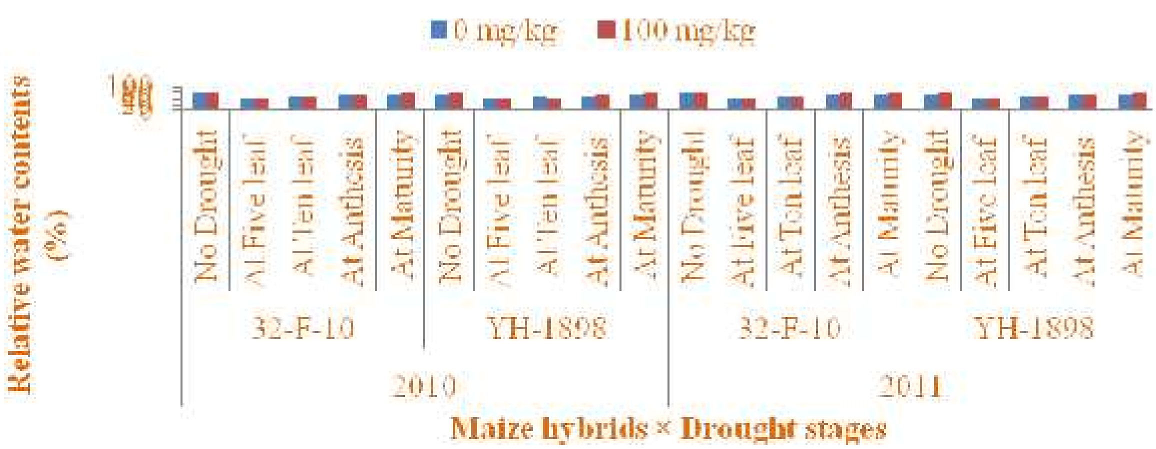

Fig. 1. Role of potassium on the relative water contents of maize hybrids under drought stress during different growth stages.

Leaf Water Potential: The effect of potassium on leaf water potential of maize hybrids under drought at different growth stages was found statistically significant during 2010 ($p \leq 0.05$) and during 2011 ($p \leq 0.01$). Data (Table 4) elaborated that potassium has enhanced leaf water potential significantly as compare to without potassium. The maize hybrid 32-F-10 performed better under drought in both the potassium levels as compare to YH-1898. Graphical representation elaborates the leaf water potential of maize hybrids during both the years under drought stress at different growth stages (Fig. 2). Leaf water potential enhanced by potassium application in the present study. It was due to osmoticum role of potassium in maintaining leaf water potential. Potassium ions contribute significantly to the osmotic potential of the vacuoles even under drought conditions (Marschner, 1995). Thus, suitable potassium fertilization of crop plants could stimulate osmotic adjustment that stabilize turgor pressure at lower leaf water potentials and can increase the capability of plants to tolerate drought stress (Bukhsh *et al*., 2012). Studies have shown that optimum potassium application is beneficial to the growth and development of plants. However, little information is available about the influence of potassium on whole-plant drought resistance. Thus, information about adequate levels of potassium fertilizer that would optimize drought resistance in maize is still lacking.

Table 4. Effect of potassium on leaf water potential (-MPa) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	1.36 j	1.28 k	1.53 h	1.35 j
	Five leaf stage	1.92 b	1.70 d	1.91 a	1.73 bcd
	Ten leaf stage	1.69 d	1.65 e	1.68 d	1.68 d
	Anthesis	1.50 h	1.56 g	1.55 gh	1.60 efg
	Grain Formation	1.37 j	1.46 i	1.46 i	1.52 h
YH-1898	No drought	1.50 h	1.44 i	1.57 efgh	1.52 h
	Five leaf stage	2.14 a	1.92 b	1.93 a	1.78 b
	Ten leaf stage	1.79 c	1.70 d	1.74 bc	1.70 cd
	Anthesis	1.59 f	1.65 e	1.61 ef	1.62 e
	Grain formation	1.46 i	1.55 g	1.54 h	1.55 fgh

LSD ($P \leq 0.05$) = 0.02 LSD ($P \leq 0.05$) = 0.054
Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

