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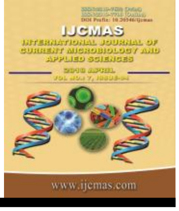

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Screening of Maize Genotypes for Drought Tolerance Related Trait Variability

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A B S T R A C T

Plant roots play an important adaptive role in drought prone environments. Although there have been many efforts to improve root traits to develop drought tolerant maize varieties but significant progress has not yet been made mainly due to difficulty in screening root traits. The aim of the study was to develop an easy and reliable screening method for deep root mass and related root/shoot traits of maize in greenhouse and evaluate their association with the grain yield under water-deficit conditions. The present study was conducted in the green house facility at the Division of Genetics and Plant Breeding, Faculty of Agriculture, Wadura. Thirteen released varieties of maize were evaluated in the present study under drought and irrigated conditions. Highest rooting depth under drought was shown by C-4 (126.50 cm). Recorded highest recorded Root biomass under drought was for C-15 (40.50 g). Root biomass at bottom was recorded highest under drought for GM-6 (0.414 g). Root shoot ratio was recorded highest under drought for C-15 (0.764). Under drought most of the traits had decreased value except for root biomass at bottom and shoot to total biomass which had higher values under drought. The highest percentage decrease was observed for root biomass (70.891) followed by shoot biomass (67.759) and plant height (27.120) while, as lowest percent decrease was recorded in case of shoot to total biomass (3.484). The traits root biomass at bottom and root shoot ratio had increased values under drought 28.463 and 9.388 respectively.

Keywords

Drought, Root traits, Greenhouse, Root biomass, Shoot biomass

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Introduction

Maize is one of the most important cultivated grain crops around the world and is widely used to provide food, forage, and industrial raw materials. Due to rapid changes in populations, society, and economies, the demand for maize is expected to be higher than for wheat or rice by 2020 (Pingali, 2001). The productivity and yield of maize are frequently limited by various biotic and abiotic stress factors, such as drought, salinity, high and low temperatures, nutrient deficiencies, disease, and insect pests. Drought stress can affect yield through different mechanisms across the whole life cycle of the maize plant (Leach *et al.*, 2011). Therefore, drought is one of the most serious causes of productivity loss. Drought tolerance is a complex trait (Quarrie, 1996) involving a number of morpho-physiological traits, including root characters (Ludlow and Muchow, 1990; Tuberosa *et al.*, 2002). It can be achieved in a number of ways, including drought avoidance or desiccation prevention, or combination of both, or through effective use of limited water supply, or through recovery of growth following rehydration after drought stress (Chaves *et al.*, 2003; Passioura, 2012). Under drought stress, plants seek to reduce the impact of the lack of water by reducing the transpiration rate and by increasing the efficiency of water acquisition from the soil (Vegh, 2013). Plants have developed numerous adaptive mechanisms for better growth under drought conditions such as modification of the root system, osmotic adjustments, stomatal regulation, chemical production, and accumulation. The root system not only supports the above ground organs of the plant but also plays a crucial role in obtaining water by accessing sources far down in the soil profile. The roots are the first organs to sense a water shortage (Trachsel *et al.,* 2010). The root system is therefore generally considered as the most important organ with respect to improving crop adaptation to water stress (Vadez, 2014).

