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VARIABILITY IN ROOT ARCHITECTURAL TRAITS IN MAIZE (*ZEA MAYS* L.) INBRED LINES UNDER MOISTURE STRESS CONDITIONS

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Abstract

Root architectural traits are of fundamental importance to soil exploration and below-ground resource acquisition. Although the root system is indispensable for absorption of nutrients and water, it is poorly studied in maize owing to the difficulties of direct measurement of roots. The aims of this study were to examine the extent of variability in root architectural traits under drought and irrigated conditions and to evaluate their correspondence to drought tolerance. The present study was conducted in the greenhouse facility at the Division of Genetics and Plant Breeding, Faculty of Agriculture, Wadura. In the present study thirty maize inbreds were evaluated for various root and shoot traits under drought and irrigated conditions. The highest percentage decrease under drought was observed for shoot biomass (113.18) followed by root volume (62.60) and root biomass (45.15) while as lowest percent decrease was recorded in root depth (35.64). The trait root shoot biomass ratio had increased value under drought 247.36. The inferences from this study revealed that water stress throughout maize development significantly affected maize growth processes resulting in a sharp decrease in root depth, root biomass, root volume, shoot height and shoot biomass. However there was increase in root shoot biomass ratio under stressed conditions.

***Keywords*:** Root architectural traits, variability, drought tolerance, root shoot biomass ratio

Introduction

Maize (*Zea mays* L.) is one of the important food and industrial crops grown extensively in major parts of the world and it ranks third after wheat and rice. Maize is the principal staple food in many countries, particularly in the tropics and subtropics. Due to the growing demand for dairy and meat products in developing countries and the decline in rice production in China and India, maize has been projected to become the most important crop by 2030 (Salvi *et al.*, 2007). The crop is cultivated in a wider range of environments than either wheat or rice because of its wider adaptability. There are several abiotic factors limiting maize production in different parts of the world. Among them, drought is one of most important factors limiting maize production and productivity (Araus *et al.*, 2002). Drought is the most pervasive limitation to the realization of yield potential in maize (Edmeades *et al.*, 2001) Drought, which is derived from an Anglo-saxon word, meaning dryland, is a comparative and not an exact term. Meterological drought results when precipitation falls significantly below the long term average over a large area for an extended period. Agricultural drought is said to exist when the level and distribution of precipitation is sufficiently low to cause serious shortfalls in crop yields (Hulse, 1989). Drought tolerance is a complex trait (Quarrie, 1996) involving a number of morpho-physiological traits, including root characters (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 (Passioura, 2012). 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 (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). 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. Considerable variation for root architecture exists among and between crop species allowing for soil exploration in dynamic soil conditions (Fitter, 2002). 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). 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. 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). As maize is often produced in the areas of sub-optimal rainfall, additional yield increase may be achieved by selecting genotypes with greater plant productivity under limited soil moisture condition (Boyer, 1982). The selection of tolerant lines for drought in maize depends largely on efficient selection criteria. To stabilize the production for year to year, emphasis should be given to the screening and identification of genotypes under artificially created moisture stress condition, is pre-requisite to achieve the goals of high yield and moisture stress tolerance. The aims of this study were to examine the extent of variability in root architectural traits under drought and irrigated conditions and to evaluate their correspondence to drought tolerance.

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. Thirty Inbreds of maize were evaluated in the present study viz., L-1, L-2, L-9, L-18, L-6, L-10, L-8, HKI- 101, CML-129, HKi-1015-W8,CML-470, L-72, CML-488, CML-167,LM-14, DMR-N6,CML-135, CML-415, LM-12, CML-139, CML-425, CML-286, CML-474, V-338, V-5, V-412, V-351, V-405, V-400, V-335 in well-watered and water-deficit 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 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. . Data on various parameters were recorded such as rooting depth, root volume, root biomass, shoot length and shoot biomass, root/shoot biomass ratio. The design used was factorial CRD with three replications.

