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RESEARCH ARTICLE

Influence of Potassium Levels on the Phenology of Maize (*Zea mays* L.) Hybrids Grown Under Drought Stress

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ABSTRACT

An experiment to mitigate the effects of drought on maize growth and yield of autumn maize was conducted at Postgraduate Agricultural Research Station (PARS), Faisalabad Pakistan. Drought stress was maintained in term of field capacity using gravimetric techniques. For this experiment, two maize hybrids 32F10 (drought tolerant) and YH1898 (drought sensitive) were sown on 5th August 2010 and on 7th August, 2011 during cropping years. The planned experiment was comprised of five drought treatments viz. viz. Factor A: Maize hybrids (32F10 and YH1898), Factor B; drought treatments at various growth stages (no drought [control], drought at five leaf stage, drought at ten leaf stage, drought at anthesis and drought at grain formation) and Factor C; Potassium levels (0 and 100 mg/ kg of soil). The stress was imposed on various growth stages with out and with 100 mg/kg of soil potassium treatments. Data depicted that water stress level directly reduced growth and development parameters like plant height, leaf length, leaf area index, shoot fresh weight per plant, cob length, and cob diameter declined in 2010 and 2011due to drought stress. The application of potassium had promoting effects on all the attributes. It is clarified that potassium applications performed well in term of growth and yield under drought stress condition. Therefore, it is suggested that it should be applied as a strategy to mitigate drought stress in maize crop.

INTRODUCTION

Water is very important for seed germination, seedling growth initiation and maintenance of various plant developmental processes during the whole life, and at the end for sustaining the crop production (Aslam et al. 2014). It is estimated that maize crop utilizes about 400-600 mm of water during its whole life cycle (Mishra and Yeh, 2011). Hence, paucity of moisture at any stage of maize growth has negative impacts on its growth and yield. In addition to, drought hazards on maize plant depend on its time, intensity and duration (Chen et al., 2012). Hence, it is the requirement of the time to investigate the deleterious effects of water stress on the various crop growth stages to develop drought tolerance in maize plant.

During drought conditions, maintenance of plant fresh and dry weights is the optimally desirable characteristics. But drought decreases the shoot length and shoots fresh weight in plants (Nahar and Gretzmacher, 2011). Hence, the common harmful impacts of drought on crop plants are observed in term of lower of fresh and dry weights (Farooq et al., 2009). In addition to, the capacity of dry matter partitioning and the biomass production in plants under drought stress is factor to get highest yield (Kage et al., 2004). Similarly, Dai et al. (1990) concluded that moderate water stress at different growth stages of maize slowed down its growth, development and yield.

A full grown maize plant can accumulate up to 300 kg/ha potassium in above ground plant parts, while more amounts are taken up in silage production maize (Hafner et al., 2012). Maize plants absorb potassium rapidly in early growing period (Aslam et al., 2013). However, this ability depend on many factors such as soil solution potassium concentration, soil moisture content, soil texture and structure and distribution of soil potassium reserves (White, 2003). In addition to, tolerance ability in the plant body can be improvised and improved by the application of potassium. That's why; potassium could be an easy and quick way to sustain and improve the crops production, quality and profitability (Cakmak, 2010) for the increasing world population with decreasing water sources on the globe, especially in the developing counties, due to climate change. Keeping in view the water scarcity, the present study was planned to determine the effect of drought stress imposed at various maize growth stages and to explore promoting ability of potassium on growth, development and phenology of maize cultivars under various drought stress conditions.

MATERIALS AND METHODS

Site geography: The research experiments were conducted at the Postgraduate Agricultural Research Station (PARS), Faisalabad, Pakistan. The research station is located at longitude 73°74 E and latitude 30°31.5 N having 184m elevation above sea level. The weather parameters i.e. rainfall (mm), temperature (°C), relative humidity (%) and potential ET (mm) during the study period in both years were recorded as represented in the Table 1.

