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Full Length Article

Improving Drought Tolerance in Maize (*Zea mays*) with Potassium Application in Furrow Irrigation Systems

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Abstract

Crop management techniques are useful tools to enhance the drought tolerance and crop yield when moisture supply is limited. A field study was conducted to predict the effects of potassium (K) doses (0, 90, 120, 150 kg/ha) on drought resistance and growth of maize under different furrow irrigation systems. Irrigation in alternate-furrow irrigation (AFI), fixed-furrow irrigation (FFI) and conventional-furrow irrigation (CFI) significantly improved the growth attributes such as leaf area index, leaf area duration, crop growth rate and total dry matter. These attributes improved more by adopting fixed furrow method under limited water supply. Interactive effects of irrigation methods and K on all growth and yield components were significant except number of grain rows per cob. Maximum grain and biological yields (4.94 and 11.15 t/ha, respectively) were achieved with FFI-120 kg/ha K treatment in contrast to K-application along with other irrigation methods (AFI and CFI). The highest plant population (62), plant height (216 cm), cob length (19 cm), grains per grain row (37) and 100-grain weight (62 g) were achieved with the application of K at 120 kg/ha in FFI system. Higher leaf water potential (-0.26 MPa), turgor potential (1.41 MPa) and lower osmotic potential (-1.67 MPa) were attained in K fertilized plants compared to non-fertilized plants in FFI. In conclusion, adequate K nutrition proved to be promising in improving drought resistance and higher growth and yields in maize under FFI system. © 2013 Friends Science Publishers

Keywords: Drought tolerance; K-application; *Ψw*; *Ψs*; Maize; K-FFI interaction

Introduction

Drought is a major devastating factor at multiple stages of plant development and potentially restricts the growth and productivity (Flexas and Medrano, 2002; Caballero *et al.*, 2005). Extreme water shortage causes considerable physiological, metabolic and morphological changes in plants and ultimately reduces crop yields and quality (Farooq *et al.*, 2009; Maqsood *et al.*, 2012). Water stress reduces evapo-transpiration by closing stomata, which results in reduced carbon assimilation rate and declined in biomass production (Smith *et al.*, 2002; Demir *et al.*, 2006).

Several management practices that enhance the accessibility of stored moisture in soil have been formulated to address the drought conditions (Mostafazadeh-Fard *et al.*, 2009). Compared with other irrigation systems, furrow irrigation method favors the most uniform and adequate moisture supply to the plants and also improves fertilizer use efficiency. Irrigation efficiency in maize (*Zea mays* L.) can be improved through AFI system where less water is usually applied (Mahal *et al.*, 2000; Sepaskhah and Khajehabdollahi, 2005). Irrigation can be reduced by 20–30% through AFI system without losing significant yield (Kang *et al.*, 2000; Yonts *et al.*, 2007).

Drought tolerance in plants can be increased by breeding for drought resistance (Farooq *et al.*, 2009), chemical causing the closure of stomata or diminished transpiration rate, and nutrient application (Chaves *et al.*, 2003; Waraich *et al.*, 2011). Nutrient management could be more feasible and economical method to induce drought tolerance in maize. Nutrients either free or structurally bound to essential complexes can regulate osmotic potentials and thus enhance turgor pressure which is required to sustain growth (Taiz and Zeiger, 2010). Potassium supply in water stressed plants alleviated the stress injury by reduced transpiration rate and improved cell water status (Losch *et al.*, 1992). Benefits of K supply in water stressed plants are well documented such as increased dry matter, permeability of plasmalemma, water potential, photosynthetic rate, chlorophyll content, leaf area, stem width, decreased carotenoid contents and respiration rate (Akhtar *et al.*, 1999; Farooq *et al.*, 2009).

