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Root Development, Allometry and Productivity of Maize Hybrids under Terminal Drought Sown by Varying Method

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Abstract

Water deficiency at critical growth stages of maize, tasseling in particular, hampered the crop productivity; while maize planted on ridges resulted in higher yield due to well developed root system. Therefore, a field study was designed to evaluate the effect of varying sowing methods on root development, allometry and yield of maize subjected to drought at tasseling. Two maize hybrids viz. Hi-Corn-11 Plus and NK-6621 were sown on flat seedbed, ridges and beds; and water stress was imposed at tasseling [~50% field capacity (FC)] with well watered conditions (~75% FC) were taken as control. Drought at tasseling stage hampered the yield and related traits owing to poorly developed root system in both maize hybrids, although hybrids differ slightly in their response. Ridge sown maize out yielded compared with other sowing methods both under well watered and drought conditions due to well developed root system i.e., longer roots with more proliferation. Moreover, ridge sown crop also observed higher leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) in both hybrids under well watered and drought stress at tasseling. In crux, maize sown on ridges out yielded both under well watered and drought stress at tasseling owing to well developed root system, which leads to notable expansion in allometric and yield related traits.

Keywords: Maize hybrids; Drought; Ridge sowing; Root system; CGR

Introduction

Among several abiotic stresses extensively impairing the productivity of arable crops, drought is ranked 1st causing higher yield losses than other stresses (Lambers *et al*., 2008; Farooq *et al*., 2009). Insufficient moisture supply essential for normal plant growth and development to complete its life cycle is termed as agricultural drought (Manivannan *et al*., 2008). Plants observe water shortage either due to impaired water supply to roots or higher transpiration rate (Manivannan *et al*., 2007). Different models working on climate change have predicted the occurrence of more intense and rigorous drought episodes in near future due to global climate change (IPCC, 2007; Walter *et al*., 2011). Impaired cell division and cell expansion, small leaf area, stunted elongation of stem, decreased root enlargement and penetration, impaired plant water relations, declined water and nutrients use efficiency along with lower productivity are the main significances of drought stress in crop plants (Hussain *et al*., 2008, 2009; Li *et al*., 2009; Farooq *et al*., 2009).

Maize (*Zea mays* L.) is the 3rd important cereal after rice and wheat cultivated all over the world under a wide range of soil and climatic conditions and uses moisture more efficiently due to its C_4 nature. Thus drought imposed at any phenophase of maize impairs its growth and yield to a great deal (Harold, 1986) but occurrence of drought at certain phenophases is highly sensitive (Grant *et al.*, 1989). Drought imposed at tasseling or flowering stages of maize is the most detrimental leading to sizeable decline in yield and related traits (Borras *et al*., 2002; Hammer and Broad, 2003). Terminal drought in maize badly affects the physiological status of crop due to reduced photosynthesis, assimilate transport and plant growth rates; thus grain filling becomes largely reliant on the vegetative source or photosynthesis of ear tissue (Paponov *et al*., 2005). 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 (Andrade *et al*., 1999; Hammer and Broad, 2003; Karam *et al*., 2003; Dagdelen *et al*., 2006).

Significance of better root system to perk up the crop productivity is getting recognition among the plant breeders (Gewin, 2010). Impaired root growth under drought stress is well reported both in the drought tolerant and sensitive crop genotypes, though, the effects are more prominent on sensitive ones (Piro *et al*., 2003). Nonetheless, roots elongate with much slower rate due to limited water supply and higher mechanical compaction in dry soils (Bengough *et al*., 2011); and thus enforcing the plants to extract water and nutrients from small soil volume under drought (Chassot and Richner, 2002). Impaired root growth of maize

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subjected to drought stress is well reported in literature (Thakur and Rai, 1984; Kondo *et al*., 2000). Moreover, maize cultivars with higher root growth are essentially capable of avoiding drought through enhanced water uptake (Dai *et al*., 1990; Kondo *et al*., 2000).