Field capacity determination: To impose the water stress, the field capacity was maintained using gravimetric method (Nachabe, 1998). Soil samplings were taken at the depth of 30 cm to 100 cm for soil moisture analysis and then to homogenized in to a composite soil sample. These sampling was done from randomly selected sites in each treatment of the experiment on alternate days keeping in view weather conditions.

Depth of irrigation water: The crop was irrigated as the soil moisture contents were lower down from the desired treatment in each plot of the experiment. The depth of irrigation to maintain a specific field capacity in each treatment was determined by the direct measurement or field sampling method as used by Mujumdar (2002).

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

Here in this equation; d = Water depth in (cm) [to be applied in each treatment], D = Root zone depth in (cm), F_c = Field capacity in (%/w), Bd= Bulk density of soil in (g/cm^3), M_b= water contents in soil before irrigation by weight, Cut throat flume (3' x 8") was used to determine the discharge of applied water in each treatment. The time required to supply the required depth of irrigation water to each treatment was calculated according to following equation (Rafiq, 2001).

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

Here in this equation; t = time in hours, d = depth of water in inches, a = area in acres and q = discharge of irrigation water in ft^3/s

Table 1: Daily average weather data for the experimental growing season (Month wise)

	Rainfall (mm)		Temperature (°C)		R. Humidity (%)		Potential ET (mm)	
Months	2010	2011	2010	2011	2010	2011	2010	2011
August	7.31	2.99	30.5	29.8	74.6	74.7	3.4	3.1
September	2.88	5.17	28.6	28.3	66.8	75.8	3.4	2.8
October	0	0.01	26.3	24.7	59.6	61.0	3.0	3.3
November	0	0	18.8	20.5	62.3	61.2	2.1	1.8

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

Table 2: Analysis of field soil

Parameters	Units	2010		2011	
		0-15 (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)
Texture	--	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	--	8.2	8.0	8.2	8.1
EC	(dSm^{-1})	0.72	0.58	0.68	0.53
O. M.	(%)	0.36	0.38	0.38	0.36
Nitrogen	(%)	0.046	0.038	0.043	0.038
Available P	(ppm)	7.8	5.6	7.4	5.5
Extractable K	(ppm)	125.5	121.4	112.5	102.7
Sand	(%)	56	49	55	48
Silt	(%)	22	28	22	27
Clay	(%)	22	23	24	25
F. capacity	(%)	25.4	25.8	25.5	25.9
Wilting point	(%)	7.9	8.4	7.8	8.6
SAR	--	09	11	08	10

Experimental details: The soil was taken from the field at different depths like 0-15 cm and 15-30 cm both the years and soil samples were sent to soil testing laboratory for analysis as depicted in Table 2. The design of experiment was RCBD with split-split arrangements with three replications. The experiment was comprised of following treatments viz. Factor A: Maize hybrids (32F10 and YH1898), Factor B; drought treatments at various growth stages (no drought [control], drought at five leaf stage, drought at ten leaf stage, drought at anthesis and drought at grain formation) and Factor C; Potassium levels (0 and 100 mg/ kg of soil).

Crop husbandry: Experimental field was prepared by performing one deep tillage followed by two crossed cultivations and then field was planked and leveled with the help of laser land leveler. The maize was sown on ridges that were made by using tractor mounted ridger maintaining distance of 2.5 ft from ridge to ridge. The experiment was shown on 5th August, 2010 and on 7th August, 2011. Maize hybrids 32F10 (drought tolerant) and YH1898 (sensitive) were used as test variety. The recommended fertilizer (NP: 250 $kgha^{-1}$, 125 $kgha^{-1}$ and K @ 100 $kgha^{-1}$) was applied. All recommend dose of phosphorus, potash and 1/3rd dose of nitrogenous fertilizers were broadcasted at sowing time whereas the rest of nitrogen dose was top-dressed at the knee height of maize plants. Drought stress was imposed at growth stages that were selected before the study by keeping FC at 70% after 30% depletion from it.