Maize responds to drought stress by redirecting root growth and dry matter accumulation away from the shoot to the root (Ribaut *et al.*, 2009, Sharp *et al.*, 2004). In maize, this shift involves an increase in root cell wall extensibility that is mediated by increased levels of xyloglucan endotransglucosylases/ hydrolases and other cell wall-loosening factors at the root tip. These modifications result in sustained growth of the root and inhibited growth of the shoot in the face of decreased water potential (Ober and Sharp, 2007). A deep root system with thick roots and extensive branching ability is considered a major component of drought avoidance, enabling the plants to extract water from deep soil layers (Fukai and Cooper, 1995; Gowda *et al.,* 2011). Root characteristics, particularly root depth, are likely to increase plant water uptake, and therefore, these play a role in dehydration avoidance mechanisms and crop resistance to drought (Serraj *et al.,* 2009). Root traits associated with maintaining plant productivity under drought include roots with small fine root diameters, long specific (main/laterals) root length, and considerable root length density, especially at soil depths with available water (Comas *et al.,* 2013). Crop plants with deep and very extensive root systems could simultaneously improve both soil structure and its steady-state carbon, water and nutrient retention, as well as sustainable yields (Kell, 2011). Root morphology is a poorly studied maize characteristic due to the difficulties of making direct measurements under the soil and also of observing or removing roots of plants grown under agronomic conditions. Genetic improvement to produce deep-rooted plants is considered an important strategy for improving water capture and yield stability (Kondo *et al.*, 2003). Variation in root system architecture can be explored to improve plant vigor by improving water use efficiency and nutrient extraction under difficult growing conditions (Malamy and Benfey, 1997). In the root system of maize, lateral roots are of major importance for the efficient short-distance exploitation of water and nutrients (McCully 1999), and they make up about eight times the surface area of their parental axile roots and take up about eight times as much water. In response to evapotranspiration demands, shoots drive water uptake through a root system (Comas *et al.*, 2013) and amount of water uptake is determined by root architecture, i.e., root angles, rooting depth, root diameter, number of root branches and length of root hairs (Lynch, 2013). Wasson *et al.,* (2012) proposed selection on the traits to improve root systems and water uptake in water-limited wheat crops, which includes deep roots, greater root branching at median and deeper soil layers, reduced root length density near the surface, and longer root hairs with increased xylem diameter for decreased resistance to water movement from soil to roots. Burton *et al.,* (2013) reported that maize landraces have greater variation in root architectural traits and have longer nodal roots and larger xylem than related wild Zea species. Longer roots were shown to assist in the capture of mobile resources in the soil and are considered to be a primary determinant of drought tolerance in maize (Zhu *et al.,* 2010). Hund *et al.,* (2009) observed greater rooting depth in the drought tolerant tropical maize inbred lines than the sensitive lines.

Studying roots extensively under field conditions is still limited due to the expenditure of time involved in destructive techniques like the core method and the likelihood of under-estimation of root depth and density. Using PVC tubes in greenhouse, phenotypic variation in maize root traits, such as root length, root thickness, total root mass, deep root mass, deep root ratio and deep root to shoot ratio are evaluated. In the present study, we aimed to i) assess the natural variation for root architectural traits and biomass partitioning in maize genotypes under drought conditions (ii) identify root related traits accounting for most of the variation under drought conditions.

Materials and Methods

Plant material

The present study was conducted at the green house facility of the Division of Genetics and Plant Breeding, Faculty of Agriculture Wadura, SKUAST-K Sopore. Thirteen varieties of maize were evaluated in the present study viz., Shalimar maize composite-4 (C-4), C-6, C-8, C-15, Shalimar maize composite -7 (KDM-72), Kishan Ganga-1 (KG-1), Kishan Ganga-2 (KG-2), Pratap Makka -3 (PM-3), Pratap Makka-4 (PM-4), Pratap Makka-5 (PM-5), Pratap Makka-Chari-6 (PM Chari-6), Aravali Makka-1 (AM-1), Gujrat Makka-6 (GM-6) in well-watered (WW) and water-deficit (WD) conditions.

Column culture experiment

The experiment was conducted under ambient temperature to prevent the confounding effects on account of heat stress. The plants were grown in PVC root columns of dimensions 1.3 meter height and 20 cm internal diameter in a completely randomised design with three replications each for drought and irrigated treatments. Initially four seeds each were sown after surface sterilisation with 10% NaOCl for 5 minutes and subsequent rinsing by distilled water. After the plants reached the four leaf stage, only two competitive plants per column were maintained. Drought was imposed at first fully expanded leaf stage by withholding water in drought treatment while as irrigated treatment was regularly watered. The roots and shoots were harvested after 48 days of sowing.

Analysis of root and shoot biomass parameters

Roots were carefully harvested from columns and the soil from each column was sieved to derive all possible root fractions for unbiased estimate of root biomass. The roots thus harvested were washed with a mild detergent solution to remove sand and other impurities, rinsed with tap water to remove excess soap and dried in shade and weighed for root biomass fraction. Roots were carefully separated from the growing medium without any breakage in the root system. The shoots of each plant were separated by cutting at the base of the stem. After removing shoots, roots were laid on a flat surface and stretched to measure their length (from the base of the stem to the tip of the root system) as an estimate of rooting depth. Roots were also cut into two equal sections to estimate the biomass allocation in different zones. Data on various parameters were recorded such as rooting depth, root volume, root biomass, shoot biomass, root/shoot biomass ratio and differential root biomass partitioning. The design used was CRD.

