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Potassium nutrition improves the maize productivity under water deficit conditions

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Abstract

Water scarcity at critical growth stages reduces the maize productivity; however, potassium (K) nutrition can ameliorate its adversities to a certain extent. This study was conducted to evaluate the role of K nutrition in improving the productivity of maize hybrids NK-8441 and P-32B33 under water deficit (50% field capacity) at stem elongation (BBCH-36) and tasseling (BBCH-59) stage by withholding irrigations. Both the hybrids viz. NK-8441 and P-32B33 were fertilized or not with 60 kg K ha^{-1} as basal application. Water deficit both at BBCH-36 and BBCH-59 stages reduced the productivity of both maize hybrids due to decrease in yield related traits. However, K application improved the grain yield of tested hybrids both under stress and optimal water conditions. Application of K also improved the root system in both tested maize hybrids. Although, K nutrition improved the net income from both tested hybrids; however, benefit-cost ratio was improved only in case of hybrid P-32B33. In crux, drought stress, particularly at BBCH-59 stage, reduced the yield of both tested maize hybrids. However, K nutrition helped in mitigating the damaging effects of drought due to well-developed root system, and accelerated the yield and net income.

Keywords: Maize hybrids, drought, K application, root system, BBCH-scale

Introduction

Among several environmental threats endangering the productivity of arable crops in near future, drought is on top to curb crop productivity worldwide. Currently, 45% of agricultural lands worldwide are under continuous or intermittent drought, wherein about 38% of world human populace lives (Bot *et al*., 2000). Plants undergo water scarcity either due to declined water supply to roots or due to extended transpiration rate (Manivannan *et al*., 2007). Restricted cell division and elongation, reduced leaf area, impaired stem elongation, declined root extension and penetration, altered plant water relations, abridged water and nutrients use efficiency linked with lesser crop productivity are the central significances of water deficit in arable crops including maize (*Zea mays* L.) as well (Dagdelen *et al*., 2006; Hussain *et al*., 2008, 2009, 2013; Farooq *et al*., 2014). Therefore, adequate soil water supply is imperative for crop growth, transpiration and transferring of nutrients from roots to other plant parts.

Maize ranks 3rd (after rice and wheat) among the most cultivated cereals over the world which can be successfully grown under a wider range of edaphic and climatic conditions, and uses moisture more proficiently due to its C_4 nature. Therefore, restricted water supply at any stage of maize limits its growth and productivity enormously (Harold, 1986) but incidence of drought at some critical phenophases is more destructive (Grant, 1989). For instance, drought incidence at reproductive stage of maize is more damaging leading to large decline in yield (Borras *et al*., 2002; Hammer and Broad, 2003). Drought at vegetative stage caused reduction in kernel numbers but had little effect on kernel weight in maize (Eck, 1986). Flowering or reproductive stage is more sensitive to drought causing significant yield losses (Saini and Westgate, 2000). Water stress after pollination to physiological maturity notably decreased grain weight (McPherson and Boyer, 1977). A lot of earlier published literature highlights the harmful effects of drought on maize yield due to reduced crop growth, canopy development, dry matter accretion, kernel number and weight (Hammer and Broad, 2003; Dagdelen *et al*., 2006; Hussain *et al*., 2013).

Potassium (K) nutrition seemed highly effective in improving drought resistance of plants by modulating plant water relation under water deficit conditions (Parsons *et al*., 2007). Plants getting K sustained high leaf water and turgor potential, relative water contents and lesser osmotic potential than untreated maize plants grown under water stress (Premachandra *et al*., 1991). Several

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physiological processes like enzyme activation, protein synthesis, photosynthesis, stomatal regulation etc. in plants are affected by K nutrition (Marschner, 1995). Uptake of K improved corn roots growth and thus elevated the ability to absorb more water from soil and thus increased the resistance capacity against drought that finally improved the growth of corn plant under drought (Cox, 2001). Field applied K improved photosynthetic rate, plant growth and yield of diverse crops under short water supply (Tiwari *et al*., 1998; Egilla *et al*., 2001). Moreover, collective impacts of drought and low temperature can be minimized by improving K level in the soil (Kafkafi, 1990). Moreover, the impact of fertilization and water application on plant productivity is also correlated. Fertilization plays affective role only when plants do not face water-stress conditions, and similarly irrigation plays key role in plant productivity when nutrients are not in debit (Sands and Mulligan, 1990).