Procedure for estimation of different parameters: The height of ten randomly selected plants was measured by using measuring tape. Then average of plant height was recorded. Leaf length of three leaves from each of the plant was measured and same procedure was repeated for ten plants and then average leaf length was noted. Leaf area of 10 g subsample of fresh green leaves was measured with the help of leaf area meter (Model No. CI-202-CID, Inc.). On the basis of fresh green weight of leaves of ten plants per plot leaf area was calculated. Leaf area index (LAI) was calculated using the following ratio

LAI= Leaf area/Land area

The fresh weight of ten plants was measured with the help of electric balance and average fresh weight was calculated in grams. For cob length, length of ten cobs was measured from tip to base of cob from each of the plot by using scale and hence, average cob length was calculated. Diameter of ten randomly selected cobs was measured from each of the plot and then average cob diameter was calculated.

Statistical analysis: Collected experimental data were carefully analyzed statistically by using Fisher' analysis of variance techniques. Difference among the different treatments means are compared with the help of Least Significant Difference (LSD) Test at 0.05 probability level (Steel et al., 1997) and whole statistical data analysis were smoothly done by using the MSTAT-C computer based software (MSTAT Development Team, 1989).

RESULTS AND DISCUSSION

The effect of potassium on plant height of maize cultivars grown under different drought conditions at various selected growth stages was significant statistically in the both years 2010 and 2011as depicted in Table 3. Results showed that the application of potassium dose enhanced the plant height as per treatment in 2010 and 2011 crop growing season. Drought stress had deleterious effects on plant height of hybrids sown as per treatments in the both years. Statistically, maximum plant height (204.4 & 245.3 cm) was observed in control treatments (no drought) of maize cultivars and followed by drought treatments where drought condition was imposed at grains filling stage that was least affected by drought compare to other treatments. Significantly, minimum plant height (129.0 & 154.8 cm) was recorded when drought treatment was applied at five leaf stage followed by ten leaf stage and at anthesis during 2010 and 2011,

Table 3: Effect of potassium on plant height (cm) of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 $mgkg^{-1}$	100 $mgkg^{-1}$	0 $mgkg^{-1}$	100 $mgkg^{-1}$
32-F-10	No drought	179.6 ef	204.4 a	215.5 f-h	245.3 a
	Five leaf stage	148.5 j	160.4 i	178.2 l	192.5 jk
	Ten leaf stage	168.1 gh	190.4 cd	201.7 ij	225.7 c-e
	Anthesis	176.5 ef	197.3abc	211.8 gh	234.0 bc
	Grain formation	183.8 de	199.8 ab	220.5 e-g	239.8 ab
YH-1898	No drought	172.5 fg	195.6 bc	207.0 hi	232.7 b-d
	Five leaf stage	129.0 k	134.6 k	154.8 m	161.5 m
	Ten leaf stage	156.7 i	162.8 hi	188.1 k	195.3 jk
	Anthesis	158.0 i	179.1 ef	189.6 k	214.9 gh
	Grain formation	158.1 i	187.5 d	189.7 k	224.5 d-f

LSD ($P \leq 0.05$) = 7.49; LSD ($P \leq 0.05$) = 9.44; Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test. ns; non-significant respectively. Overall results showed that the application of potassium increased the plant height by improving the growth activities. Plant height was decreased under water deficit condition (Table 3). Zhao et al. (2006) reported that the imposed drought conditions affected plant height due to change in hormonal concentrations i.e. Cytokines and Abscisic acid that are significantly affected the plant growth by lowering the cell wall extensibility. Similarly, the adverse effects of water deficit condition might also minimized by assuring more availability of water to the plant body by the partial closure of the stomata during transpiration (Alfredo and Setter, 2000; Hoad et al., 2001). It has been suggested that plants mineral nutrient status plays a vital role in improving the resistance of plant to stress conditions (Yadov, 2006).