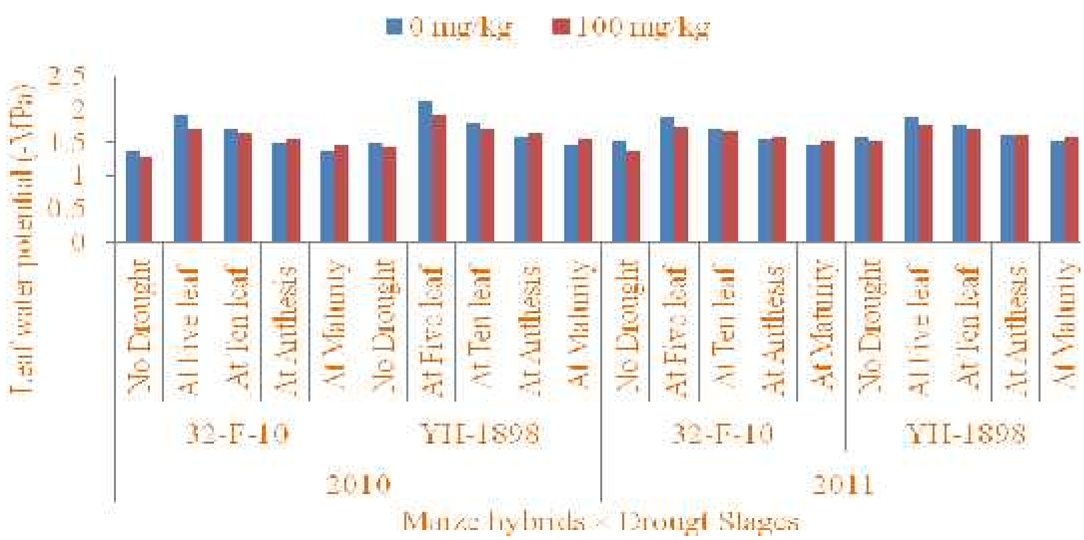

Fig. 2. Role of potassium on the leaf water potential of maize hybrids under drought stress during different growth stages.

Osmotic Potential: The role of potassium on osmotic potential of maize hybrids under drought stress was statistically significant during 2010 ($p \leq 0.01$) while it was non-significant during 2011 ($p > 0.05$). During the year 2010 application of potassium has significantly ($p \leq 0.01$) enhanced the osmotic potential as compared to without potassium as per treatments (Table 5). The application of potassium enhanced the osmotic potential in every treatment of drought, which shows the role of potassium for drought tolerance (Fig. 3). The drought imposed from five leaf stage greatly reduced the osmotic potential but drought imposed from later growth stages had little effect on osmotic potential as per treatment of drought. Drought reduced effect when it was imposed from grain filling. The drought tolerant maize hybrid 32-F-10 produced higher osmotic potential as compared to drought sensitive maize hybrid YH-1898. Potassium enhanced the osmotic potential in 2010. Potassium is an essential element for plant growth and is the most abundant cation in plants. Potassium ions contribute significantly to the osmotic potential of the vacuoles even under drought conditions (Marschner, 1995). Thus, application of adequate amount of potassium to crop plants may regulate osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and can increase the capability of plants to tolerate against drought stress (Bukhsh *et al*., 2012).

Table 5. Effect of potassium on osmotic potential (-MPa) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	1.79 n	1.65 p	1.86	1.85
	Five leaf stage	2.18 b	2.01 e	2.13	1.97
	Ten leaf stage	1.99 f	1.95 g	1.93	1.88
	Anthesis	1.85 l	1.89 i	1.80	1.85
	Grain Formation	1.75 o	1.82 m	1.80	1.82
YH-1898	No drought	1.86 k	1.79 n	1.76	1.96
	Five leaf stage	2.37 a	2.16 c	2.03	1.96
	Ten leaf stage	2.11 d	1.99 f	1.95	1.94
	Anthesis	1.89 i	1.94 h	1.84	1.89
	Grain formation	1.82 m	1.87 j	1.82	1.89

LSD (P≤0.05) = 0.002

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

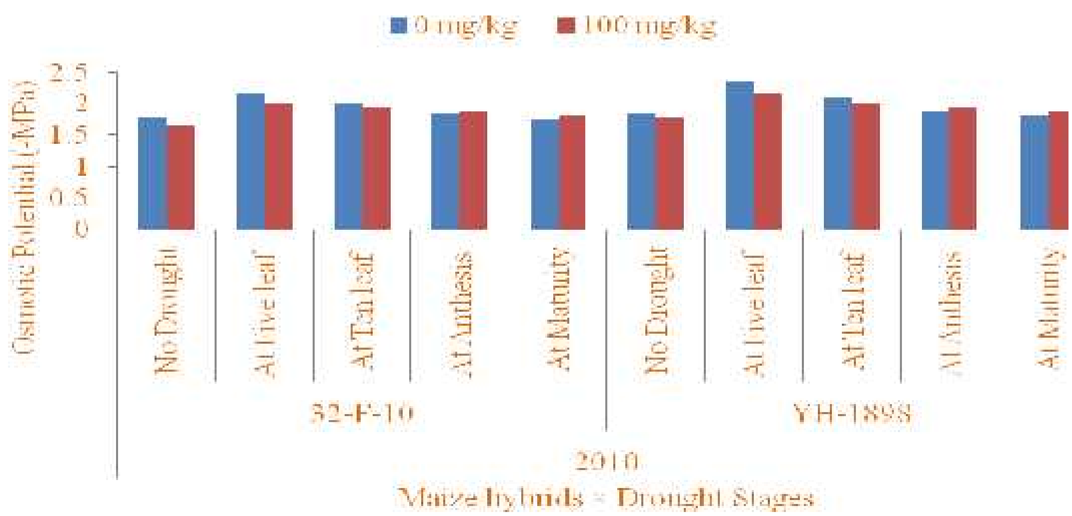

Fig. 3. Role of potassium on the osmotic potential of maize hybrids under drought stress during different growth stages.