There is extensive genetic diversity among maize genotypes, and therefore divergent genotypes respond differently to different agro-management practices, particularly water and nutrient management. These differences are mainly due to their divergent morphology (Benga *et al*., 2001), intraspecific competition in maize plants for water (Maddonni and Otegui, 2006), plant growth rate (Aslam *et al*., 2006), crop duration (Ying *et al*., 2000; Echarte *et al*., 2006) and root system (Khan *et al*., 2012a, b). Better-developed root system plays a crucial role in improving plant growth mainly under restricted water and nutrients supply in soil. Water stress inhibits root growth even in tolerant genotypes while the effect is highly distinct on sensitive ones (Piro *et al*., 2003). Roots extend slowly owing to water paucity and mechanical impedance in water deficient soils (Bengough *et al*., 2011); and ultimately plants explore small volume of soil to attain water and nutrients in dry soils (Chassot and Richner, 2002). Khan *et al*. (2012b) reported higher grain and water productivity of maize hybrids having better root system.

Although it is well documented that water deficit leads to a notable yield penalty in maize which can be overcome to a certain extent by K nutrition but information about the interactive effects of water deficit and K nutrition on root system of divergent maize hybrids under field conditions is missing yet. Therefore, this field study was designed with the hypothesis that water deficit reduces the maize productivity owing to impaired root system; however, it can be overcome to a certain extent by K nutrition due to well-developed root system.

Table 1: Weather data during the crop growth period

Month	Mean monthly temperature (ºC)	Total monthly rainfall (mm)	Mean monthly RH (%)
February	15.40	29.50	68.00
March	20.90	6.70	58.00
April	26.00	30.50	45.00
May	33.40	16.80	38.00
June	33.40	7.80	44.90

Source: Central Cotton Research Institute (CCRI), Multan

Materials and Methods

This field trial was conducted at Research Farm of Department of Agronomy, Bahauddin Zakariya University, Multan (71.43^o E, 30.2^o N and 122 m asl), Pakistan, during spring, 2011. Before sowing, soil sampling was done to estimate the soil fertility status and samples were tested at Soil and Water Testing Laboratory, Multan. Samples were air dried, passed through 2 mm sieve and analyzed for soil texture, by hydrometer method (Malik *et al*., 1984), electrical conductivity (EC) by preparing 1:10 soil and water suspension (Soil Salinity Lab. Staff, 1954), pH (Schofield and Taylor, 1955), organic matter (Nelson and Sommers, 1982), available P (Olsen and Sommers, 1982) and K (Helmke and Sparks, 1996). The experimental land was sandy clay loam having pH = 7.82, EC = 1.39 dS m^{-1}, organic matter = 0.56%, total nitrogen (N) = 0.03%, available phosphorus (P) = 10 mg kg^{-1} and available potassium (K) = 110 mg kg^{-1}. The climate of the area is subtropical and semi-arid. Weather data during the whole course of study is given in Table 1. Two maize hybrids viz. NK-8441 (long duration hybrid) and P-32B33 (short duration hybrid) were fertilized or not with 60 kg K ha^{-1}. Water deficit was imposed at BBCH-36 (stem elongation; six nodes detectable) and BBCH-59 (end of tassel emergence) stages by withholding irrigations up to ~50% field capacity (FC; 12.80% soil moisture contents) level while well-watered conditions (~75% FC; 19.15% soil moisture contents) were taken as control following Hussain *et al*. (2013), Zafar-ul-Hye *et al*. (2014) and Khan *et al*. (2015). Randomized complete block design under split-split plot arrangement was used to layout the experiment with three replications and net plot size of 3.5 m × 3 m. Water deficit levels were kept in main plots, K levels in sub-plots and maize hybrids in sub-sub plots.

Crop husbandry

Pre-sowing irrigation of 10 cm was given in order to create conditions favorable to seedbed preparation. At workable moisture level, soil was cultivated twice with tractor-mounted cultivator followed by planking to prepare seedbed. Both tested hybrids were sown on February 4, 2011 with single row hand drill in 75 cm spaced rows by using seed rate of 30 kg ha^{-1}. To maintain plant to plant distance of 22.5 cm, thinning was done when the seedlings attained the height of 30 cm. Field was fertilized with 200 kg of N and 150 kg of P_2O_5 ha^{-1} by using di-ammonium phosphate and urea. Full dose of P and one 1/3rd dose of N was applied at sowing and K was applied in half plots according to treatments. Remaining 2nd and 3rd dose of N (1/3rd each) was applied with 1st and 2nd irrigations. When the soil achieved the suitable moisture level after 1st irrigation, hoeing was practiced to keep the crop free from weeds and then earthing up was done. Carbofuran (Furadan 3G) was applied for the control of top borer at 12.5 kg ha^{-1}. Mature crop was harvested on June 8, 2011.