The problem of poor root development is further provoked with more soil compaction due to use of heavy farm machinery in arable systems; so mechanical impedance turns into more imperative in restricting root growth than water stress (Bengough *et al*., 2006). Higher bulk density or dense surface layer of soil results in smaller root length concentrating near the soil surface; hence forcing the plants to extract water and nutrients from small soil volume (Chassot and Richner, 2002). Thus, well developed root system of plants capable to explore more soil volume to ensure adequate water and nutrient uptake is crucial for better plant growth mainly under limited water and nutrients in soil (Horst *et al*., 2001). In that scenario, better sowing methods such as ridges and raised beds can play a noteworthy role to augment crop productivity owing to better developed root system (Khan *et al*., 2012a, b). Ridges offer loose fertile layer of soil which outcomes in well-built root system and enabling the plants to uptake more water and nutrients (Khan *et al*., 2012a); as water and nutrient uptake is watchfully linked to root growth and morphology (Bucher, 2007; Ao *et al*., 2010).

Moreover improved sowing methods not only assist to attain optimal plant population due to higher germination but also facilitate the plants to exploit land, light and further input resources evenly and proficiently. So it is direly needed to develop such a sowing method which may help in evading unnecessary crowding and thus aiding the maize plants to utilize the applied resources more efficiently and successfully (Quanqi *et al*., 2008). In the light of continual decline of world water resources, water wise cultivation becomes the need of time which focuses on enhancing water-use efficiency (WUE) of arable crops. Improving WUE of crops is a priceless tool to maximize the full use of natural rainfall and efficient management of irrigation network by choosing a correct sowing method (Hussain *et al*., 2010). Different sowing methods not only advance water application efficiency but also perk up the WUE. For example, Khan *et al*. (2012a, b) reported higher productivity and WUE of ridge sown maize than other sowing methods.

Due to cross pollinated nature of maize, noteworthy genotypic variances in root growth and development under normal and drought stress exist (Maiti *et al*., 1996; Mehdi *et al*., 2001), which can be used as selection criteria to improve drought tolerance. For example, hybrids with thicker roots penetrate compacted soil layers more powerfully and uphold better root elongation rate in hard soils (Materechera *et al*., 1991). Moreover, 25-30% of the total cropped area of Pakistan is rainfed where crop production totally depends on rainfall that is always erratic. Although a plenty of published literature on performance of different maize genotypes under drought is available, however, little is known about the interactive effect of maize hybrids and sowing method on the development of root system, crop allometry and productivity under drought stress. Therefore, this field study was designed with the hypothesis that improved sowing methods like ridges and raised beds improved the productivity and WUE of maize hybrids due to well developed root system which results in sizeable improvement in crop allometric and yield related traits subjected to drought stress at tasseling under semi-arid environment.

Materials and Methods

Site Description

This field study was carried out at Research Farm, Department of Agronomy, Bahauddin Zakariya University Multan, Pakistan during autumn, 2011. The climate of the region is semi-arid to subtropical. Weather data collected during the crop season is summarized in Table 1.

Experimental Details

Two maize hybrids viz., Hi-Corn-11 Plus and NK-6621 were sown on flat seedbed, ridges and beds subjected to water stress at tasseling stage (~50% FC), while watered conditions (~75% FC) were taken as control; and half of the soil saturation percentage was considered as 100% FC. The experiment was laid out in Randomized Complete Block Design (RCBD) with split-split plot arrangements. Water stress levels were arranged in main plots while sowing methods and maize hybrids were randomized in sub and sub-sub plots, respectively with net plot size of 5 m × 3 m.

Crop Husbandry

A pre-soaking irrigation of 10 cm was applied to the experimental area and when the field attained the workable moisture regime, seedbed was prepared by cultivating land twice with tractor mounted cultivator each followed by planking. Both the maize hybrids (Hi-Corn-11 Plus and NK-6621) were sown on aforementioned seedbeds on 30th July, 2011. Sowing was done manually on ridges and beds, and by using dibbler on flat surface. The row to row distance of 75 cm and plant to plant distance of 20 cm was maintained for flat and ridge sowing while 120 cm wider beds along with 30 cm furrow were used. Fertilizers were applied @ 200 and 150 kg ha^{-1} nitrogen (N) and phosphorus (P),

Table 1: Weather data during the course of experiment

Month	Mean Monthly Temperature (°C)	Mean Monthly Relative Humidity (%)	Total Monthly Rainfall (mm)
August	31.50	66.50	70.40
September	29.00	74.00	134.20
October	26.20	67.60	9.50
November	18.00	60.70	0.00

Source: Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan respectively by using urea and diammonium phosphate (DAP) as source. Whole P along with $1/3^{rd}$ of N was applied at sowing time, while left over N was applied in two equal splits with 2^{nd} and 3^{rd} irrigation. Water stress at tasseling stage was imposed by stopping irrigation at tasseling stage until the plots reached to 50% FC level while well watered crop was irrigated at 75% FC level. When soil reached to feasible moisture regime after 1^{st} irrigation hoeing was done to keep crop free from weeds. All other agronomic practices were kept optimum to keep crop free from diseases and insects. Mature crop was harvested on 10^{th} November, 2011.