Turgor Potential: Potassium effect on turgor potential of maize hybrids under drought stress was statistically significant during both the years 2010 (p≤0.01) and 2011 (p≤0.01). Data (Table 6) showed that potassium application enhanced turgor potential in well watered (no drought) and even in drought during different growth stages such as; from anthesis and grain filling. However, effect of potassium was clearly verified when drought was imposed from five and ten leaf stages. Meanwhile, application of potassium enhanced the turgor pressure significantly as compared to without potassium application. In all the drought treatments at various growth stages potassium enhanced turgor pressure. Maize hybrid 32-F-10 produced significantly higher turgor potential as compared to YH-1898 during both the years. Osmotic adjustment maintained cell turgor potential in a better way and regulated turgor-related processes, such as the stomata opening, photosynthesis, shoot growth and roots extension in deeper soil layers. Studies showed that under drought stress conditions mustard leaves have better leaf turgor pressure than canola and leaf turgor is positively correlated to leaf area duration and crop growth rate reported by Wright *et al*. (1996). Thus, it can be concluded that Potassium plays an important role in osmotic adjustment, enzyme activation and stomatal conductance. It is also evident from the Fig. 4 that potassium dramatically enhanced the turgor potential during 2011 while this behavior was different during 2010.

Table 6. Effect of potassium on turgor potential (MPa) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	0.43 a	0.37 bc	0.39 c	0.51 a
	Five leaf stage	0.26 k	0.31 fghi	0.21 kl	0.22 k
	Ten leaf stage	0.30 ghij	0.30 ghij	0.23 j	0.27 h
	Anthesis	0.35 de	0.33 ef	0.26 hi	0.33 f
	Grain Formation	0.38 b	0.36 cd	0.37 d	0.39 c
YH-1898	No drought	0.36 cd	0.35 de	0.35 e	0.48 b
	Five leaf stage	0.23 l	0.24 l	0.20 l	0.18 m
	Ten leaf stage	0.32 fg	0.29 j	0.21 k	0.25 i
	Anthesis	0.30 hij	0.29 ij	0.23 j	0.29 g
	Grain formation	0.36 bcd	0.32 fgh	0.33 f	0.38 c

LSD ($P \leq 0.05$) = 0.02 LSD ($P \leq 0.05$) = 0.011

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

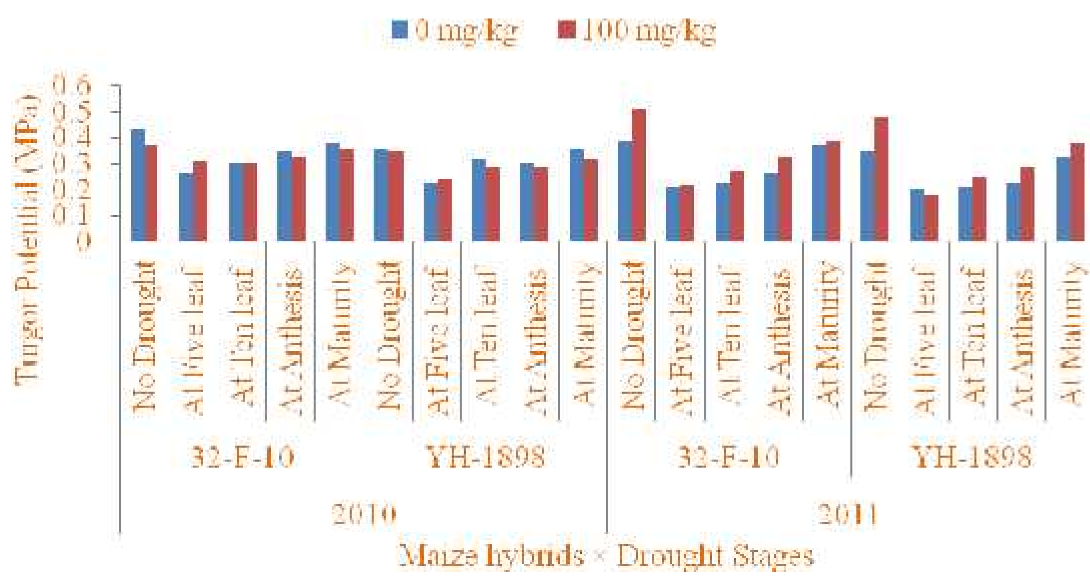

Fig. 4. Role of potassium on the turgor potential of maize hybrids under drought stress during different growth stages.