Observations recorded

At harvest, plant population was recorded by counting total number of plants in each plot. Ten randomly selected plots were used to note plant height (cm) and number of cobs per plant; whereas ten randomly selected cobs of aforesaid plants were used to record cob length, number of rows per cob and number of grains per cob after averaging. To record 1000-grain weight, five random samples of 1000 grains were taken from seed lot of every plot, weighed by electronic balance and averaged to calculate 1000-grain weight. To record grain yield, all plants in each plot were harvested at maturity, cobs were separated, sun dried for five days, threshed manually and grain yield was recorded on plot basis and then into tons ha^{-1}. After that weight of air-dried plants (without cobs) for three days was taken on plot basis and converted into t ha^{-1}. This weight was added to grain yield to estimate biological yield. Harvest index was intended as a ratio amid grain and biological yield articulated in percentage.

Five plants selected randomly from each plot were uprooted with intense care to avoid roots injury, washed with tap water and dried in air for some time. Primary root length was measured with meter rod and all the lateral roots of five uprooted plants were counted and averaged to note primary root length and lateral roots per plant at fortnight intervals (Khan *et al*., 2012a, b; Hussain *et al*., 2013; Khan *et al*., 2015). Likewise root and shoot dry weight was recorded at fortnight intervals and then root and shoot growth rate was estimated by following Hunt (1978). Moreover, leaf chlorophyll content was measured by using leaf chlorophyll meter.

Statistical and economic analysis

All collected data were analyzed by using computer statistical MSTAT-C program (Freed and Eisensmith, 1986). Analysis of variance (ANOVA) technique was used to test the significance of data and least significance difference (LSD) test at p=0.05 was used to compare the differences among treatment's means. For economic analysis, total expenses of crop including the cost of seedbed preparation, seed and sowing, irrigation fertilizing, crop protection, weeding, earthing up, harvesting and land rent was worked out. Total income was calculated by using existing price of maize grain in local market of the country. Net return was computed by deducting the total expenses from total income whereas benefit:cost ratio (BCR) was worked out by dividing gross income with total expenses (Shah *et al*., 2013).

Results

Both hybrids did not differ for plant population at maturity, plant height, cob length and number of rows per cob either with potassium (K) nutrition or not (Table 2). However, water deficit imposed either at BBCH-36 (stem elongation; six nodes detectable) and BBCH-59 (end of tassel emergence) stage of maize caused substantial reduction in plant height and cob length; however K nutrition did not improve the plant height but cob length was improved both under well watered and drought imposed at BBCH-36 stage only (Table 2). Moreover, water deficit imposed at BBCH-36 and BBCH-59 had non-significant effect on plant population and number of rows per cob either with K nutrition or not (Table 2).

Potassium nutrition significantly improved grain and biological yield of both hybrids, although the hybrids differed in this regard, due to notable expansion in yield related traits like grains per cob and grain weight while the effect was non-significant on harvest index (Table 3). Hybrid NK-8441 recorded more grains per cob, and grain and biological yield than P-32B33 either K was applied or not but both the hybrids behaved similarly for 1000-grain weight and harvest index (Table 3). Water deficit either at BBCH-36 and BBCH-59 stage caused substantial reduction in number of grains per cob, 1000-grain weight, and grain and biological yield, though the stress at BBCH-59 stage seemed more detrimental (Table 3). Nonetheless, K nutrition notably improved grains per cob, grain size, and grain and biological yield under well watered and stress conditions either imposed at BBCH-39 or BBCH-59 stage of maize (Table 3). Water deficit at BBCH-59 stage improved the harvest index compared with well watered

Table 2: Influence of K nutrition on plant height and yield components of maize hybrids under drought stress