Measurements

Primary root length, number of lateral roots and root growth rate were measured at fortnightly intervals by uprooting five plants from each experimental unit with intensive care to save the roots from any injury. Plants were washed with tap water and air dried for some time and then primary root length was measured with the help of measuring tape. Total number of lateral roots of all five plants were counted and averaged to record number of lateral roots. Roots were separated from stem; weighed fresh and dried in an oven; root growth rate (RGR) was computed following the protocol devised by Hunt (1978). Sampling for root related traits was started 30 days after sowing (DAS) of crop and terminated at the harvest of crop.

Leaf area was recorded using Leaf area meter (DT Area Meter, Model MK2, Delta T Devices, Cambridge, UK) at 15 days interval starting from 30 DAS until harvesting of crop. Leaf area index (LAI) was then calculated following Watson (1947). Crop growth rate (CGR) and net assimilation rate (NAR) was recorded following Hunt (1978).

Ten plants at maturity were harvested; their heights were measured with the help of measuring tape and averaged to record plant height at maturity. Total number of cobs from ten randomly selected plants from each experimental unit were counted and averaged to record number of cobs per plant. Number of grain rows from ten cobs selected at random from individual experimental unit was counted and averaged to record number of grain rows per cob. Grains from individual grain row from ten randomly selected cobs were counted and averaged to record number of grains per grain row. Total number of grains from ten selected cobs at random from each experimental unit were counted and then averaged to record number of grains per cob. Three random samples of 1000 grains from each experimental unit were taken; weighed on an electric balance and averaged to record 1000-grain weight. At maturity, crop was harvested; sun dried for four days, tied into bundles and biological yield was recorded by using spring balance which was converted into t ha^{-1} by unitary method. After that cobs were separated, threshed manually and grains were separated to compute grain yield by using an electric balance. Grain yield was adjusted to 10% moisture contents by taking random samples and converted into t ha^{-1} following unitary method. Harvest index was taken as ratio among biological and grain yield expressed in percentage.

Statistical Analysis

Collected data were statistically analyzed by using Fisher's ANOVA technique and LSD test at 5% probability was used to compute the differences among treatment's means (Steel *et al*., 1997). Graphical representations of data were carried out by using Microsoft Excel program.

Results

Water stress at tasseling stage substantially reduced the primary root length of both tested maize hybrids, at 75 DAS in particular, compared with well watered crops (Fig. 1). However ridge sowing improved the primary root length of tested hybrids both under stressed and well watered conditions through the entire growth period (Fig. 1). Equally drought imposed at tasseling significantly decreased number of lateral roots in both hybrids; however, ridge sown crop observed higher number of lateral roots under well watered conditions and subjected to drought at tasseling. Bed sown crop performed poor with lesser lateral roots in both hybrids under drought at tasseling (Fig. 2). Root growth rate (RGR) progressively increased with time and ridge sowing consistently resulted in higher RGR under well watered conditions as well as under drought at tasseling (Fig. 3). Water stress at tasseling severely impaired the RGR in both hybrids especially at 75 DAS and hybrid Hi-Corn-11 observed slightly higher RGR than NK-6621 (Fig. 3).

Leaf area index (LAI) and crop growth rate (CGR) progressively increased with time up to 60 DAS and then start declining (Figs. 4-5). Drought imposed at tasseling substantially decreased the LAI at 75 DAS in both maize hybrids, however, hybrid Hi-corn 11 observed a bit higher LAI both under well watered and stress conditions (Fig. 4). With respect to sowing methods, both hybrids observed higher LAI when sown on ridges under well watered and stress conditions as well (Fig. 4). CGR was also hampered by drought at tasseling at 75 DAS in both tested hybrids and hybrid Hi-corn 11 maintained slightly higher CGR than NK-6621. However, ridge sowing improved the CGR under well watered and drought stress in both the hybrids while the performance of crop sown either on beds or on flat surface remained poor in this regard (Fig. 5). Similarly moisture stress at tasseling notably decreased the net assimilation rate (NAR) in both hybrids and hybrid NK-6621 seemed more sensitive in this regard (Fig. 6). Moreover, ridge sowing improved the NAR of both hybrids against the crop sown on flat surface and on beds not only under well watered conditions but also under water stress (Fig. 6).