Results and Discussion

Root traits under greenhouse conditions

The data pertaining to various root and shoot parameters under drought and irrigated conditions is presented in Table 1 (Figure 1) reveled that under drought plant height was highest in C-8 (111.00 cm) followed by C-15 (107.50 cm) and KDM-72 (107.00 cm) and was lowest in GM-6 (93.50 cm) and PM-5 (93.50 cm), while as under irrigated conditions it was highest in C-8 (161.00 cm) followed by KG-1 (153.00 cm) and C-6 (147.00 cm) and was lowest in C-15 (117.00 cm) and GM-6 (117.00 cm). Under drought shoot biomass was highest in C-8 (83.00 g) followed by C-6 (73.00 g) and KDM-72 (65.00 g) and was lowest in KG-1 (35.00 g) and PM Chari-6 (35.00 g), while as under irrigated conditions it was highest in C-6 (210.00 g) followed by C-4 (208.00 g) and C-8 (183.00 g) and was lowest in PM-4 (116.00 g). Under drought root depth was highest in C-4 (126.50 cm) followed by PM Chari-6 (113.50 cm) and Aravali Makka-1 (113.00 cm) and was lowest in KG-2 (62.50 cm), while as under irrigated conditions it was highest in PM-4 (156.00 cm) followed by C-8 (154.00 cm) and C-6 (141.50 cm) and was lowest in PM-5 (92.50 cm). Under drought root biomass was highest in C-15 (40.50 g) followed by KDM-72 (34.50 g) and PM-4 (31.50 g) and was lowest in PM-5 (17.00 g), while as under irrigated conditions it was highest in PM-4 (105.50 g) followed by Aravali Makka-1 (95.50 g) and C-15 (94.50 g), PM-3 (94.50 g) and was lowest in KG-2 (62.50 g). The results from this study demonstrated that water stress throughout maize development significantly affected maize growth processes, resulting in a sharp decrease in plant height, leaf area, stem diameter, biomass accumulation, and root traits also. Drought caused a decrease in plant height, shoot biomass, root depth and root biomass. Under water-stressed conditions, maize lines with different genetic backgrounds and origins displayed different drought tolerance capabilities and showed varied root architecture traits at the seedling stage (Kumar *et al.,* 2012; Liang *et al.,* 2013). Hund *et al.,* (2009) observed greater rooting depth in the drought tolerant tropical maize inbred lines than the sensitive lines. An inverse relationship between rooting depth and available soil water was reported in maize under field conditions (Dwyer *et al.,* 1988). Earlier Ogawa *et al.,* (2005) also reported declined root length and roots density in maize in water deficit environment. Eggball and Maranville (1993) reported that root weight and length of maize cultivars differed among genotypes. The genotype with the greatest amount of roots deep in the soil had highest grain yield. Severe water stress reduced the root mass and length in the green house. Overall, our experimental results suggest that root length, deep root mass and total root mass are related and are implicated with drought tolerance, but deep root mass could be used as a more reliable trait for selection for drought tolerance in maize. Further studies in greenhouse and in fields as well are required using a larger panel of genotypes to validate this kind of association.