Photosynthetic Rate: Potassium had its greater role in enhancing photosynthetic rate of maize hybrids grown under drought stress during both the years 2010 ($p \leq 0.05$) and 2011 ($p \leq 0.05$). Data (Table 7) indicated that potassium application enhanced photosynthetic rate significantly in both the maize hybrids. The effect of drought stress was more severe when imposed from five leaf stage followed by ten leaf and anthesis stage. The loss of drought was minimum when imposed from grain filling stage. Although potassium application enhanced photosynthesis however, this response was higher during 2010 as compared to 2011. Plants suffering from environmental stresses such as drought have a bigger internal requirement for potassium (Cakmak and Engels, 1999). Environmental stress factors that increase the requirement for potassium also cause oxidative damage to cells through induction of ROS, especially during photosynthesis (Bukhsh, *et al*., 2012). The reason for the higher need of potassium by plant is that potassium is required for the maintenance of photosynthetic CO_2

fixation. In wheat experiments observed higher photosynthetic rates in plants with higher potassium than under standard fertilization (Cakmak, 2005).

Table 7. Effect of potassium on photosynthetic rate (µ mole m^{-2} s^{-1}) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	12.03 f	26.75 a	16.47 d	19.28 a
	Five leaf stage	7.77 k	8.71 hijk	12.52 l	14.54 jk
	Ten leaf stage	9.61 hi	17.61 d	15.13 hi	17.55 c
	Anthesis	11.65 fg	19.89 c	15.54 gh	18.61 b
	Grain Formation	11.79 f	23.68 b	16.13 def	18.80 ab
YH-1898	No drought	10.18 gh	24.19 b	15.57 gh	16.53 d
	Five leaf stage	5.91 l	7.79 jk	11.35 m	12.81 l
	Ten leaf stage	8.38 ijk	15.56 e	14.23 k	15.37 ghi
	Anthesis	9.27 hij	16.15 de	14.97 ij	15.79 efg
	Grain formation	13.13 f	20.43 c	15.73 fg	16.30 de

LSD ($P \leq 0.05$) = 1.49 LSD ($P \leq 0.05$) = 0.52

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

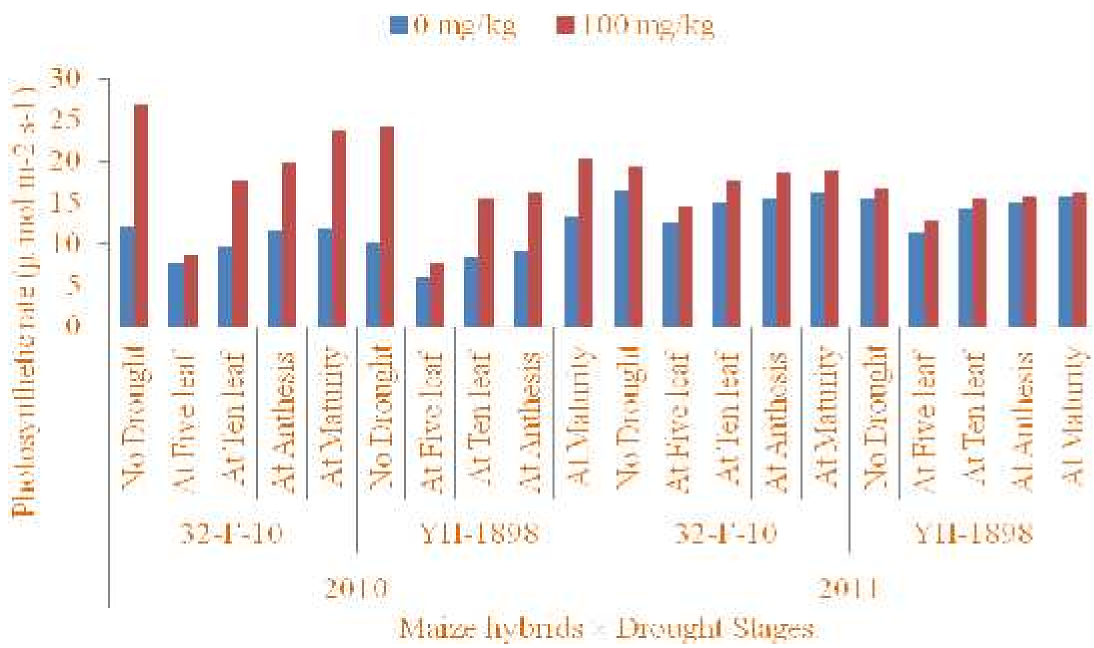

Fig. 5. Role of potassium on photosynthetic rate of maize hybrids under drought stress during different growth stages.