Treatment	Plant population per plot		Plant height (cm)		Cob length (cm)		Number of rows per cob		Number of grains per cob	
K application	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}
Hybrids										
NK-8441	47.67	47.56	149.28	150.22	15.77	15.83	13.21	13.67	392.44 b	405.44 a
P-32B33	47.64	48.11	149.94	150.36	15.46	15.55	13.22	13.55	375.56 c	388.67 b
LSD at 5%	ns		ns		ns		ns		12.96	
Water stress										
Well watered	49.17	48.67	154.52 a	152.04 b	15.97 b	16.55 a	14.67	14.67	398.50 b	409.67 a
Drought at BBCH-36	46.83	47.67	148.86 c	148.86 c	15.29 c	15.79 b	13.50	12.83	379.83 d	395.50 bc
Drought at BBCH-59	47.00	47.17	147.48 c	147.93 c	15.17 c	15.13 c	12.17	12.67	373.00 e	391.67 c
LSD at 5%	ns		1.76		0.36		ns		6.08	

Means not sharing the same letter within a same column or row for each parameter differ significantly from each other at 5% level of probability

Table 3: Influence of K nutrition on 1000-grain weight, grain and biological yield and harvest index of maize hybrids under drought stress

Treatment	1000-grain weight (g)		Biological yield (t ha^{-1})		Grain yield (t ha^{-1})		Harvest index (%)	
K application	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}
Hybrids								
NK-8441	314.00 b	324.70 a	14.89 bc	16.11 a	5.59 b	5.85 a	37.84	37.98
P-32B33	315.64 b	322.23 a	14.51 c	15.08 b	5.33 c	5.64 b	37.46	37.65
LSD at 5%	6.54		0.42		0.20		ns	
Water stress								
Well watered	330.63 b	337.86 a	17.28 b	18.29 a	6.29 b	6.83 a	36.40 c	37.34 b
Drought at BBCH-36	310.50 d	317.58 c	13.87 d	14.77 c	5.14 d	5.39 c	37.06 bc	36.49 c
Drought at BBCH-59	303.33 e	317.96 c	12.95 e	13.72 d	4.95 e	5.27 cd	38.22 a	38.41 a
LSD at 5%	6.06		0.37		0.16		0.79	

Means not sharing the same letter within a same column or row for each parameter differ significantly from each other at 5% level of probability

Table 4: Influence of K nutrition on net income and BCR of maize hybrids under drought stress

Treatment	Total expenses (US$ ha^{-1})		Gross income (US$ ha^{-1})		Net income (US$ ha^{-1})		BCR	
K application	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}	0 kg ha^{-1}	60 kg ha^{-1}
			Maize hybrids					
NK-8441	876.06	925.15	1270.45	1320.45	394.39	395.30	1.45	1.43
P-32B33	876.06	925.15	1211.36	1293.18	335.30	369.85	1.38	1.40
			Water stress					
Well watered	888.18	937.27	1429.55	1547.73	541.36	610.45	1.61	1.65
Water stress at BBCH-36	870.00	919.09	1168.18	1225.00	298.18	305.91	1.34	1.33
Water stress at BBCH-59	870.00	919.09	1125.00	1197.73	255.00	278.64	1.29	1.28

Note: 1 US$ = 110 Pakistan Rs.

and stress at BBCH-36 stage; while added K only improved the harvest index under well watered conditions (Table 3).

Root and shoot growth rates progressively increased with increasing crop growth period (Figure 1). Water deficit at BBCH-36 stage observed the least root and shoot growth rate at 50 days after sowing (DAS), while stress at BBCH-59 stage noted the least root and shoot growth rate at 70 DAS compared with well watered plots of both hybrids with K nutrition or not (Figure 1). However, K nutrition somewhat improved root and shoot growth rate of both hybrids, though the hybrid P-32B33 observed higher root and shoot growth rate (Figure 1). Root length and roots density remained increasing with growth period and K nutrition improved only number of lateral roots of both hybrids (Figure 2). Well watered conditions uphold higher root length at 50 and 70 DAS than water stressed conditions in absence of K, while under K nutrition; water stress had non-significant effect on root length of both hybrids (Figure 2). Moreover, plants in well watered plots recorded more number of lateral roots at 70 DAS than stressed plots of both hybrids with K nutrition, while in absence of K; the effect was non-significant (Figure 2). Water deficit imposed at BBCH-36 and BBCH-59 stages had non-significant effect on leaf score of hybrid NK-8441 with K nutrition or not while in case of hybrid P-32B33, drought imposed at BBCH-36 stage observed a bit higher leaf score. Moreover, K application slightly improved the leaf score of both hybrids (Figure 3). However both the hybrids observed higher leaf chlorophyll contents under stressful environment which were further improved by K nutrition as well (Figure 3).