Biomass partitioning under greenhouse conditions

The data pertaining to various root and shoot parameters under drought and irrigated conditions is presented in Table 2 reveled that under drought root to total biomass was highest in C-15 (0.429 g) followed by PM-4 (0.408 g) and PM Chari-6 (0.401 g) and was lowest in C-6 (0.215 g), while as under irrigated conditions it was highest in PM-4 (0.488 g) followed by C-15 (0.415 g) and PM-3 (0.415 g) and was lowest in C-6 (0.279 g). Under drought shoot to total biomass was highest in C-6 (0.793 g) followed by C-8 (0.755 g) and PM-3 (0.699 g) and was lowest in C-15 (0.569 g), while as under irrigated conditions it was highest in C-6 (0.720 g) followed by C-8 (0.707 g) and KG-2 (0.697 g) and was lowest in PM-4 (0.511 g). Under drought root shoot ratio was highest in C-15 (0.764) followed by PM-4 (0.691) and PM Chari-6 (0.671) and was lowest in C-6 (0.282), while as under irrigated conditions it was highest in PM-4 (0.987) followed by PM-3 (0.714) and C-15 (0.712) and was lowest in C-6 (0.387). Under drought root biomass at top was highest in PM-5 (0.826 g) followed by Aravali Makka-1 (0.776 g) and KG-1 (0.770 g) and was lowest in GM-6 (0.585 g), while as under irrigated conditions it was highest in PM Chari-6 (0.935 g) followed by GM-6 (0.893 g) and C-15 (0.799 g) and was lowest in KG-1 (0.600 g). Under drought root biomass at bottom was highest in GM-6 (0.414 g) followed by C-15 (0.395 g) and KG-2 (0.392 g) and was lowest in PM-5 (0.124 g), while as under irrigated conditions it was highest in KG-1 (0.399 g) followed by PM-5 (0.273 g) and KG-2 (0.256 g) and was lowest in PM Chari-6 (0.064 g). Root: shoot ratio increases dramatically under drought conditions suggesting that functional responses to reduced soil moisture primarily occur through increased growth of roots, as has been shown suggested by Quezada and Gianoli (2010). Similarly, Huang *et al.,* (2013) also reported that deficiencies of soil water resulted in high root: shoot ratio. Relatively, more biomass was allocated to the root than to the shoot, and plant allocated more resource to the belowground growth. The same pattern of partitioning has also been observed in other plants (Gonzales *et al.,* 2008). In response to evapotranspiration demands, shoots drive water uptake through a root system (Comas *et al.,* 2013) and amount of water uptake is determined by root architecture, i.e., root angles, rooting depth, root diameter, number of root branches and length of root hairs (Lynch, 2013). Changes in biomass partitioning under stress determine plants ability to respond to environmental changes that alter resource availability and plants invariably respond by increasing its efficiency of the resource that tends to limit plant growth and finally change its yielding ability. Recently, there has been greater emphasis on remobilization of photosynthates from vegetative parts such as shoot to cob and then from cob on to grains, as an important mechanism of drought resistance (Rao *et al.*, 2012). Aslam *et al.*, (2013) concluded that stem elongation in maize under water stress was reduced during vegetative period.

Characterization of maize germplasm with better stress tolerance traits and screening for drought tolerant maize lines are essential to the success of breeding programs. A deep root system with thick roots and extensive branching ability is considered a major component of drought avoidance, enabling the plants to extract water from deep soil layers (Fukai and Cooper, 1995; Gowda *et al.,* 2011). Burton *et al.,* (2013) reported that maize landraces have greater variation in root architectural traits and have longer nodal roots and larger xylem than related wild *Zea* species. Longer roots were shown to assist in the capture of mobile resources in the soil and are considered to be a primary determinant of drought tolerance in maize (Ribaut *et al.*, 2009; Zhu *et al.*, 2010). However, moderate water stress in the field, significantly increased root length. Changes in biomass partitioning under stress determine plants ability to respond to environmental changes that alter resource availability and plants invariably respond by increasing its efficiency of the resource that tends to limit plant growth and finally change its yielding ability.

Effect of drought on root traits and biomass partitioning

The factorial ANOVA for root and biomass and biomass partitioning is presented in Table 3. The mean square due to genotypes was significant for all traits except plant height and root depth. The mean square due to water regime was significant for all the traits studied. The first order interaction of genotype x water treatment was significant for root depth, root biomass, percent root biomass at top and percent root biomass at bottom, while it was non-significant for all other traits.

The data pertaining the effect of drought on various root and shoot traits and biomass partitioning is presented in Table 4 reveled that percent increase were highest recorded for root biomass at bottom and root shoot ratio. The data revealed that under drought most of the traits had decreased value except for root biomass at bottom and root shoot ratio which has higher values under drought.

The highest percentage decrease was observed for root biomass (70.891) followed by shoot biomass (67.759) and plant height (27.120) while, as lowest percent decrease was recorded in case of shoot to total biomass (3.484). The traits root biomass at bottom and root shoot ratio had increased values under drought 28.463 and 9.388 respectively. Huang *et al.*, (2013) reported that deficiencies of soil water resulted in high root: shoot ratio. Relatively, more biomass was allocated to the root than to the shoot, and plant allocated more resource to the belowground growth. The same pattern of partitioning has also been observed in other plants (Gonzales *et al.*, 2008).