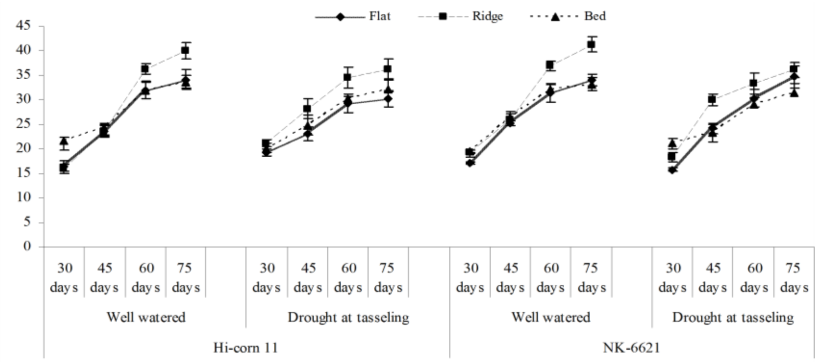

Fig. 1: Effect of sowing methods on primary root length (cm) of different maize hybrids subjected to drought at tasseling

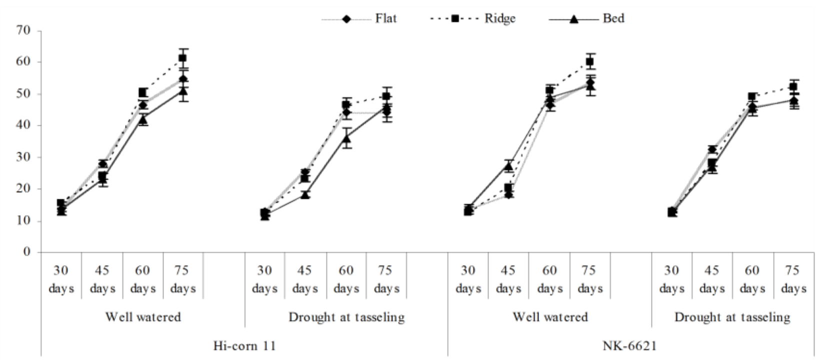

Fig. 2: Effect of sowing methods on number of lateral roots of different maize hybrids subjected to drought at tasseling

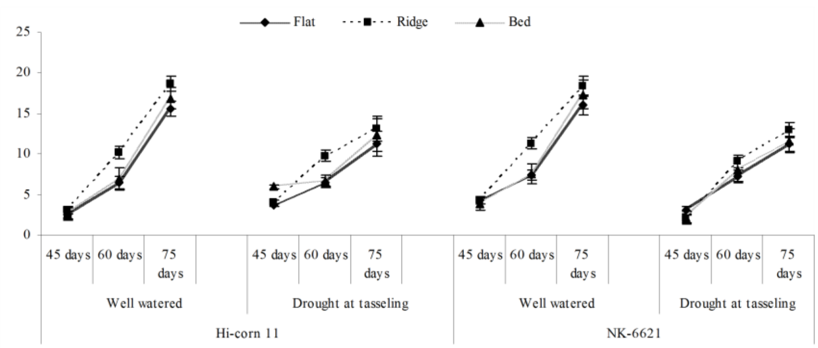

Fig. 3: Effect of sowing methods on root growth rate (g $m^{-2}day^{-1}$) of different maize hybrids subjected to drought at tasseling

Maize hybrids and varying sowing methods had non-significant effect on plant population under well watered conditions and subjected to drought at tasseling (Table 2). Drought at tasseling substantially decreased the plant height of both hybrids and hybrid NK-6621 seemed more sensitive in this regard while sowing methods had non-significant effect on plant height under well watered and drought conditions (Table 2). Drought at tasseling caused sizeable decline in number of cobs per plant and cob length of both hybrids in a similar fashion (Table 2). Amid sowing methods, ridge sowing notably improved the number of cobs per plant and cob length of tested maize hybrids under both well watered conditions and drought at tasseling and bed sowing performed poor in this regard (Table 2). Drought at tasseling caused notable decline in yield related traits like number of grain rows per cob, number of grains per row, number of grains per cob and 1000-grain weight of both maize hybrids and hybrids behaved similarly in this regard (Table 3). Moreover, ridge sown maize observed sizable expansion in aforementioned yield related traits