Improved water use efficiency (WUE) and induced drought resistance by upholding relatively higher water potential in maize has been reported with application of K (Li *et al.*, 2007). As stomatal function is regulated among others by K content of guard cells (Epstein and Bloom, 2005; Taiz and Zeiger, 2010), availability of adequate K supply improves the WUE by closing stomata during night to avoid water loss (Bajwa, 1995). Therefore, K application

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to crops can be an efficient and viable management practice to improve production potential and to enable plants to withstand water deficit conditions. We hypothesize that exogenous K-application in different furrow-irrigation systems may substantially improve the maize water status and growth. Keeping the above facts in view, an experiment was conducted to explore the rate of K application in order to alleviate the drought in maize under different furrow-irrigation systems.

Materials and Methods

The research work was conducted at Agronomic Research Farm, Department of Agronomy, University of Agriculture, Faisalabad (Pakistan) during the year 2011. Climate of the region is semi-arid to subtropical. The experimental site was located at longitude 73′-06^o E, latitude 31′-26^o N and at an altitude of 184.4 meters above sea level. Soil samples were collected at 30 cm depth prior to sowing of the crop. Soil was clayey-loam with slight alkaline reaction and consists of 33.80% sand, 34.00% silt, 32.20% clay. Based on chemical analysis, the experimental soil have 37% saturation percentage, 8.1 pH, 1.2 dS/m electrical conductivity, 0.78% organic matter, 0.048% nitrogen content, 8.8 ppm available P, 130 ppm available K and 5% $CaCO_3$. Soil samples were analyzed for its various chemical properties by using the methods as described by Homer and Pratt (1961). Meteorological observations for the entire growing period of maize crop were obtained from the meteorological observatory of the Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan (Fig. 1).

The experiment was laid out in randomized complete block design with split plot arrangement, replicated thrice in a plot size of 3 m × 6 m. The experimental treatments were: irrigation methods; alternate-furrow irrigation (AFI), fixed-furrow irrigation (FFI), conventional-furrow irrigation (CFI). In AFI, one of the two neighboring furrows was alternately irrigated during consecutive watering. Under FFI, irrigation was fixed to one of the two neighboring furrows. CFI is a conventional method in which every furrow was irrigated within each irrigation. K-levels were: control (no K), 90, 120 and 150 kg/ha. Irrigation levels were allocated to main-plots, while K levels to sub-plots.

Seedbed preparation was done by plowing the soil 2-3 times via tractor mounted plow followed by planking. Maize variety Pioneer-32-F10 was sown on 2nd week of August, 2011 by using single row hand drill on the seed bed according to pretreatment pattern. The seed sowing was done to accomplish 25 cm plant to plant distance using a seed rate of 30 kg/ha with 75 cm row spacing. Nitrogen (N) was applied as urea (46% N); 1/3 at sowing; 1/3 at 60 cm height; 1/3 at tasseling. Phosphorus (P; diammonium phosphate) and K (murate of potash) fertilizers were applied completely as a basal dose. Crop was kept free of weeds by hoeing twice to avoid weed-crop competition. For AFI, FFI and CFI, the irrigation interval was 7 days for the one and a half month after which irrigation was applied fortnightly. Thinning was done when crop attained the height of 15 cm to maintain plant-to-plant spacing.

Data were recorded for leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), total dry matter (TDM), plant population, plant height, cobs per plant, grain rows per cob, cob length (cm), grains per cob, 100-grain weight, economic and biological yields, harvest index (HI) and economic analysis using standard procedures. Plant sampling was done for LAI, LAD, CGR and TDM at 40 DAS (days after sowing), 55 DAS, 70 DAS, 85 DAS and 100 DAS while for yield and yield attributes measurements were taken at maturity stage. Leaf water potential (Ψw) was measured using pressure chamber (Arimad-2, ELE International, Tokyo, Japan). The upper fully expended sunlit leaves of two plants from each treatment were used. The same leaf, as used for water potential measurement, was frozen in a freezer at -20^{o}C for seven days to measure the leaf osmotic potential (Ψs). The cell sap extracted from previously thawed leaves by using disposable syringe. Osmotic potential of the sap was determined by osmometer (Wescor 5500, USA). Leaf turgor potential (Ψp) was computed by subtracting the osmotic potential from water potential.

$$\Psi p = \Psi \mathrm{w} - \Psi s$$

Statistical Analysis

Data were analyzed using MSTATC statistical package (Steel *et al.*, 1997) by Fisher’s analysis of variance technique. Least significant difference (LSD) test was employed for the comparison of treatments’ differences by keeping probability level at 5%.