The decrease to shoot in allocation may be beneficial to plant water economy during drought stress because the reduction of leaf area accomplishes a typical response of plants to diminish drought stress: the reduction of transpiring surface (Grace, 1997). There can be substantial and stable differences between species and varieties in the patterns of dry matter allocation to roots and in root system architecture (de Dorlodot *et al.*, 2007). Under some conditions these differences can be clearly related to crop performance (Manschadi *et al.*, 2006). Wasson *et al.*, (2012) stated that maximum rooting depth and shifting of rooting density to deeper layers were most relevant root traits for yield under rainfed conditions. On the other hand, Vadez *et al.*, (2008) could not establish desirable correlation between root length density distribution and water uptake in tropical residual moisture environment for groundnut and as such proposed to focus on root functionality via water uptake and to only subsequently characterize root morphological differences between genotypes. Another major issue to create a framework for large scale use of root architecture as a selection trait is that not all the studies conducted have reported correspondence between better rooting ability and water uptake and better yields. However, Beebe *et al.*, (2014) has reported that deeper roots alone are not sufficient to confer drought resistance if not combined with other traits.

Correlation of root and shoot parameters under drought and irrigated conditions

The data pertaining to correlation for root and shoot parameters under drought and irrigated conditions are presented in Table 5.

Positive correlations

Plant height

Under drought condition plant height had significant positive correlation with root biomass (0.719) followed by shoot biomass (0.675) and root biomass at bottom (0.181).

Table.1 Mean performance of maize genotypes for various root and shoot parameters under drought and irrigated conditions

Genotypes	Plant Height (cm)		Shoot biomass (g)		Rooting Depth (cm)		Root biomass (g)	
	Irrigated	**Drought**	**Irrigated**	**Drought**	**Irrigated**	**Drought**	**Irrigated**	**Drought**
KDM-72	143.50	107.00	155.00	65.00	134.00	109.50	80.50	34.50
C-8	161.00	111.00	183.00	83.00	154.00	102.00	75.50	26.50
KG-1	153.00	95.00	144.00	35.00	114.50	98.00	67.50	17.50
C-6	147.00	98.50	210.00	73.00	141.50	99.00	81.50	18.50
AM-1	146.50	98.50	182.00	57.00	126.00	113.00	95.50	24.50
PM Chari-6	142.00	99.50	177.00	35.00	106.50	113.50	92.50	23.50
PM-4	125.50	103.50	116.00	45.50	156.00	100.50	105.50	31.50
C-15	117.00	107.50	133.00	54.00	122.50	98.50	94.50	40.50
GM-6	117.00	93.50	135.00	44.00	134.00	111.50	84.50	26.50
PM-3	132.50	96.00	135.00	41.00	127.50	96.50	94.50	17.50
PM-5	139.00	93.50	164.00	39.00	92.50	110.50	91.50	17.00
KG-2	134.50	102.00	147.00	54.00	134.00	62.50	62.50	25.50
C-4	133.50	100.50	208.00	48.00	115.00	126.50	90.50	21.50
Mean	**137.85**	**100.46**	**160.69**	**51.81**	**127.54**	**103.19**	**85.88**	**25.00**
C.D (p ≤ 0.05)	**16.112**		**36.403**		**26.798**		**7.105**	

Table.2 Mean performance of maize (*Zea mays* L.) genotypes for biomass partitioning under different water regimes and effect of drought under greenhouse screening