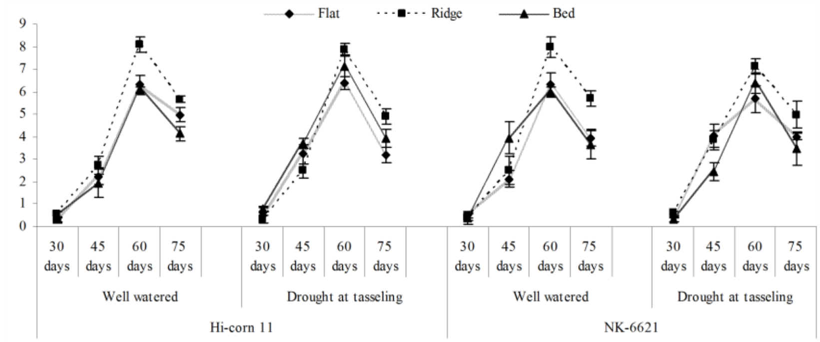

Fig. 4: Effect of sowing methods on LAI of different maize hybrids subjected to drought at tasseling

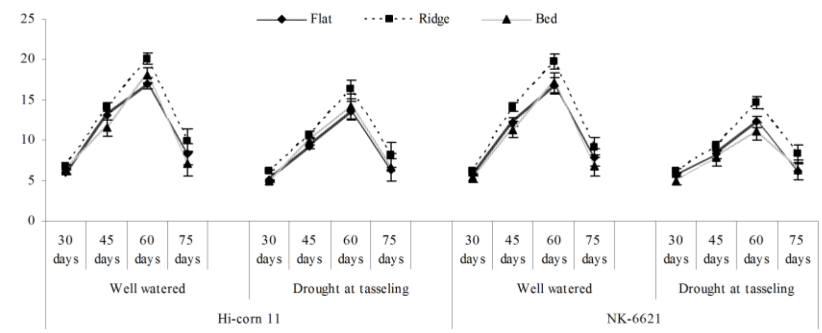

Fig. 5: Effect of sowing methods on CGR (g $m^{-2}day^{-1}$) of different maize hybrids subjected to drought at tasseling

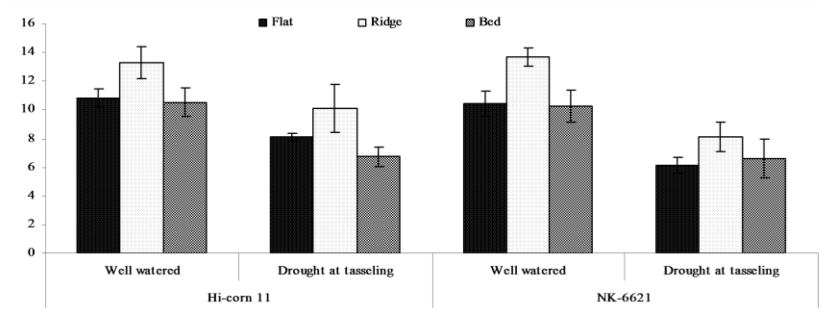

Fig. 6: Effect of sowing methods on NAR (g $m^{-2}day^{-1}$) of different maize hybrids subjected to drought at tasseling

both under well watered and drought at tasseling against the maize sown on flat seedbed and on beds (Table 3).

Drought at tasseling remarkably decreased the grain and biological yield of both hybrids. Hybrid Hi-corn-11 outperformed with highest grain and biological yield under well watered conditions while both the hybrids behaved similarly in this regard under drought at tasseling (Table 4). Ridge sowing observed notably higher maize productivity not only under well watered circumstances but also under drought at tasseling while bed sown crop performed poor under drought at tasseling and well watered conditions (Table 4). Higher harvest index was noted in Hi-corn-11 under well watered conditions while NK-6621 performed poor under both well watered conditions and drought at tasseling in this regard. Harvest index was substantially improved by ridge sowing not only in well watered conditions but also under drought at tasseling while bed sowing performed poor in this regard (Table 4). Drought stress significantly reduced the WUE of both hybrids and Hi-corn-11 observed higher WUE than NK-6621 under both well watered conditions and drought at tasseling (Table 4). Ridge sowing observed sizably higher WUE under well watered and drought at tasseling while other sowing methods seemed poor in this regard (Table 4).