Transpiration Rate: Application of potassium enhanced transpiration rate of maize hybrids grown under drought stress significantly during both the years 2010 ($p \leq 0.05$) and 2011 ($p \leq 0.05$). Data (Table 8) indicated that potassium enhanced transpiration rate significantly in both the maize hybrids. The impact of drought stress was more severe when imposed from five leaf stage followed by ten leaf and anthesis stage. The loss of drought was reduced when imposed from grain filling stage. The aim is to control the stomatal plant water loss by evaporation during drought stress. When potassium is low, the stomata cannot function properly, and the loss of water from the plant could reach harmful level (Gething, 1990). This has been proven in a barley field experiment in which the plants were exposed to the hot wind, which resulted in a sharp increase in the intensity of evaporation where potassium supplied plants react quickly closing the stomata and maintained internal moisture.

Table 8. Effect of potassium on transpiration rate (µ mole $m^{-2}s^{-1}$) of maize hybrids under drought stress in spring season.

Hybrids	Drought imposed from growth stages	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	6.85 cd	8.85 a	4.81 e	7.31 a
	Five leaf stage	2.26 mn	3.15 klm	1.06 m	1.69 k
	Ten leaf stage	2.76 lm	5.74 ef	1.33 l	4.46 f
	Anthesis	3.58 ijkl	6.19 de	2.22 j	4.48 f
	Grain Formation	5.19 fg	7.24 bc	3.50 h	5.89 b
* YH-1898	No drought	6.04 def	7.19 bc	3.94 g	5.59 c
	Five leaf stage	1.49 n	3.33 jkl	1.04 m	1.39 l
	Ten leaf stage	4.25 hij	3.89 hijk	1.22 lm	3.36 h
	Anthesis	4.26 hi	7.35 bc	2.71 i	4.12 g
	Grain formation	4.58 gh	7.95 ab	2.51 i	5.20 d

LSD (P≤0.05) = 0.91 LSD (P≤0.05) = 0.25

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

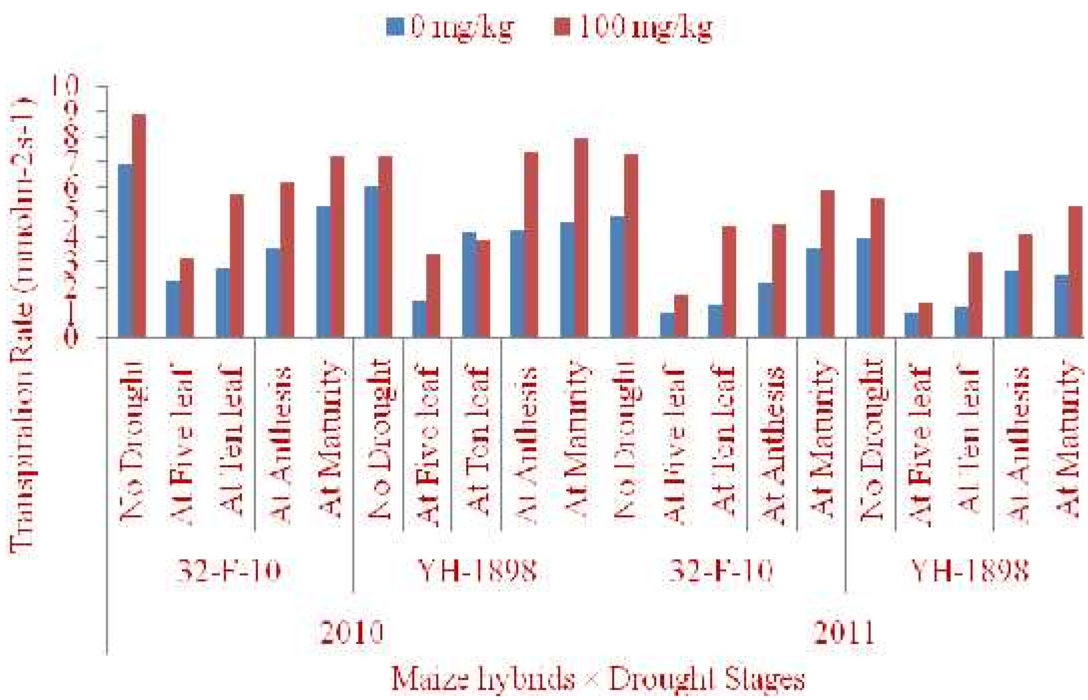

Fig. 6. Role of potassium on transpiration rate of maize hybrids under drought stress during different growth stages.