Economic analysis elucidated that K nutrition enhanced the net income of both hybrids whereas BCR was improved only in case of hybrid P-32B33 (Table 4). Moreover K nutrition notably elevated the net returns under both well watered and stressful environment while BCR was improved only under well watered conditions (Table 4).

Discussion

Water deficit at BBCH-36 (stem elongation; six nodes detectable) and BBCH-59 (end of tassel emergence) stages substantially curtailed the yield of both hybrids, although stress at BBCH-59 stage seemed more sensitive; however, the hybrids differ notably in this regard. Moreover, K application enhanced the yield of both hybrids under well watered and stressful environment (Table 3).

Impaired cell division and extension due to reduced enzyme activities, loss of turgor potential and declined energy supply might be responsible for lessened root length and roots density under water deficit at BBCH-36 and BBCH-59 stages (Ogawa *et al*., 2005; Kiani *et al*., 2007;

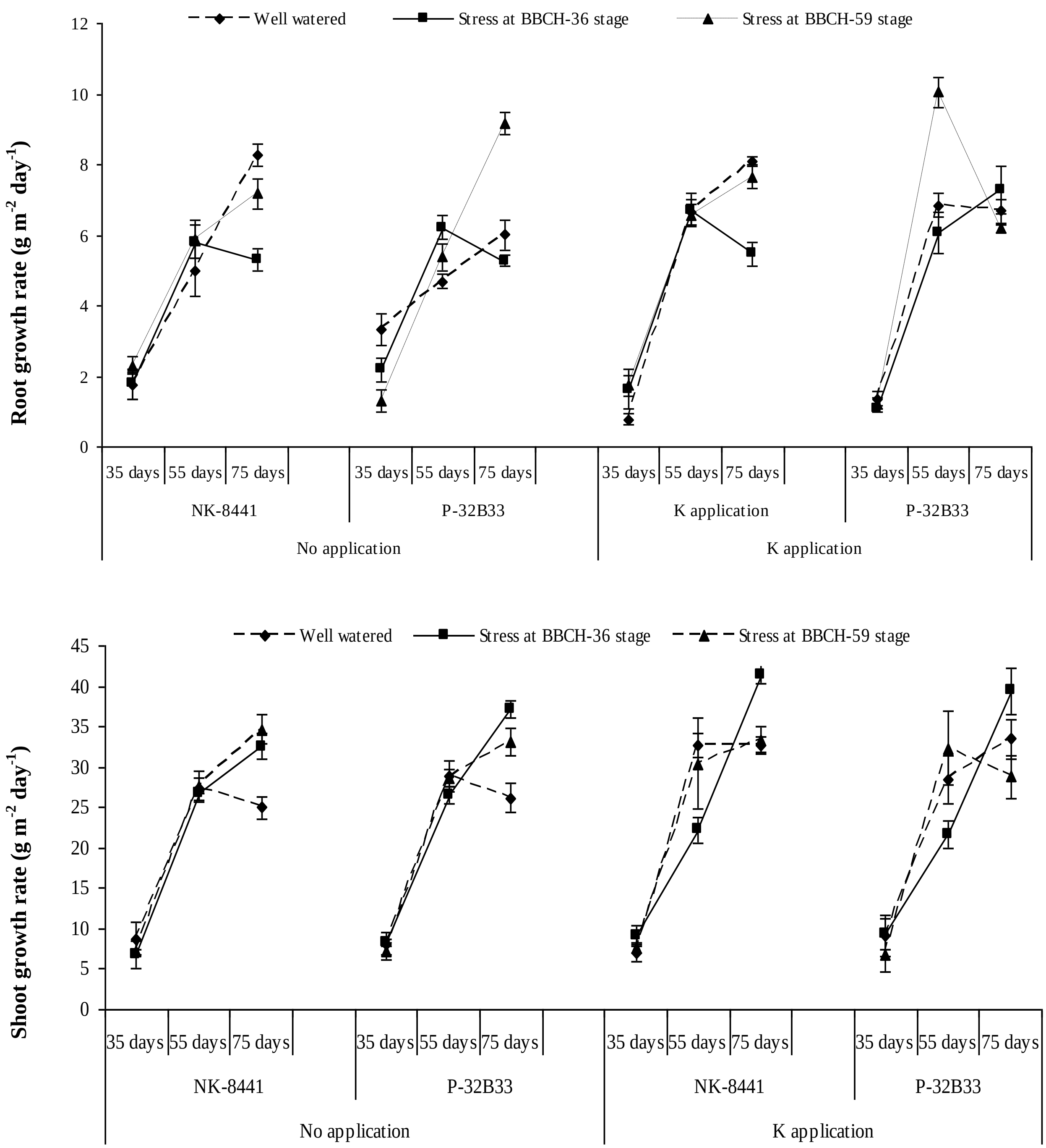

Figure 1: Influence of K nutrition on the root and shoot growth rates of maize hybrids exposed to drought at BBCH-36 and BBCH-59 stages

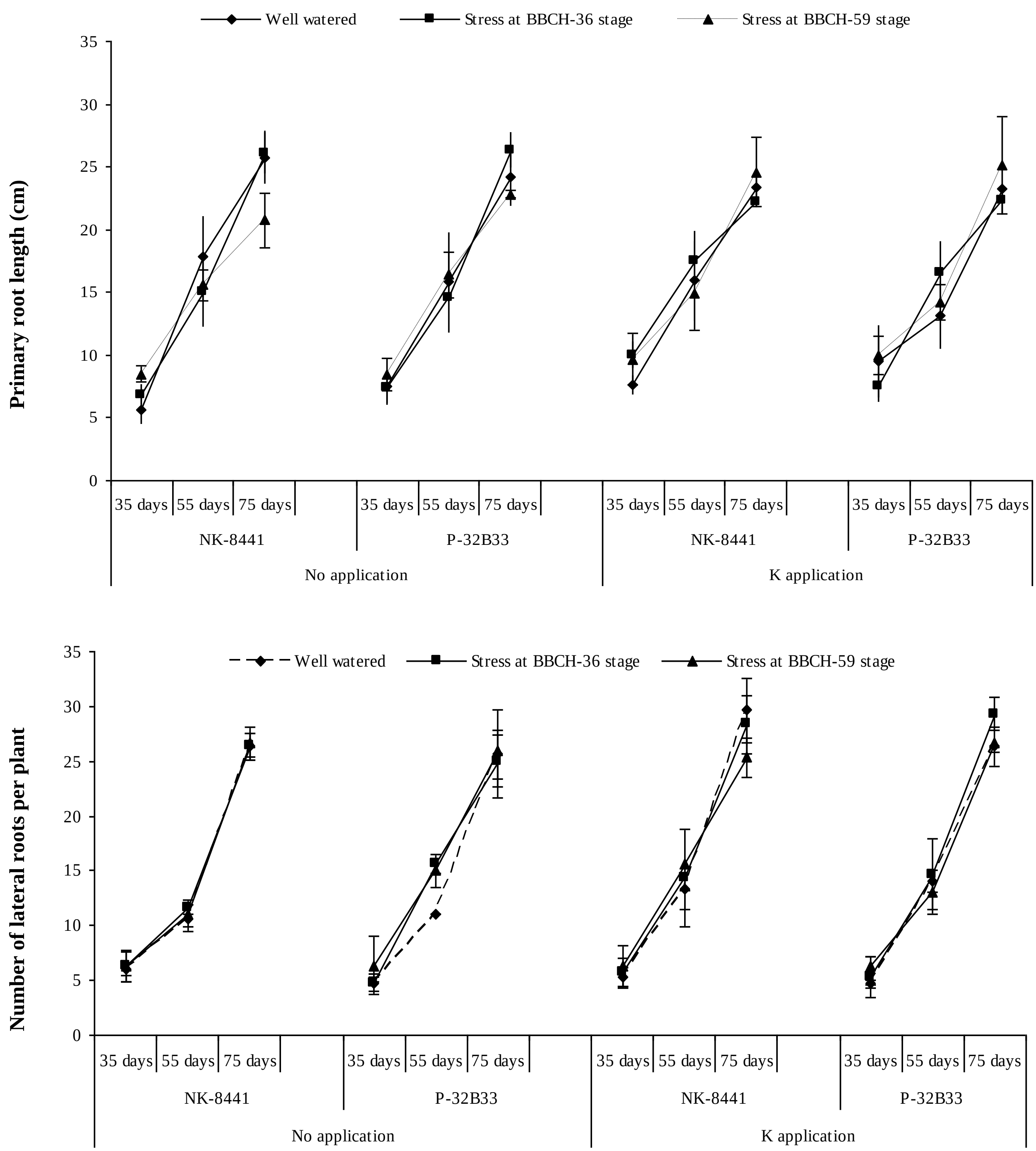

Figure 2: Influence of K nutrition on primary root length and number of lateral roots of maize hybrids exposed to drought at BBCH-36 and BBCH-59 stages