Results

Growth Indices

Irrigation methods and K application imposed in maize had significant ($P \leq 0.05$) effect on LAI taken at 25, 40, 55, 70, 85 and 100 days after sowing (DAS) while their interactive effects were non-significant ($P \geq 0.05$). Maximum LAI across irrigation methods was recorded at 85 DAS, which declined thereafter. FFI displayed higher LAI (3.26) at 85 DAS compared to AFI and CFI. Individual comparison among K treatments indicated that 120 kg/ha provided the maximum LAI (3.32) at 85 DAS, which was non-significantly different from 150 kg/ha (3.20), Control exhibited the lowest (2.69) LAI (Fig. 2).

The maximum LAD (199.3) was achieved with FFI, while the lowest one in AFI at 85 DAS, which further declined. Individual comparison of K levels had significant effect on LAD; among K levels, 120 kg/ha K gave maximum LAD (194.02) followed by 150 kg/ha K, while it was minimum (184.30) in control (Fig. 2).

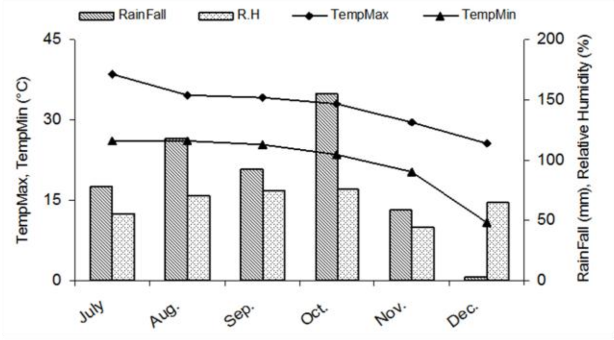

Fig. 1: Average maximum and minimum temperatures (^{o}C), monthly rainfall (mm) and relative humidity (%) measured at the experimental site during 2011

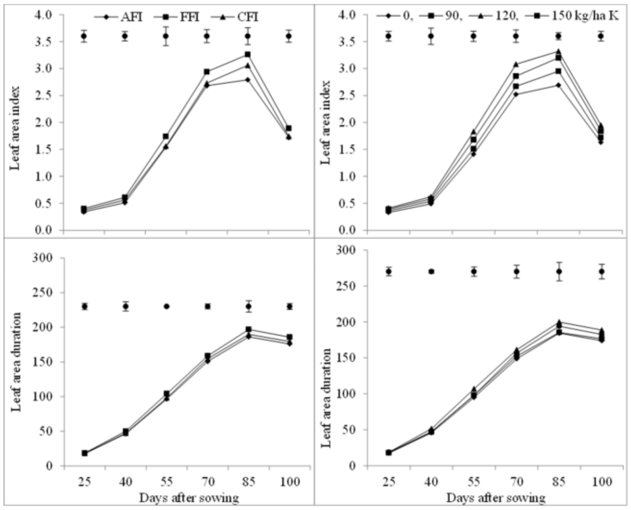

Fig. 2: Effect of irrigation methods (AFI, FFI and CFI) and potassium levels (K_0, control; 90, 120 and 150 kg ha^{-1}) on leaf area index and leaf area duration of maize. Vertical bars show the LSD value following periodic data at ($P \leq 0.05$)