Grain Weight Cob^{-1}: Effect of potassium on grain weight per cob of maize hybrids grown under drought at various growth stages was statistically significant during both the years 2010 (p≤0.01) and 2011 (p≤0.05) (Table 9). Data showed that application of potassium enhanced the grain weight per cob as per treatment during both the years 2010 and 2011. Drought also had significant effect on grain weight per cob of grown maize hybrids. The maximum grain weight per cob was observed in well watered (no drought) treatment in both the maize hybrids followed by when drought was imposed from grain filling stage which was less affected by drought as compare to other drought treatments. The minimum grain weight per cob was observed when drought was imposed from five-leaf stage followed by drought at ten-leaf stage. In the present study, potassium enhanced the grain weight per cob. It was might be due to more translocation of assimilates to cob efficiently. Nesmith and Ritchie (1992) found water stress decreased the grain weight per cob as compare to well water treatment. Potassium helps the plant to absorb more water from soil also by root elongation. Potassium takes part in photosynthesis activates many enzymes and thus transport more food from leaves to grain.

Table 9. Effect of potassium on grain weight cob^{-1} (g) of maize hybrids under drought stress in spring season.

Hybrids	Growth stages to impose drought	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	87.29 j	146.0 a	120.0 d	185.5 a
	Five leaf stage	53.92 r	72.96 n	95.64 hi	106.9 fg
	Ten leaf stage	65.48 p	99.80 h	100.8 gh	136.5 c
	Anthesis	77.75 m	117.5 d	88.36 ij	158.8 b
	Grain formation	80.26 l	131.7 b	112.4 def	179.4 a
YH-1898	No drought	102.7 g	112.2 e	110.3 ef	159.9 b
	Five leaf stage	39.46 s	61.31 q	80.62 jk	94.50 hi
	Ten leaf stage	67.27 o	91.53 i	93.20 hi	119.2 de
	Anthesis	78.71 m	110.4 f	77.61 k	117.3 de
	Grain formation	85.54 k	128.8 c	106.1 fg	152.2 b

LSD (P≤0.05) = 1.53 LSD (P≤0.05) = 9.06

Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

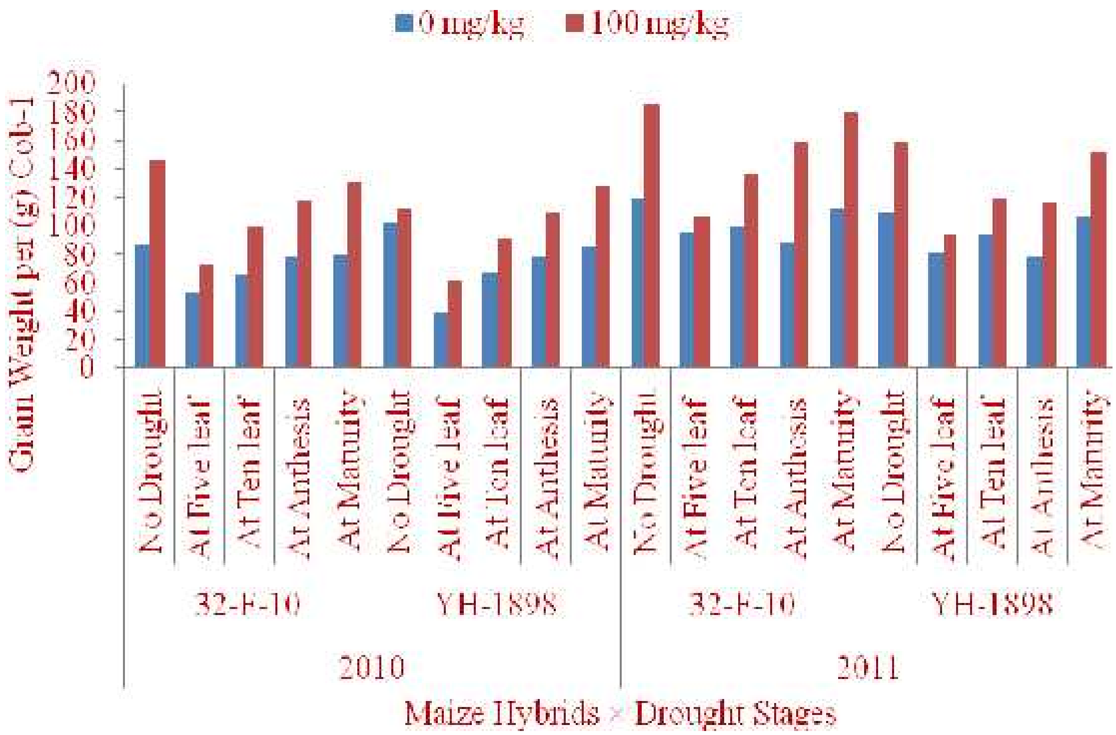

Fig. 7. Role of potassium on grain weight per cob of maize hybrids under drought stress during different growth stages.