Results and Discussion

Root traits under greenhouse conditions

The data pertaining to various root and shoot parameters under drought and irrigated conditions is presented inTable-1

In the present study, under irrigated conditions root depth recorded highest value in HKI-101 (118.00cm) and was lowest in CML-286 (68.00cm) while as under drought conditions highest value was recorded in CML-425 (108.00 cm) and was lowest in CML-135 (34.00 cm). Under irrigated conditions root biomass recorded highest value in V-338 (83.00 g) and lowest in CML-129 (19.00 g) while as under drought conditions it recorded highest value in CML-167 (32.00g) and lowest in CML-129 (8.00 g). Under irrigated conditions root volume recorded highest value in L-1 (61.00 cm^3) and lowest in CML-129 (20.00 cm^3) while as under drought conditions it recorded highest value in CML-470 (30.00 cm^3) and lowest in L-10 (5.00 cm^3). Under irrigated conditions shoot height recorded highest value in HKI-101 and V-412 (132.00cm) and lowest in CML-286 (78.00cm) while as under drought conditions it recorded highest value in CML-470 (87.00 cm) and lowest in DMR-N6 and CML-286 (36.00 cm). Under irrigated conditions shoot biomass recorded highest value in L-8 (196.00g)) and was lowest in L-9 (56.00g) while as under drought conditions it recorded highest value in CML-488 (36.00g) and lowest in CML-470 and CML-135 (6.00g). Under irrigated conditions root shoot biomass ratio recorded highest value in L-2 (1.34) and lowest in CML-129 (0.14) while as under drought conditions it recorded highest value in CML-470 (4.37) and lowest in CML-129 (0.27). The inferences from this study revealed that water stress throughout maize development significantly affected maize growth processes resulting in a sharp decrease in root depth, root biomass, root volume, shoot height and shoot biomass. Significant decrease in root and shoot parameters under water stress conditions has been reported by(Dar *et al*., 2018; Comas *et al*., 2013). However there was increase in root shoot biomass ratio under stressed conditions. This was in agreement with the results obtained by (Feng *et al*., 2012) in rice. Shoot heights of all the irrigated genotypes were higher than their corresponding stressed plants. This finding agrees with (Edmeades and Gallaher, 1992; Bio *et al*., 2011) who reported higher shoot heights for the irrigated site than the rain fed site for 140 maize full-sib families tested for their tolerance to drought in Florida. Different maize inbreds under water-stressed conditions displayed different drought tolerance capabilities and a significant variability in root architectural traits (Kumar *et al.,* 2012; Liang *et al.,* 2013).

The factorial ANOVA for root and shoot parameters is presented in table-2. The mean square due to genotypes, water regime and interaction genotype x water regime was significant for all traits

Bloom *et al*. (1985) suggests that some plants respond to drought by stimulating or maintaining root growth while reducing shoot growth. Drought tolerant tropical maize inbred lines have greater rooting depth than the sensitive lines (Hund *et al*., 2009). The benefit of a deep and proliferative root system for drought tolerance has been reported in various crops including rice (Bernier *et al*., 2009; Uga *et al*., 2013), maize (Hammer *et al*., 2009; Landi *et al*., 2010; Hund *et al*., 2011), barley (Forster *et al*., 2005), wheat (Manschadi *et al*., 2006; Wasson *et al*.,2012), chickpea (Varshney *et al*., 2011; Chen *et al*., 2012), and soyabean (Sadok and Sinclair, 2011). Huang *et al.* (2013) also reported that deficiencies of soil water resulted in high root:shoot ratio. Our experimental results suggest that the root parameters like root depth and root biomass, root- shoot biomass ratio are related and are implicated with drought tolerance and can be used as selection criterion for drought tolerance in maize. Inbred lines are worth to be considered as parents for hybrid seed production because of their genetic purity. Observed variation in susceptibility to water stress among genotypes suggests that the trait can be improved (Fischer *et al*., 1983).

Effect of Drought on various root and shoot traits

The data pertaining the effect of drought on various root and shoot traits is presented in table-3

In our study, the data pertaining the effect of drought on various root and shoot traits revealed that under drought most of the traits had decreased value except for root shoot biomass ratio which has higher value under drought. The highest percentage decrease was observed for shoot biomass (113.18) followed by root volume (62.60) and root biomass (45.15) while as lowest percent decrease was recorded in root depth (35.64).