The maximum CGR value was obtained at 55 DAS among the harvests. CFI did not fair-well as compared to FFI and AFI methods ($P \leq 0.05$). Maximum value of CGR (24.03) increased up to the harvest date of 55 DAS by FFI method then goes to depress. The role of K in CGR was also found to be significant ($P \leq 0.01$). Among K levels, 120 kg/ha displayed greater CGR (23.73) compared to other levels at various DAS. A minimum CGR (20.01) in control (no-K) confirmed the role of K in drought alleviation in maize pants (Fig. 3). For highest TDM the main effect of irrigation methods and K levels was significant ($P \leq 0.05$) but non-significant ($P \geq 0.05$) for their interactive effect as maximum value (1003.9) on TDM was achieved with FFI followed by AFI and CFI. Among K levels, 120 kg/ha gave the highest TDM (1124.8) at 100 DAS that at other K-levels (Fig. 3).

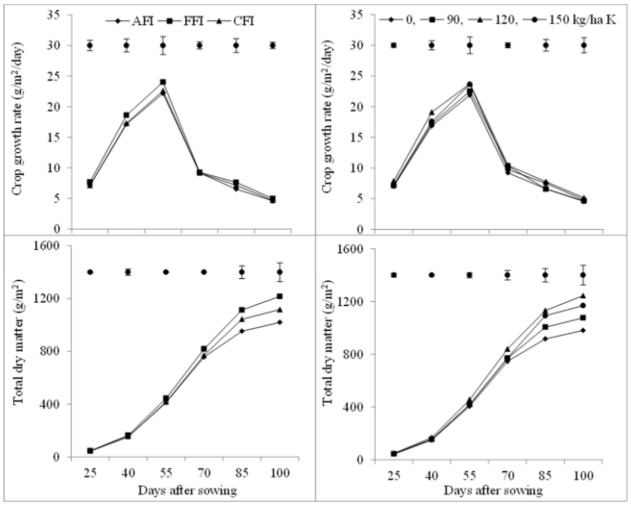

Fig. 3: Effect of irrigation methods (AFI, FFI and CFI) and potassium levels (0; control, 90, 120 and 150 kg/ha) on CGR and TDM of maize. Vertical bars shows the LSD value following periodic data ($P \leq 0.05$)

Water Relations

Leaf water potential (*Ψw)*, osmotic potential (*Ψs*) and leaf turgor pressure *(Ψp*) remained statistically significant ($P \leq 0.05$) under K and irrigation methods interaction (Fig. 4). FFI showed improved results for water potential compared to alternate and conventional furrow irrigation methods in conjunction with K supply. Results showed that K supply at 120 kg/ha proved helpful in plant performance during limited moisture supply. Higher leaf water potential (-0.26 MPa) was observed in FFI at 120 kg/ha K level. However, lower leaf water potential (-0.42; -0.38 and -0.39 MPa) was notable with no K supply in all irrigation systems. Leaf *Ψs* was low (-1.08, -1.10 and -1.11 MPa, respectively) with noK application and further decreased (-1.67 MPa) with 120 kg/ha K-application in FFI. Similarly, K-fed plants with 120 kg/ha fertilizer application maintained higher leaf *Ψp* (1.41 MPa) in FFI compared to other K levels. All furrow irrigation methods were responsible for lower *Ψp* (0.66, 0.73, 0.71 MPa, CFI, FFI and AFI, respectively) where no K was applied.

Yield Attributes

Potassium application at 120 kg/ha under FFI was responsible for maximum plant population (61.59). The lowest plant population (41.93) was attained in K deficient plots (K_0) with CFI irrigation method, which was statistically equal to the AFI × K_0 in AFI (Table 1). Application of K at 120 kg/ha showed the highest plant height (216 cm) when irrigation was applied under FFI system, which was statistically non-significant with AFI × K_2, FFI × K_3, CFI × K_2 treatment combinations with mean values of 210.33, 209.00 and 212.33 cm, respectively.