Genotypes	Root to total biomass		Shoot to total biomass		Root shoot ratio		Root biomass at top		Root biomass at bottom	
	Irrigated	**Drought**	**Irrigated**	**Drought**	**Irrigated**	**Drought**	**Irrigated**	**Drought**	**Irrigated**	**Drought**
KDM-72	0.344	0.346	0.655	0.653	0.526	0.530	0.764	0.724	0.235	0.275
C-8	0.292	0.244	0.707	0.755	0.414	0.324	0.768	0.757	0.231	0.242
KG-1	0.319	0.353	0.680	0.645	0.469	0.573	0.600	0.770	0.399	0.229
C-6	0.279	0.215	0.720	0.793	0.387	0.282	0.752	0.732	0.247	0.267
AM-1	0.343	0.316	0.656	0.683	0.523	0.473	0.760	0.776	0.239	0.224
PM Chari-6	0.349	0.401	0.650	0.597	0.542	0.671	0.935	0.702	0.064	0.297
PM-4	0.488	0.408	0.511	0.592	0.987	0.691	0.782	0.714	0.217	0.285
C-15	0.415	0.429	0.584	0.569	0.712	0.764	0.799	0.604	0.201	0.395
GM-6	0.399	0.375	0.600	0.624	0.687	0.601	0.893	0.585	0.106	0.414
PM-3	0.415	0.299	0.584	0.699	0.714	0.428	0.790	0.685	0.209	0.314
PM-5	0.358	0.304	0.641	0.695	0.558	0.440	0.726	0.826	0.273	0.124
KG-2	0.302	0.321	0.697	0.678	0.438	0.474	0.743	0.607	0.256	0.392
C-4	0.303	0.309	0.696	0.690	0.435	0.447	0.767	0.721	0.232	0.279
Mean	**0.354**	**0.332**	**0.645**	**0.667**	**0.569**	**0.515**	**0.775**	**0.708**	**0.224**	**0.287**
C.D (p ≤ 0.05)	**0.071**		**0.073**		**0.188**		**0.044**		**0.040**	

Table.3 Analysis of variance for various root and shoot parameters and biomass partitioning traits under greenhouse conditions in maize (*Zea mays* L.) genotypes

Source of Variation	**d.f.**	**Plant Height (cm)**	**Shoot Biomass (g)**	**Rooting Depth (cm)**	**Root Biomass (g)**	**Total Biomass**	**Root Biomass at Top**	**Root Biomass at Bottom**	**Root to Total Biomass**	**Shoot to Total Biomass**	**Root Shoot Rato**
Genotypes	12	223.897	1461.167*	374.317	232.423**	1399.798*	0.006**	0.007**	0.013**	0.013**	0.079**
Water Regime	1	18168.923**	154126.173**	7705.558**	48190.173**	374680.692**	0.059**	0.053**	0.006**	0.006**	0.037*
Genotype X Water Treatment	12	180.340	717.923	715.599*	163.590**	1115.567	0.017**	0.019**	0.002	0.002	0.017
Error	**26**	**129.808**	**620.404**	**359.058**	**23.635**	**799.615**	**0.001**	**0.001**	**0.002**	**0.002**	**0.017**

Table.4 Effect of drought on various root and shoot traits and biomass partitioning in maize (*Zea mays* L.) genotypes