Statistically significant results regarding to leaf length were obtained by the application of potassium to maize plants grown under drought stress at different growth stages in 2010 and 2011 growing years as represented in Table 4. Results indicated that application of potassium enhanced the leaf length as per treatment in the both years (2010 and 2011). Similar to plant height, drought also had adverse effects on leaf length of hybrids sown as per treatment in the both years. Maximum leaf length of the both maize plants was observed in well-watered treatments (no drought) and followed by drought stress when it was imposed at grains filling stage that had least affected by drought compare to other drought treatments while in some treatments leaf length of no drought and drought at grain filling was almost equal (statistically at par) however, in some treatments it was equal to no drought treatment. The minimum leaf length was recorded when drought condition was imposed at five leaf stage that was followed by the drought treatment imposed at ten leaf stage (Table 4). Drought stress greatly reduced the leaf length (62.39 & 74.87 cm) while application of potassium enhanced the leaf length (72.41 & 86.89 cm) during the year 2011 and 2012, respectively. The leaf length was reduced might be due to less availability of water to photosynthetic mechanism. Leaf length was increased by potassium application because of more growth rate. It was reported by Aslam et al. (2013) that maize leaves elongation was greatly sensitive to minute reduction in soil and leaf water potential but application of potassium enhanced the water budget of plant body helps in leaf length enhancement (Marschner, 1995).

Maize hybrids when grown under drought stress at different growth stages show statistically significant ($P \leq 0.01$) results regarding to leaf area index by the application of potassium in the both years 2010 and

Table 4: Effect of potassium on leaf length (cm) of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 $mgkg^{-1}$	100 $mgkg^{-1}$	0 $mgkg^{-1}$	100 $mgkg^{-1}$
32-F-10	No drought	62.39 cd	72.41 a	74.87 cd	86.89 a
	Five leaf stage	41.39 i	52.65 h	49.67 i	63.18 h
	Ten leaf stage	54.48 gh	60.39 c-e	65.37 gh	72.47 c-e
	Anthesis	60.82 c-e	66.41 b	72.99 c-e	79.69 b
	Grain formation	62.47 c	74.23 a	74.96 c	89.08 a
YH-1898	No drought	59.42 e	65.48 b	71.30 e	78.58 b
	Five leaf stage	38.39 j	43.42 i	46.07 j	52.10 i
	Ten leaf stage	52.41 h	58.74 ef	62.89 h	70.49 ef
	Anthesis	56.28 fg	59.05 e	67.54 fg	70.86 e
	Grain formation	59.42 e	59.85 de	71.30 e	71.82 de

LSD ($P \leq 0.05$) = 2.61; LSD ($P \leq 0.05$) = 3.127; Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test

Table 5: Effect of potassium on leaf area index of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 $mgkg^{-1}$	100 $mgkg^{-1}$	0 $mgkg^{-1}$	100 $mgkg^{-1}$
32-F-10	No drought	3.68 d	4.09 a	3.86 e	4.30 a
	Five leaf stage	2.91 k	3.35 g	3.05 m	3.52 h
	Ten leaf stage	3.27 hi	3.68 d	3.44 ij	3.86 de
	Anthesis	3.45 f	3.97 b	3.62 g	4.17 b
	Grain formation	3.58 e	4.08 a	3.76 f	4.28 a
YH-1898	No drought	3.41 f	3.82 c	3.58 g	4.01 c
	Five leaf stage	2.64 l	3.10 j	2.77 n	3.25 l
	Ten leaf stage	3.22 i	3.61 e	3.38 k	3.79 f
	Anthesis	3.27 hi	3.71 d	3.43 jk	3.90 de
	Grain formation	3.25 gh	3.73 d	3.49 hi	3.92 d

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

Table 6: Effect of potassium on shoot fresh weight plant^{-1} (g) of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 mgkg^{-1}	100 mgkg^{-1}	0 mgkg^{-1}	100 mgkg^{-1}
32-F-10	No drought	334.6 f	379.4 a	478.0 f	542.0 a
	Five leaf stage	230.3 r	250.6 q	329.1 r	358.0 q
	Ten leaf stage	262.6 p	291.1 l	375.1 p	415.9 l
	Anthesis	270.4 o	311.5 j	386.3 o	445.0 j
	Grain formation	333.8 g	362.5 b	476.9 g	517.9 b
YH-1898	No drought	358.4 c	332.4 h	512.0 c	474.8 h
	Five leaf stage	220.5 t	221.4 v	315.0 t	316.3 s
	Ten leaf stage	316.5 i	272.2 n	452.2 i	388.8 n
	Anthesis	340.6 e	288.4 m	486.5 e	412.0 m
	Grain formation	352.3 d	302.6 k	503.3 d	432.4 k