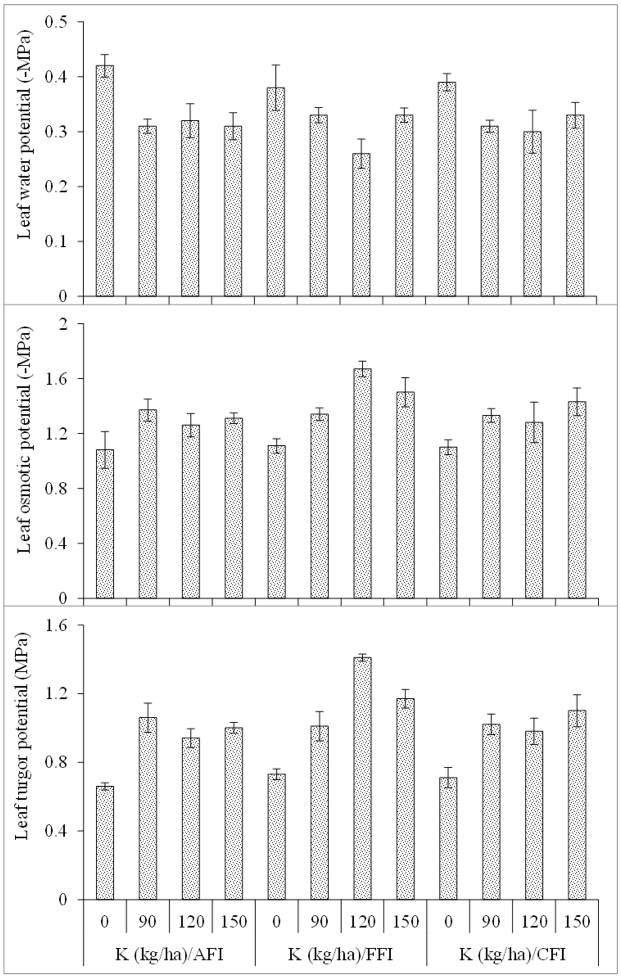

Fig. 4: Water relations of maize crop when subjected to irrigation methods and potassium application. Means ± SD

AFI with 90 kg of potash (K$_1$) provided minimum plant height (189.67) contrast to FFI and CFI and K (K$_2$ and K$_3$) levels (Table 1). Highest number of cobs (1.46) were documented in K$_3$ (150 kg/ha K) through CFI irrigation application, which was statistically similar with 100 kg/ha K in FFI. Increase in cob length (19.11 cm) was confirmed in K$_2$ (120 kg/ha K) and FFI irrigation method. K (120 and 150 kg/ha) application in CFI also increased cob length (17.80 and 17.25 cm, respectively) compared to minimum cob length (14.73 cm) in 90 kg/ha K when applied in AFI method followed by noK application in CFI (Table 1).

The results about grain rows per cob were recorded as non-significant ($P \geq 0.05$) across the treatments (Table 1). Highest grain number (37.33) for each grain row was attained in 120 kg/ha K applied with FFI that was statistically similar with 120 kg/ha K by FFI with 33.66 grains for each grain row, while the least number of grains were achieved in 90 kg/ha K when practiced in AFI method (Table 1). The interaction of irrigation methods and K showed maximum 100 grain weight (61.74 g) in K$_2$ (120 kg/ha) when irrigation was applied as FFI. Application of 150 kg/ha K under CFI yielded maximum (59.93 g 100 grain weight) grain weight as compared to the minimum (41.58 g) in 90 kg/ha K under CFI (Table 1). Maximum economic yield (4.94 t/ha) was recorded in 120 kg/ha when applied in FFI, which was similar to 150 kg/ha K applied as CFI. Low economic yield of 3.11 t/ha was recorded in 0 kg of K-applied in CFI. Similar trend was observed for biological yield (11.36 t/ha) and followed by grain yield (Table I).