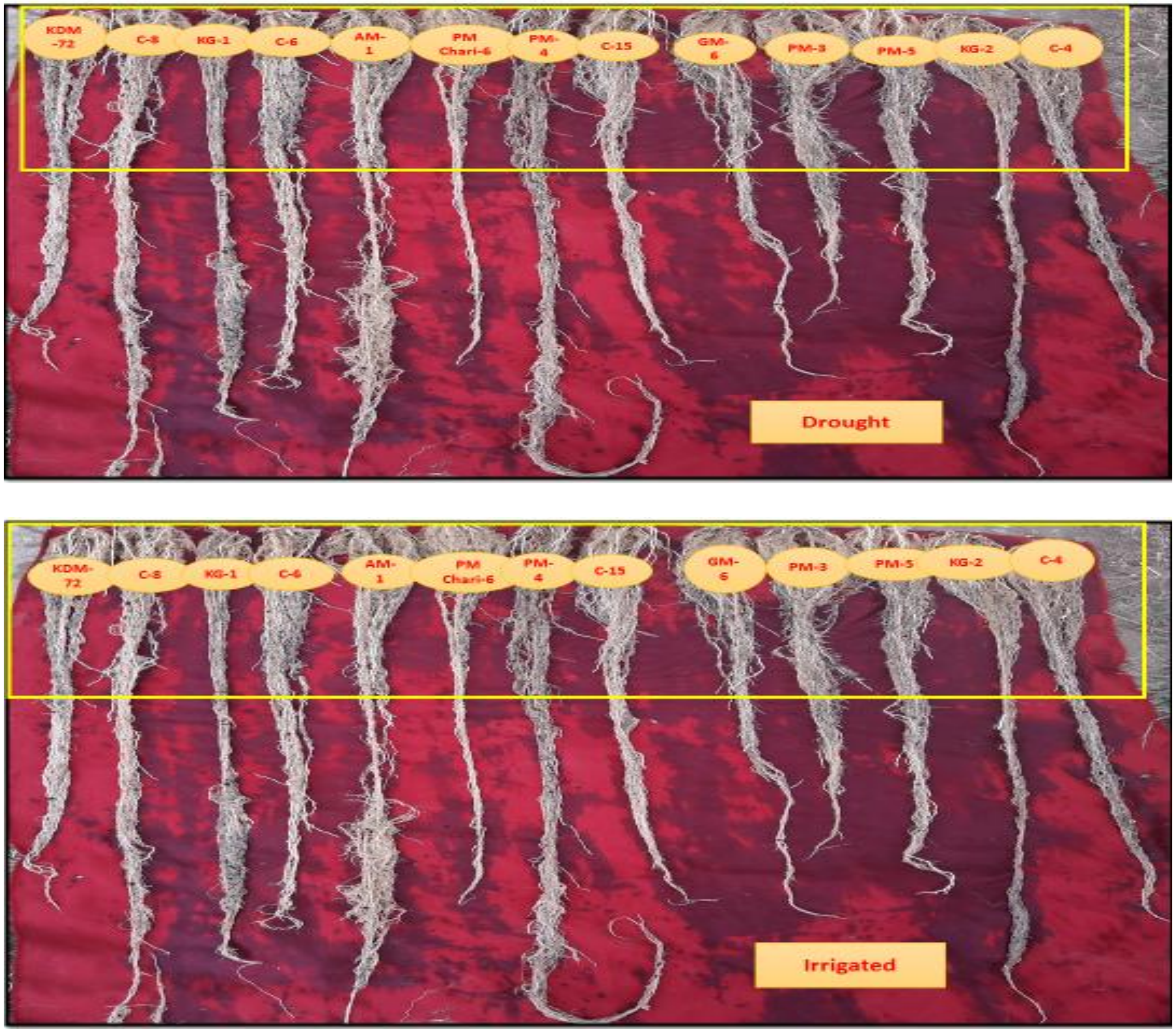
Treatment	**Plant height (cm)**	**Shoot biomass (g)**	**Rooting depth(cm)**	**Root biomass (g)**	**Root biomass at top (g)**	**Root biomass at bottom (g)**	**Root to total biomass**	**Shoot to total biomass**	**Root shoot ratio**
Irrigated	137.846	160.692	127.538	85.884	0.775	0.224	0.354	0.667	0.515
Drought	100.461	51.807	103.192	25.000	0.707	0.287	0.332	0.644	0.568
Percent increase or decrease	-27.120	-67.759	-19.089	-70.891	-8.691	+28.463	-6.209	-3.484	+9.388
CD ($p \leq 0.05$)	**6.531**	**14.279**	**10.862**	**2.787**	**0.017**	**0.016**	**0.026**	**0.028**	**0.720**

Table.5 Correlation of root and shoot parameters under drought and irrigated conditions in maize (*Zea mays* L.) genotypes

Genotype	**Treatment**	**Plant height**	**Shoot biomass**	**Root depth**	**Root biomass**	**Root biomass at top**	**Root biomass at bottom**	**Root to total biomass**	**Shoot to total biomass**	**Root shoot ratio**
Plant height	**Irrigated**	-	0.556*	0.032	-0.447*	-0.449*	0.447*	-0.698*	0.698*	-0.679*
	Drought	-	0.675*	-0.146	0.719*	-0.129	0.181*	0.044	-0.045	0.073
Shoot biomass	**Irrigated**		-	-0.159	-0.125	-0.018	0.017	-0.787*	0.787*	-0.772*
	Drought		-	-0.127	0.287*	0.064	-0.013	-0.587*	0.593*	-0.547*
Root depth	**Irrigated**			-	-0.070	0.047	-0.047	0.137	-0.137	0.227*
	Drought			-	-0.065	0.393*	-0.379*	0.067	-0.068	0.054
Root biomass	**Irrigated**				-	0.442*	-0.442*	0.700*	-0.700*	0.686*
	Drought				-	-0.492*	0.503*	0.584*	-0.579*	0.604*
Root biomass at top	**Irrigated**					-	-0.999*	0.318*	-0.318*	0.300*
	Drought					-	-0.988*	-0.439*	0.434*	-0.439*
Root biomass at bottom	**Irrigated**						-	-0.317*	0.317*	-0.299*
	Drought						-	0.421*	-0.415*	0.425*
Root to total Biomass	**Irrigated**							-	-0.999*	0.991*
	Drought							-	-0.999*	0.993*
Shoot to total Biomass	**Irrigated**								-	-0.991*
	Drought								-	-0.990*
Root shoot Ratio	**Irrigated**									-
	Drought									-

* Significant at probability of 0.05

Fig.1 Root of Maize (*Zea mays* L.) genotypes under drought and irrigated conditions



However under irrigated condition plant height had significant positive correlation with shoot to total biomass (0.698) followed by shoot biomass (0.556) and root biomass at bottom (0.447).