LSD ($P \leq 0.05$) = 0.12; LSD ($P \leq 0.05$) = 0.17; Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test

2011 as depicted in Table 5. Results indicated that the application of potassium enhanced the leaf area index as per treatment. Drought also had adverse effects on leaf area index of sown hybrids as per treatment in the both years. The maximum leaf area index was observed in control (no drought) treatments of the both maize cultivars and that was followed by drought treatments that was started to impose at grains filling stage which was least affected by drought when compared to the all other drought treatments. Significantly, minimum leaf area index was noted when the drought stress was started to impose at five leaf stage. There was a critical role of potassium on enhancing leaf area per plant in the present study. It was studied that application of potassium resulted to rapid growth of leaf and maintenance of osmotic potential of cells (Aslam et al., 2014). Green parts of maize leaf decreased due to water deficit stress which reduced consumption of potassium from soil. More consumption of potassium increased leaf area as compare to un-consumption under proper moisture. Leaf area index was enhanced by potassium as studied by Ebrahimi et al. (2011). Similar trend was observed in this study during both years. Leaf area index was improved due to enhanced leaf growth.

By the application of potassium, maize hybrids when grown under drought stress at different growth stages show statistically significant results ($P \leq 0.01$) regarding to shoot fresh weight per plant in both the years 2010 and 2011 as shown in Table 6. Data indicated that the application of potassium increased the shoot fresh weight per plant as per treatment in the both years. Drought produced adverse effects on shoot fresh weight per plant of sown hybrids as per treatment in both the years. The maximum shoot fresh weight per plant was recorded in control (no drought) treatments of the both maize cultivars and that was followed by drought condition that was stated to impose at grains filling stage which was least affected by the drought when compare to all other drought treatments. Statistically, minimum shoot fresh weight per plant was recorded when drought stress was imposed at five leaf stage (Table 6). Plant fresh weight reduced under water deficit conditions (Zhao et al., 2006). This reduced biomass might have created the disorders in the remobilization of the assimilates from source to mature grain that resulted in short and shriveled kernel or it might be due to disturbed grain growth pattern or its improper position between and within the spikelets under drought stress showing assimilate limitation (Yang et al., 2003). The current outcomes agreed with the findings of Schuppler et al. (1998). Slam et al. (2006) and Ashraf and Ibram (2005) who reported that the shoot fresh weight of two leguminous plants i.e. *Phaseolus vulgaris* and *Sesbania aculeata,* reduced considerably due to water deficit stress that disturb the normal functioning of photosynthesis. Moreover, reduction in the vegetative growth of plants under drought conditions, in specific the shoot growth, reduced the cyclin dependent kinase activity resulting in slower division of cells as well as inhibition of the growth (Schuppler et al., 1998). During the period of study in both years it was found that potassium improved the shoot fresh weight. It was might be due to the role of Potassium in vegetative growth including root elongation (Aslam et al., 2014). Similarly, Marschner, 1995 reported that Potassium has ability to improve the plant girth and diameter. Moreover, it is the most abundant available cation in plant cells (Marschner 1995). So, the decreased irrigation availability resulted in abnormal crop growth and finally, significantly lower yield in crop plants.