Table 2: Effect of different planting methods on allometry and yield related traits of different maize hybrids subjected to drought at tasseling

Treatments	Plant population per plot		Plant height (cm)		Number of cobs per plant		Cob length (cm)	
	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling
Hi-corn 11	47.11	46.66	152.74 b	151.48 b	1.51 a	1.32 b	15.48 a	9.80 b
NK-6621	46.44	45.88	154.56 a	146.97 c	1.54 a	1.27 b	15.53 a	9.56 b
LSD at 5%	NS		1.74		0.05		0.25	
Flat	43.66	44.50	153.83	144.83	1.43 b	1.30 c	15.12 b	8.98 e
Ridge	46.66	46.33	153.83	149.83	1.58 a	1.39 b	17.10 a	11.08 d
Bed	50.00	48.00	150.33	149.67	1.41 b	1.20 d	14.39 c	8.21 f
LSD at 5%	NS		NS		0.08		0.85	

Means sharing the same letters within a column did not differ significantly from each other at 5% probability level

Table 3: Effect of different planting methods on yield related traits of different maize hybrids subjected to drought at tasseling

Treatments	Grains rows per cob		Number of grains per row		Number of grains per cob		1000-grain weight (g)	
	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling
Hi-corn 11	15.48 a	9.46 b	29.50 a	21.44 b	415.78 a	327.78 b	288.89 a	229.44 b
NK-6621	15.58 a	9.39 b	30.00 a	20.44 b	414.00 a	315.11 b	292.56 a	217.22 c
LSD at 5%	0.46		1.03		23.54		7.77	
Flat	13.16 abc	12.66 bc	27.00 cd	20.33 e	385.33 b	311.33 cd	287.83 b	211.33 e
Ridge	14.66 a	14.00 ab	32.00 a	25.00 d	471.50 a	343.00 bc	318.50 a	222.50 d
Bed	12.00 bc	12.00 bc	29.50 bc	19.00 e	387.83 b	280.00 d	265.83 c	206.17 f
LSD at 5%	2.05		1.54		59.34		8.92	

Means sharing the same letters within a column did not differ significantly from each other at 5% probability level

Table 4: Effect of different planting methods on productivity and WUE of different maize hybrids subjected to drought at tasseling

Treatments	Grain yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest index (%)		WUE (kg m^{-3})	
	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling	Well watered	Drought at tasseling
Hi-corn 11	5.85 a	4.34 c	18.45 a	15.43 c	31.70 a	28.13 c	1.14 a	0.99 c
NK-6621	5.51 b	4.32 c	17.96 b	15.62 c	30.68 b	27.66 d	1.07 b	0.98 d
LSD at 5%	0.03		0.18		0.54		0.003	
Flat	5.78 b	4.49 e	18.90 b	15.19 e	30.58 b	29.56 cd	1.12 b	1.02 d
Ridge	6.23 a	4.62 d	19.70 a	15.68 d	31.62 a	29.46 d	1.21a	1.05 c
Bed	5.27 c	3.96 f	17.62 c	13.97 e	29.91 c	28.45 e	1.02 d	0.90 e
LSD at 5%	0.05		0.26		0.37		0.005	

Means sharing the same letters within a column did not differ significantly from each other at 5% probability level

Discussion

Drought imposed at tasseling stage notably decreased the maize yield and WUE due to poorly developed root system (Table 4; Figs. 1–3); however ridge sowing improved the maize yield and WUE both under well watered and stress conditions in consequence of well developed root system, although hybrids differ slightly in this regard (Table 4; Figs. 1–3).

Reduced primary root length and roots proliferation of maize under drought at tasseling might be due to the hampered cell division and expansion owing to impaired enzyme activities, loss of turgor, reduced energy supply and mechanical impedance restricting the root growth in dry soil (Bengough *et al*., 2006; Farooq *et al*., 2009; Taiz and Zeiger, 2010; Zharfa *et al*., 2010). Earlier Ogawa *et al*. (2005) also reported declined root length and roots density in maize in water deficit environment. Similarly higher LAI and CGR under well watered conditions (Fig. 4 and 5) seemed the possible motive of higher root growth rate (RGR) due to more supply of assimilates. Moreover slightly better root system as observed in hybrid Hi-corn 11 might be due to its better genetic makeup. Recently, Khan *et al*. (2012a) also reported different behavior of maize hybrids with respect to root system. Low soil water potential coupled with poorly developed root system (lesser root length and roots proliferation) (Fig. 1-2) at terminal stage of crop by imposing drought at tasseling might impaired the water and nutrient supply and thus substantially reduced the LAI (Fig. 4). This decreased LAI at terminal phase of maize hybrids under drought at tasseling resulted in declined CGR due to low availability of assimilates; as leaves are the units of assimilatory system of plants. Similar findings were earlier reported in maize under drought (Thatikunta *et al*., 2003; Rahman *et al*., 2004). Low availability of assimilates as indicated by small values of CGR under drought stress might be responsible of notable decline in NAR of both hybrids compared with well watered conditions (Fig. 6).