Discussion

The study was aimed to alleviate the drought stress in maize by application of K nutrition under various irrigation methods. Generally, K reduce the adverse effects of drought by inducing various physiological changes such as osmotic adjustment, protein synthesis and reduction in transpiration rate in water deficient plants (Ruan *et al.*, 1997; Quintero *et al.*, 1998; Farooq *et al.*, 2009). A significant increase in plant growth with K supply reveals that 120 kg/ha K was adequate for satisfactory maize growth under limited moisture supply (Figs. 2, 3). In maize, K content in leaf tissueand dry matter increased due to significant effect of K supply on plant growth under drought. Low K supply reduced the leaf area, dry matter and yield of water stressed plants. Cao and Tibbitts (1991) reported that K play an important role in translocation of other mineral nutrients and enzymes in both xylem and phloem tissues, therefore limited supply of K could exert adverse effect on leaf growth indices (Hussain *et al.*, 2007).

In general, marked decrease in leaf water potential (Ψw), turgor potential (Ψ_p) and increase in osmotic potential (Ψs) of maize plants were noticed under limited water supply (Fig. 4). K supply sustained higher Ψw, Ψ_p, lowered Ψs, increased photosynthetic rate and improved drought tolerance in K-treated maize compared to K-deficient maize under drought stress (Nandwal *et al.*, 1998). Tolerance in plants against drought stress may be contributed by K fertilization that causes osmotic adjustment via upholding turgor pressure at low water potential (Premachandra *et al.*, 1991; Taiz and Zeiger, 2010).

This study proposes a linear association between K supply and tolerance to limited moisture supply in maize when fertilized with 120 kg ha^{-1} K in comparison to K deficient plants in AFI method. In AFI, weak plants were senesced and thus plant population declined. Application of K improved the growth of roots and therefore provides more chances to survive under severe environment. Better root system also facilitates the plants to anchor fit and take up more nutrient elements, which eventually enhanced the plant population (Pettigrew, 2008). During the vegetative stage of crop development, plant height was reduced due to drought conditions. However, significantly ($P \leq 0.05$) taller plants were observed under K fertilization treatment (Table 1). Gupta *et al.* (1989) recorded a strong relationship between K supply and moisture stress tolerance in maize.

Table 1: Mean squares and effect of irrigation methods and potassium application on growth and yield attributes of maize