Drought significantly modified root morphological traits and increased root mortality, and the drought-induced decrease in root biomass was less than shoot biomass, causing higher root: shoot mass ratio. (Manshadi *et al*., 2006; Zhou *et al*., 2018). Fernández *et al*. (1996) found that drought affected shoot growth before the root growth. Huang *et al.* (2013) reported that deficiencies of soil water resulted in high root: shoot ratio. 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

Table 1: Mean performance of maize (*Zea mays* L.) genotypes for various root and shoot parameters under drought and irrigated conditions

Inbreds	Root depth		Root biomass		Root volume		Shoot height		Shoot biomass		Root shoot biomass ratio	
	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
L-1	109.00	59.00	76.00	19.00	61.00	9.00	110.00	48.00	136.00	9.00	0.56	2.12
L-2	104.00	61.00	82.00	14.00	48.00	10.00	82.00	76.00	61.00	10.00	1.34	1.41
L-9	101.00	72.00	32.00	10.00	32.00	7.00	90.00	59.00.	56.00	11.00	0.57	0.92
L-18	89.00	57.00	53.00	12.00	37.00	10.00	128.00	66.00	184.00	11.00	0.29	1.09
L-6	94.00	42.00	43.00	9.00	29.00	11.00	108.00	55.00	164.00	8.00	0.26	1.11
L-10	81.00	36.00	36.00	13.00	40.00	5.00	116.00	42.00	73.00	9.00	0.49	1.44
L-8	87.00	78.00	38.00	11.00	30.00	10.00	109.00	62.00.	196.00	10.00	0.19	1.10
HKI-101	118.00	70.00	32.00	14.00	26.00	8.00	132.00	68.00	142.00	13.00	0.22	1.07
CML-129	97.00	65.00	19.00	8.00	20.00	12.00	125.00	64.00	134.00	29.00	0.14	0.27
HKI-1015-W8	110.00	55.00	38.00	14.00	35.00	15.00	88.00	84.00	151.00	28.00.	0.25	0.50
CML-470	101.00	53.00	41.00	26.00	40.00	30.00	107.00	87.00	98.00	6.00	0.42	4.37
L-72	72.00	42.00	41.00	17.00	30.00	18.00	112.00	43.00	106.00	11.00	0.39	1.54
CML-488	99.00	58.00	36.00	23.00	40.00	20.00	106.00	68.00	90.00	36.00	0.40	0.64
CML-167	64.00	72.00	28.00	32.00	35.00	27.00	90.00	79.00	128.00	28.00	0.22	1.14
LM-14	106.00	57.00	35.00	18.00	45.00	10.00	123.00	68.00	138.00	18.00	0.25	1.00
DMR-N6	76.00	53.00	46.00	16.00	48.00	15.00	99.00	62.00	119.00	14.00	0.39	1.14
CML-135	99.00	34.00	69.00	12.00	55.00	15.00	113.00	36.00	141.00	6.00	0.49	2.02
CML-415	70.00	87.00	28.00	22.00	35.00	18.00	87.00	72.00	122.00	19.00	0.23	1.16
LM-12	112.00	69.00	32.00	14.00	30.00	10.00	130.00	63.00	128.00	16.00	0.2	0.87
CML-139	105.00	40.00	69.00	11.00	53.00	18.00	125.00	61.00	146.00	23.00	0.47	0.48
CML-425	78.00	108.00	35.00	22.00	25.00	16.00	95.00	68.00	124.00	33.00	0.28	0.67
CML-286	68.00	77.00	30.00	30.00	22.00	28.00	78.00	36.00	118.00	22.00	0.25	1.36
CML-474	92.00	65.00	38.00	17.00	33.00	20.00	94.00	43.00	130.00	11.00	0.29	1.55
V-338	86.00	42.00	83.00	16.00	45.00	12.00	112.00	39.00	136.00	19.00	0.61	0.84
V-5	87.00	99.00	50.00	23.00	25.00	15.00	120.00	49.00	164.00	13.00	0.3	1.79
V-412	113.00	38.00	38.00	16.00	45.00	10.00	132.00	54.00	174.00	14.00	0.22	1.14
V-351	92.00	40.00	66.00	18.00	35.00.	12.00	118.00	59.00	136.00	11.00	0.49	1.66
V-405	89.00	60.00	60.00	20.00	36.00	15.00	117.00	63.00	127.00	9.00	0.47	2.22
V-400	77.00	37.00	49.00	15.00	35.00	10.00	115.00	54.00	126.00	800	0.39	1.88
V-335	76.00	45.00	38.00	17.00	25.00	8.00	108.00	65.00	118.00	16.00	0.32	1.06
Mean	**91.73**	**59.03**	**45.36**	**16.96**	**36.50**	**14.13**	**108.96**	**59.76**	**128.88**	**15.7**	**0.38**	**1.32**
C.D (p ≤ 0.05)	Genotype =4.267		Genotype =1.828		Genotype =1.846		Genotype =1.949		Genotype =8.986		Genotype =0.090	
	Water regime = 1.102		Water regime = 0.472		Water regime = 0.477		Water regime = 0.503		Water regime = 2.320		Water regime = 0.023	
	Genotype x Water regime=6.035		Genotype x Water regime= 2.585		Genotype x Water regime=2.610		Genotype x Water regime=2.756		Genotype x Water regime=12.708		Genotype x Water regime=0.127	