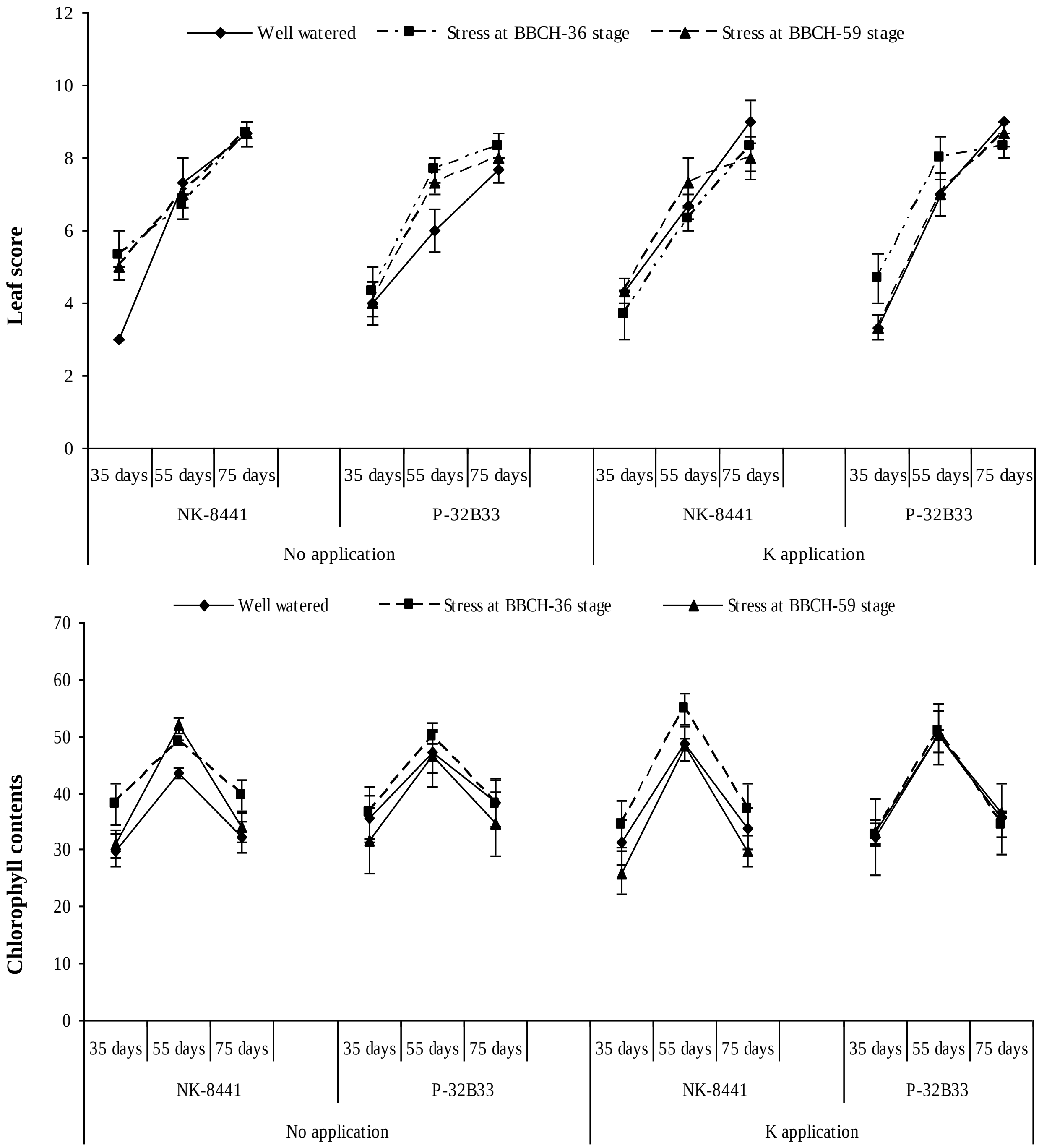

Figure 3: Influence of K nutrition on leaf score and chlorophyll contents of maize hybrids exposed to drought at BBCH-36 and BBCH-59 stages