Biological Yield: Effect of potassium on biological yield of maize hybrids grown under drought was statistically significant (p≤0.05) during both the years 2010 and 2011 (Table 10). Data indicated that application of potassium enhanced the biological yield during both the years 2010 and 2011. Drought also had deleterious effect on biological yield of sown hybrids in both the years. The maximum biological yield was observed in well water (no drought) treatment in both the maize hybrids followed by when drought was imposed from grain filling stage, which was less affected by drought as compare to other drought treatments. The minimum biological yield was observed when drought was imposed from five-leaf stage. In this study, potassium improved biological performance. It was might be due to the growth rate improved by applying potassium. Increase in the thickness of layers of sclerenchyma tissue in optimal nutrition of potassium has been described for rice. Meanwhile, other scientists also verified that application of potassium enhanced biological yield as compared to zero application of potassium (Abasiyeh *et al*., 2013).

Table 10. Effect of potassium on maize hybrids under drought levels on biological yield (kg ha^{-1})

Hybrids	Growth stages to impose drought	2010		2011	
		0 mg/kg	**100 mg/kg**	**0 mg/kg**	**100 mg/kg**
32-F-10	No drought	12320 def	16880 a	13970 def	15760 a
	Five leaf stage	9360 j	12870 de	9245 m	12620 jk
	Ten leaf stage	11100 ghi	14980 c	13090 hij	13470 fgh
	Anthesis	11530 fgh	15180 c	13310 ghi	14450 cd
	Grain formation	12250 ef	16360 ab	13070 hij	14910 bc
YH-1898	No drought	12810 de	15380 bc	13750 efg	15310 ab
	Five leaf stage	8695 j	8413 j	10730 l	13070 hij
	Ten leaf stage	10450 i	10560 hi	12150 k	13750 efg
	Anthesis	11090 ghi	13290 d	12830 ij	14320 cde
	Grain formation	12080 efg	14560 c	13130 ghij	14410 cd

LSD (P≤0.05) = 1001 LSD (P≤0.05) = 633.4
Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

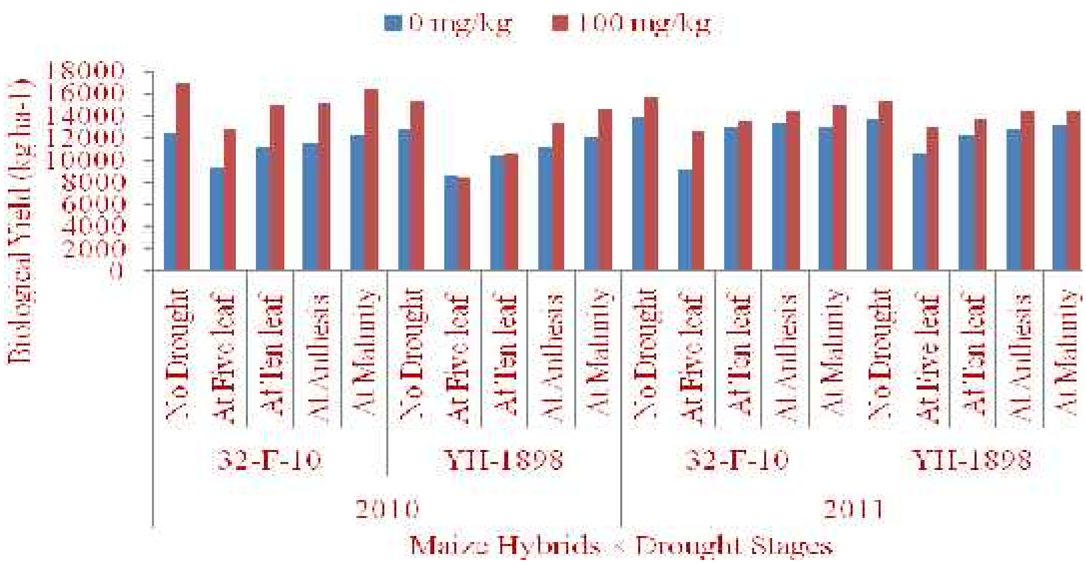

Fig. 8. Role of potassium on biological yield of maize hybrids under drought stress during different growth stages.