Cob length of maize hybrids when grown under drought stress at various growth stages show statistically significant ($P \leq 0.05$) results by the application of potassium in the both (2010 and 2011) as depicted in Table 7. Data showed that the application of potassium enhanced the cob length. Drought also had significantly adverse effects on cob length of hybrids sown as per treatment in the both years. Significantly, maximum cob length was observed in control (no drought) treatments of the both maize cultivars and that was followed by drought treatment when it was imposed at

Table 7: Effect of potassium on cob length (cm) of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 mgkg^{-1}	100 mgkg^{-1}	0 mgkg^{-1}	100 mgkg^{-1}
32-F-10	No drought	14.01 f	19.87 a	16.29 f	19.77 a
	Five leaf stage	11.31 i	13.46 fg	12.55 m	16.72 e
	Ten leaf stage	13.04 g	17.03 d	14.49 j	18.41 c
	Anthesis	14.02 f	17.17 d	14.79 i	18.98 b
	Grain formation	14.03 f	18.87 b	15.98 g	19.09 b
YH-1898	No drought	13.35 g	17.86 c	16.31 f	18.31 c
	Five leaf stage	10.17 j	12.29 h	12.35 m	15.75 h
	Ten leaf stage	12.18 h	16.65 d	14.09 k	17.39 d
	Anthesis	12.38 h	15.85 e	13.13 l	17.32 d
	Grain formation	12.39 h	16.69 d	14.08 k	18.33 c

LSD ($P \leq 0.05$) = 0.60; LSD ($P \leq 0.05$) = 0.22; Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test. ns; non-significant

Table 8: Effect of potassium on cob diameter (cm) of maize hybrids under drought stress in autumn season

Hybrids	Growth stages to impose drought	2010		2011	
		0 mgkg^{-1}	100 mgkg^{-1}	0 mgkg^{-1}	100 mgkg^{-1}
32-F-10	No drought	5.32 f-h	6.23 a	6.27 d	6.57 c
	Five leaf stage	4.47 ij	4.63 i	4.63 n	5.29 k
	Ten leaf stage	4.99 h	5.24 gh	5.56 i	6.13 e
	Anthesis	5.14 h	5.83 b-d	5.92 f	6.73 b
	Grain formation	5.23 gh	6.04 a-c	6.12 e	6.88 a
YH-1898	No drought	5.18 gh	6.07 ab	5.58 i	5.88 g
	Five leaf stage	4.62 i	4.62 i	4.47 o	4.96 m
	Ten leaf stage	4.18 j	5.48 e-g	5.13 l	5.27 k
	Anthesis	5.05 h	5.59 d-f	5.56 i	5.41 j
	Grain formation	5.18 gh	5.71 c-e	5.88 g	5.64 h

LSD ($P \leq 0.05$) = 0.33; LSD ($P \leq 0.05$) = 0.033; Means followed by common letter (s) are not significantly different according to Fisher's protected LSD test

grains filling stage which was least affected by drought compare to all other drought treatments. Statistically, minimum cob length was recorded when drought stress was imposed at five leaf stage. In the both years, the application of potassium increased the cob length.

Effect of potassium on cob diameter of maize cultivars grown under water deficit condition at various selected growth stages was statistically significant ($P \leq 0.01$) as described in Table 8 in the both years 2010 and 2011. Data showed that the application of potassium enhanced the cob diameter as per treatment in both years 2010 and 2011. Significantly, maximum cob diameter was observed in control (no drought) treatment of the both maize cultivars and followed by drought treatment that was imposed at grains filling stage which had least affected by drought compare to all other drought treatments, however, in 2011 cob diameter was more in grains filling drought treatment compare to no drought. Statistically, minimum cob diameter was observed when the drought stress was imposed at five leaf stage (Table 8). Due to enhanced growth of maize by potassium application cob was also increased by potassium as it takes part in growth and development of plant (Marschner, 1995).

Conclusion

The results from this study on maize, contributes additional valuable information to the continuing effort to determine the influence of potassium fertilizer on the responses of plants to water stress. In general, water stress level directly decline in parameters like plant height, leaf length, leaf area, shoot fresh weight, cob length, and cob diameter. On the other hand, application of potassium gradually mitigated the negative effects of water stress. To sum up, the results of recent study confirmed recovery impacts of potassium application under water stress conditions on maize plants.

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