Taiz and Zeiger, 2010; Zharfa *et al*., 2010). Due to more water and nutrient supply in consequence of better root system (root length and roots density; Figure 2), well watered plants maintained higher root and shoot growth rate than stressed plants due to higher accrual of assimilates. Nonetheless, K nutrition improved the root system of both hybrids under normal and stressful environment (Figure 1 and 2). More water uptake and turgidity in consequence of K nutrition might be the reason of more root length and proliferation. It is well reported that K nutrition is helpful in sustaining water relations and cell membrane stability of maize plants grown under drought conditions (Premachandra *et al*., 1991). Hence ample K supply is crucial to enhance drought resistance by increasing root elongation and maintaining cell membrane stability. Moreover, K absorption positively correlated with water uptake and K uptake in the xylem reconciled the xylem hydraulic conductance which maintains cell turgor, stomatal aperture and gas exchange rates as part of their drought adaptations (Zwieniecki *et al*., 2001; Oddo *et al*., 2011).

Generally water deficit at BBCH-36 and BBCH-59 stages caused significant yield reduction; nonetheless drought at BBCH-59 stage was found more drastic. Water deficit conditions resulted in impaired root system (Figure 1-2; Hussain *et al*., 2013); which ultimately diminished the water and nutrient supply due to small feeding area. Hence, small supply of water and nutrients might impair the crop growth and resulted in poor expansion of yield attributes due to poor root system. Khan *et al*. (2012a) also reported a positive alliance amid root system and yield related traits of maize. Data indicated that substantial decrease in yield related traits like cob size, grains per cob and grain size was the major motive of yield penalty under drought stress imposed at BBCH-59 stage (Tables 2 and 3). Sever yield penalty in maize owing to poor expansion in yield related traits like cob length, number of grains per cob and size is well documented (Zinselmeier *et al*., 1995; Cakir, 2004; Xin *et al*., 2011). Pollen sterility tied with less distribution of assimilates to ear during the early stages of development might be the cause of poor grain set in maize facing water shortage at reproductive phase (Richards, 2006).

Significant expansion in yield related traits with K application improved the productivity of both hybrids under well watered and stressful environment (Tables 2 and 3). Well developed root system with applied K (Figure 2 and 3) enabled the plants to acquire more water and nutrients under well watered and stress conditions and thus improved the growth and productivity. Many physiological processes like enzyme activation, protein synthesis, carbon fixation and stomatal regulation are regulated by K application (Marschner, 1995). K uptake improved corn roots growth and thus elevated the ability to absorb more water from soil and thus increased the resistance capacity against drought (Cox, 2001). Field application of K improved photosynthetic rate, plant growth and yield of several crops under water deficit conditions (Tiwari *et al*., 1998; Egilla *et al*., 2001).

Due to notable expansion in yield related traits like number of grains per cob in particular and 1000-grain weight, hybrid NK-8441 observed higher grain yield than hybrid P-30Y87 both with and without K application (Tables 2 and 3). Several earlier reports underline the role of drought in yield reduction roughly in all hybrids of maize; although different maize hybrids differ significantly due to their genetic makeup (McCutcheon *et al*., 2001; Kamara *et al*., 2003; Monneveux *et al*., 2006; Xin *et al*., 2011). Therefore better performance of hybrid NK-8441 might be due to its better genetic makeup (Khan *et al*., 2012b).

The feasibility and commercial adoption of any practice largely depends on its monetary viability and cost involved (Shah *et al*., 2013). Economic analysis highlighted that K nutrition observed higher net income under well watered and drought conditions but BCR was only improved under well watered conditions (Table 4). These results highlighted the fact that K nutrition was highly economical with optimal water supply; as the impact of fertilizer and irrigation applied on crop productivity is well correlated (Sands and Mulligan, 1990).

Conclusions

In crux drought stress at BBCH-36 and BBCH-59 stages, BBCH-59 (tasseling) seemed more sensitive, substantially reduced the yield due to poorly developed root system. However, K application neutralized the damaging effects of drought due to well developed root system, and accelerated the yield and net income. Hence to get more yield and net income, maize should be grown with optimal water supply with K fertilization and water stress at BBCH-59 (end of tassel emergence) should be avoided.

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