Grain Yield: Data showed that application of potassium enhanced the grain yield during both the years 2010 (p≤0.01) and 2011 (p≤0.05) significantly (Table 11). Drought also had adverse effect on grain yield of sown hybrids during both the years. The maximum grain yield was observed in well watered (no drought) treatment in both the maize hybrids followed by when drought was imposed from grain filling stage which was less affected by drought as compare to other drought treatments. The minimum grain yield was observed when drought was imposed from five-leaf stage. The application of potassium had greatly enhanced the grain yield in both the maize hybrids. An adequate supply of soil moisture is essential for crop growth, replacing loss of transpiration, and the transport of nutrients by crop roots. Severe drought limits water consumption and reduces crop yields. Meanwhile, Earl and Davis (2003) summarize the three main mechanisms by which corn yield was reduced by soil water deficit: (i) reduces the absorption of radiation incident photo-synthetically active canopy, (ii) decrease the effectiveness of use radiation, and (iii) reduced harvest index. The ability to tolerate drought and acceptable yields is limited in cultivars within a species (Serraj and Sinclair, 2002). Similarly, Nejad *et al*. (2010) reported that water stress induced at the pre-flowering, flowering, post-flowering phases, compared to control plants decreased corn yield of 21%, 5%, 25%, respectively. Water deficit during the flowering phase of pollination induced yield loss through intense abnormal development of embryo sac, pollen abortion and ultimately reduces the number of grains productive (Nejad *et al*., 2010). Various studies have shown that frequent application of potassium fertilizer mitigate the adverse effects of drought on plant growth in barley (Andersen *et al*., 1992), sunflower (Lindhauer, 1985), cane sugar (Sudama *et al*., 1998) and rice (Tiwari *et al*., 1998), which confirmed the result of this study. The greatest need of potassium to plants is under different abiotic stresses appears to be related to the inhibitory role of potassium against the reactive oxygen species (ROS) production during photosynthesis and NADPH oxidase (Cakmak, 2005).

Table 11. Effect of potassium on grain yield (kg ha^{-1}) of maize hybrids under drought stress in spring season.

Hybrids	Growth stages to impose drought	2010		2011	
		0 mg/kg	100 mg/kg	0 mg/kg	100 mg/kg
32-F-10	No drought	5941 gh	10220 a	8254 d	12720 a
	Five leaf stage	3475 k	4760 ij	6641 fg	7422 def
	Ten leaf stage	4584 ij	6736 ef	7198 ef	10110 bc
	Anthesis	5531 h	8091 c	5712 hi	10930 b
	Grain formation	5649 h	9195 b	7802 de	12280 a
YH-1898	No drought	6819 e	7472 d	7640 de	10000 c
	Five leaf stage	2528 l	4282 j	5132 i	6048 gh
	Ten leaf stage	4866 i	5814 gh	6000 gh	7837 de
	Anthesis	5541 h	7438 d	5745 hi	7849 de
	Grain formation	6248 fg	9367 b	7019 ef	10800 bc

LSD (P≤0.05) = 516.5 LSD (P≤0.05) = 837.5
Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test at P = 0.05.

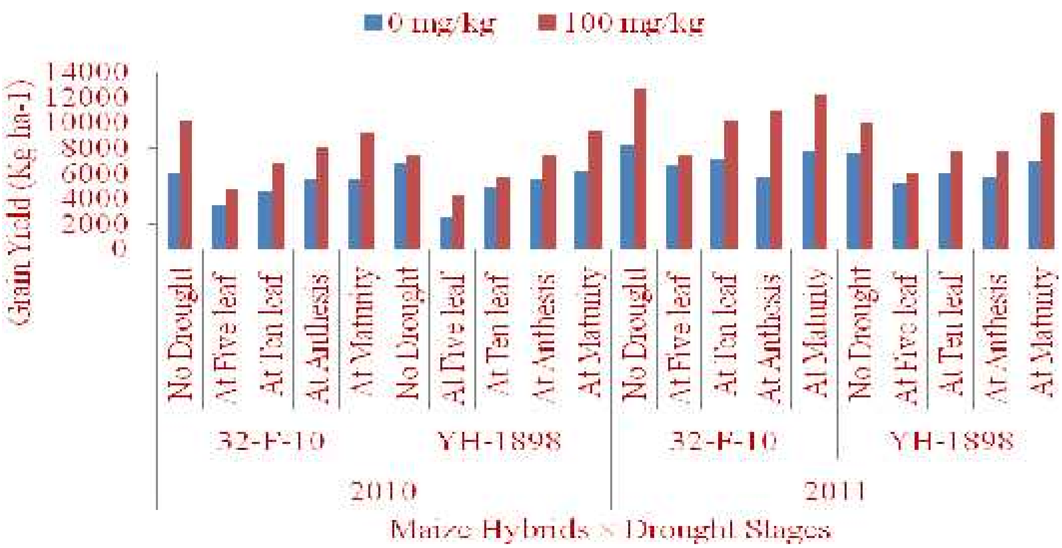

Fig. 9. Role of potassium on grain yield of maize hybrids under drought stress during different growth stages.

Conclusion: In general, water stress level directly decline physiological and yield related parameters like leaf water contents, leaf water potential, osmotic potential, turgor potential, photosynthetic rate, transpiration rate, grain weight per cob, biological yield and grain yield. However, application of potassium to drought stress treatments at different growth stages and to well water treatment improved the efficiency of plant for various parameters. Application of potassium gradually mitigated the harmful effects of drought stress on maize plants. Meanwhile, osmotic potential was not regulated effectively by potassium application during 2011. The results of recent study confirmed recovery impacts of potassium application under drought stress on maize plants. Hence, it can be concluded that drought stress to plants grown under acute water shortage could be mitigated to some extent along with good quality produce by potassium application.

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