SOV	df	Mean square								
		PP	PH	C/P	CL	GR/C	G/GR	100-GW	GY	BY
Replication (r)	2	4.77	148.11	0.018	0.48	0.08	17.86	8.46	0.20	1.08
Irrigation methods (I)	2	76.19**	165.36*	0.029*	2.47*	3.58^{NS}	76.86*	54.02**	0.33*	1.76*
Error a	4	1.61	23.19	0.003	0.15	0.54	6.32	1.17	0.04	0.21
Potassium (K)	3	396.32**	301.58**	0.235**	13.53**	17.22**	149.14**	301.19**	2.52**	14.05**
I × P	6	24.71**	108.81**	0.033**	1.27**	2.03^{NS}	57.31**	93.92**	0.46**	2.04**
Error b	18	1.55	17.76	0.004	0.15	1.20	9.05	1.25	0.05	0.28
Irrigation methods × Potassium										
AFI	0	42.33± 4.92 g	204.33± 1.86 bc	1.00± 0.03 fgh	16.00± 0.51 ef	10.33± 0.51	23.67± 1.86 de	51.18± 1.39 e	3.55± 0.15 efg	7.75± 0.54 fgh
	90	48.00± 4.97 e	189.67± 4.92 e	1.05± 0.02 efg	14.73± 0.27 g	11.67± 1.03	19.33± 1.36 e	41.58± 1.17 g	3.37± 0.23 fgh	8.17± 3.56 efg
	120	56.67± 0.51 c	210.33± 2.87 ab	1.24± 0.06 bc	17.67± 2.67 b	14.01± 1.78	30.33± 5.39 bc	56.70± 0.35 d	4.19± 1.94 bc	9.65± 0.86 bc
	150	53.67± 4.03 d	200.33± 5.39 cd	1.15± 0.02 cde	16.85± 0.24 cd	12.00± 0.89	26.33± 3.38 cd	55.72± 0.69 d	3.86± 0.14 cde	8.89± 0.32 cde
FFI	K_0	45.53± 0.86 f	201.33± 3.14 cd	0.98± 0.06 gh	15.39± 0.37 fg	10.67± 0.51	22.33± 1.36 de	45.53± 0.86 f	3.31± 2.83 gh	7.61± 0.60 gh
	K_1	58.99± 1.57 b	208.00± 0.89 bc	1.12± 0.02 def	16.62± 1.83 cde	12.33± 0.53	33.67± 1.56 ab	58.99± 1.57 bc	3.77± 0.11 def	8.66± 0.33 def
	K_2	61.59± 0.47 a	216.00± 1.78 a	1.44± 0.14 a	19.11± 0.61 a	15.33± 0.51	37.33± 2.25 a	61.74± 0.43 a	4.94± 0.91 a	11.15± 2.10 a
	K_3	54.44± 1.24 d	209.00± 8.04 ab	1.20± 0.05 bcd	17.74± 2.85 b	14.02± 0.91	26.00± 0.89 cd	55.18± 1.60 d	4.03± 0.36 bcd	9.28± 0.88 bcd
CFI	K_0	41.93± 0.41 g	194.00± 4.47 de	0.92± 0.08 h	15.21± 0.54 g	11.33± 1.03	21.67± 6.71 de	41.93± 0.41 g	3.12± 1.89 h	7.17± 1.19 h
	K_1	50.01± 1.15 e	207.00± 3.09 bc	1.15± 0.02 cde	16.46± 0.25 de	12.33± 0.51	23.67± 4.92 de	50.01± 1.15 e	3.86± 0.16 cde	8.88± 3.91 cde
	K_2	57.23± 0.52 bc	212.33± 8.01 ab	1.29± 0.07 b	17.80± 0.49 b	12.67± 1.02	29.00± 4.64 bc	57.23± 0.52 cd	4.33± 0.50 b	9.96± 1.15 b
	K_3	57.56± 2.77 bc	207.33± 10.36 bc	1.47± 2.77 a	17.25± 4.75 bc	13.33± 0.51	31.00± 2.36 bc	59.93± 2.44 ab	4.85± 0.65 a	11.37± 0.86 a
LSD $_{\text{Interaction}}$ ($P \leq 0.05$)		2.33	8.23	0.12	0.73	NS	5.26	2.05	0.41	0.94
P value		0.0002	0.0012	0.0005	0.0002	0.1822	0.0010	0.0001	0.0002	0.0006

^{NS} Non-significant; **Indicates the significance at ($P \leq 0.05$); Means not sharing the same letter with in a column differ significantly from each other at 5% level of probability; PP (plant population), PH (plant height), C/P (cobs per plant), CL (cob length), GR/C (grain rows per cob), G/GR (grains per grain row), 100-GW (100-grain weight), GY (grain yield), BY (biological yield)

In our study, K supply reduced the severe effects of drought stress on plant growth and development by list the factors improved by K application to complete the sentence.

Sufficient K nutrition appeared to be effective for increasing cob length, number of cobs per plant and grains number in water stress conditions (Table 1). Water stress significantly reduced the growth and development but K supplement maintained the increase in grain numbers per row in Maize (Rasheed *et al.*, 2004; Oktem *et al.*, 2005). The additive relationship between K (120 kg/ha) and 100 grain weight in water deficit condition was also observed in our work. The K feeding was responsible for higher grain and biological yield in maize plants under CFI (Table 1). In fact, detrimental effects of water stress on growth and development are minimized by K fertilization through its positive effect on stomatal regulation, osmotic adjustment, protein synthesis and photosynthesis (Asgharipour and Heidari, 2011).

In conclusion, K supply significantly increased growth and yield of maize and was also helpful in reducing the adverse effects of drought stress by improving the leaf water status. K application at 120 kg/ha was the most suitable treatment for maize growth and yield in FFI than AFI and CFI systems.

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