Shoot biomass

Under drought condition shoot biomass had significant positive correlation with shoot to total biomass (0.593) and root biomass (0.287). However under irrigated condition shoot biomass had significant positive correlation with shoot to total biomass (0.787).

Rooting depth

Under drought condition root depth had significant positive correlation with root biomass at top (0.393). However under irrigated condition root depth had significant positive correlation with root shoot ratio (0.227).

Root biomass

Under drought condition root biomass had significant positive correlation with root shoot ratio (0.604) followed by root to total biomass (0.584) and root biomass at bottom (0.503). However under irrigated condition root biomass had significant positive correlation with root to total biomass (0.700) followed by root shoot ratio (0.686) and root biomass at top (0.442).

Root biomass at top

Under drought condition root biomass at top had significant positive correlation with shoot to total biomass (0.434). However under irrigated condition root biomass at top had significant positive correlation with root to total biomass (0.318) and root shoot ratio (0.300).

Root biomass at bottom

Under drought condition root biomass at bottom had significant positive correlation with root shoot ratio (0.425) and root to total biomass (0.421).

However under irrigated condition root biomass at bottom had significant positive correlation with shoot to total biomass (0.317).

Root to total biomass

Under drought condition root to total biomass had significant positive correlation with root shoot ratio (0.993).

However under irrigated condition root to total biomass had significant positive correlation with root shoot ratio (0.991).

Negative correlations

Plant height

Under irrigated condition plant height had significant negative correlation with root to total biomass (0.698) followed by root shoot ratio (0.679) and root biomass (0.447).

Shoot biomass

Under drought condition shoot biomass had significant negative correlation with root to total biomass (0.587) and root shoot ratio (0.547). Under irrigated conditions shoot biomass had significant negative correlation with root to total biomass (0.787) and root shoot ratio (0.772).

Rooting depth

Under drought condition root depth had significant negative correlation with root biomass at bottom (0.379).

Root biomass

Under drought condition root biomass had significant negative correlation with shoot to total biomass (0.579) and root biomass at top (0.492). However under irrigated condition root biomass had significant negative correlation with shoot to total biomass (0.700) and root biomass at bottom (0.442).

Root biomass at top

Under drought condition root biomass at top had significant negative correlation with root biomass at bottom (0.988) followed by root to total biomass (0.439) and root shoot ratio (0.439). However under irrigated condition root biomass at top had significant negative correlation with root biomass at bottom (0.999) and shoot to total biomass (0.318).

Root biomass at bottom

Under drought condition root biomass at bottom had significant negative correlation with shoot to total biomass (0.415). Under irrigated condition root biomass at bottom had significant negative correlation with root to total biomass (0.317) and root shoot ratio (0.299).

Root to total biomass

Under drought condition root to total biomass had significant negative correlation with shoot to total biomass (0.999). However under irrigated condition root to total biomass had significant negative correlation with shoot to total biomass (0.999).

Shoot to total biomass

Under drought condition shoot to total biomass had significant negative correlation with root shoot ratio (0.990). However under irrigated condition shoot to total biomass had significant negative correlation with root shoot ratio (0.991).

Studying root architecture extensively under field condition is limited due to the expenditure of time and labor involved in destructive techniques like the core method, and the likelihood of under-estimation of root depth and density with alternative method like minirhizotron (Vamerali *et al.,* 2012). To circumvent these constraints, we used a simple and inexpensive system including soil media that allowed root growth in order to identify a medium which supports the best maize root growth for our future studies and easy extraction of intact roots. Overall, our experimental results suggest that root length, root biomass at bottom and root shoot ratio are related and are implicated with drought tolerance, but root biomass at bottom could be used as a more reliable trait for selection for drought tolerance in maize. Further studies in greenhouse and in field as well are required using a larger panel of genotypes to validate this kind of association.

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