Nonetheless, well developed root system of both hybrids observed in ridge sowing might be due to designing of favorable conditions for root growth; as ridges offer loose fertile surface for root penetration, elongation and proliferation both under well watered conditions and drought at tasseling (Figs. 1-2). Likewise Khan *et al*. (2012b) reported better developed root system of ridge sown maize compared with flat seedbed and bed sowing. Better developed root system of ridge sown maize enabled the plants to extract more water and nutrients by exploring the large volume of soil compared with other sowing methods (Khan *et al*., 2012a). Due to ample supply of water and nutrients in result of well developed root system, ridge sowing maintained higher LAI of both hybrids under well watered and drought conditions as well. Maintenance of higher LAI (Fig. 4) of ridge sown maize resulted in higher dry matter production which ensured higher CGR (Fig. 5); as leaves are the units of assimilatory system of plants. Higher LAI and CGR due to ridge sowing is earlier reported in sunflower and maize as well (Hussain *et al*., 2010; Khan *et al*., 2012a, b). Similarly higher NAR in ridge sown maize might be due to more dry matter accrual and higher CGR (Akram *et al*., 2010).

Notable decline in yield related traits like cob size, grains per row and cob, and 1000-grain weight was the main cause of yield penalty of both maize hybrids subjected to drought at tasseling stage (Tables 3-4). Several workers earlier reported reduced grain yield of maize under water (Cakir, 2004; Xin *et al*., 2011). Decreased supply of water and nutrients at terminal crop growth under drought due to poorly developed root system with reduced root length and proliferation (Figs. 1–2) and low soil water potential might be the reason of poor development of yield related traits. Lower number of grains per cob under water stress at tasseling might be due the pollen sterility, which results in poor grain set and reduced the number of grains per cob. Earlier, Sah and Zamora (2005) concluded 18 and 40% decrease in number of grains per cob by exposing the crop to water stress at vegetative and reproductive stage, respectively than well-watered plants. Moreover, lower accumulation of photo-assimilates in consequence of lower LAI and CRG (Fig. 4-5) might be the cause of declined biological yield of maize under drought. Decreased WUE of both hybrids under drought at tasseling was associated with substantial yield reduction (Table 4). Hussain *et al*. (2009) also reported declined WUE of sunflower subjected to drought at flowering compared with well watered conditions.

Ridge sowing observed sizeable rise in yield of both hybrids due to significant expansion in yield related traits like cob length, number of grains per cob and 1000-grain weight both under well watered and water deficit conditions (Tables 2–4). Elevated grain yield by ridge sowing is earlier reported in sunflower and maize (Hussain *et al*., 2010; Khan *et al*., 2012a, b). Better root system (deep primary roots having more lateral roots) observed under ridge sowing might enhanced the water and nutrient supply by exploring more soil volume (Khan *et al*., 2012a), which ultimately improved the LAI and CGR of both hybrids under well watered and stress conditions. Availability of more assimilates due to higher LAI and CGR under ridge sowing might improve the yield related traits and yield. Recently Khan *et al*. (2012a) reported positive correlation between lateral roots and grain yield under various sowing methods. Moreover higher WUE of ridge sown maize both under well watered and drought conditions highlighted the more efficient utilization of available water compared with other sowing methods. Earlier similar kind of findings were reported by Hussain *et al*. (2009) and Khan *et al*. (2012a, b).

In crux, drought stress at tasseling substantially reduced the yield and WUE of both hybrids, although hybrids differ slightly in this regard, owing to poorly developed root system leading to sizeable decline in allometric and yield related traits. However, maize sown on ridges out yielded both under well watered and drought stress at tasseling owing to well developed root system, which leads to notable expansion in allometric and yield related traits.

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