Table 2 : Analysis of variance for various root and shoot parameters under greenhouse conditions in maize (*Zea mays* L.) inbreds

Source of Variation	d.f.	Root depth	Root volume	Root biomass	Shoot height	Shoot Biomass	Root Shoot biomass ratio
Genotypes	1	698.450**	433.586**	194.843**	540.717**	1,621.399**	1.031**
Water Regime	29	48,118.050**	36,295.200**	22,512.050**	108,928.800**	576,527.606**	39.790**
Genotype × water regime	29	997.567**	529.510**	225.050**	712.076**	1,668.985**	0.824**
Error	120	13.9	2.55	2.6	2.9	61.639	0.006

Significant at 0.05% level

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-4. The highest positive correlation was found between root biomass under irrigated conditions and root shoot biomass ratio under irrigated conditions (0.720). The lowest positive correlation was found between root volume under drought conditions and root shoot biomass ratio under drought conditions and between shoot height under drought conditions and root shoot biomass ratio under drought conditions (0.010).The highest negative correlation was found between shoot biomass under drought conditions and root shoot biomass ratio under drought conditions (-0.622). The lowest positive correlation was found between shoot height under irrigated conditions and root shoot biomass ratio under drought conditions (-0.013). High correlation between root and shoot traits greenhouse have also been reported by (Lasley, 2013; Kashiwagi *et al.*, 2007).

Phenotypic relationships between root and shoot traits reported in maize by Richner *et al.* (1997) suggested that seedling root traits with other secondary traits could be used as indirect selection for shoot performance in maize. Since measuring roots is difficult in breeding programme, several researchers have used electrical capacitance measurements for rapid root dimensions assessment. Electrical capacitance and total root volume are positively correlated. Plants that have a long shoot system tend to have a deeper root system, while short plants tend to have shorter roots (Guerrero-Campo and Fitter, 2001) and a significant correlation between shoot length and root length is achieved in their study. Roots are central to water and nutrient uptake in plants. Hence, varieties with a more extensive root system might have a better nutrient uptake efficiency and drought tolerance and would thus be very useful in the genetic improvement of maize (Kondo *et al.*, 2003). 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). Characterization of maize germplasm with better stress tolerance traits and screening for drought tolerant maize lines are essential to the success of breeding programs

Table 3: Effect of Drought on various root and shoot traits in maize (*Zea mays* L.) inbreds

Treatment	Root depth	Root volume	Root biomass	Shoot height	Shoot Biomass	Root Shoot biomass ratio
Irrigated	91.73	45.36	36.50	108.96	128.88	0.38
Drought	59.03	16.96	14.13	59.76	15.70	1.32
Percent increase or decrease	-35.64	-62.60	-61.27	-45.150	-113.18	247.36

Table 4 : Correlation of root and shoot parameters under irrigated and drought conditions in maize (*Zea mays* L.) inbreds

		Root depth		Root Biomass		Root volume		Shoot Height		Shoot Biomass		Root Shoot biomass ratio	
		Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
Root Depth	**Irrigated**	1											
	Drought	-0.181	1										
Root Biomass	**Irrigated**	0.189	-0.384*	1									
	Drought	-0.450*	0.389*	-0.162	1								
Root volume	**Irrigated**	0.329	-0.483**	0.673**	-0.101	1							
	Drought	0.198	0.251	-0.255	0.144	-0.084	1						
Shoot Height	**Irrigated**	0.436*	-0.340	0.085	-0.403*	0.076	-0.138	1					
	Drought	0.198	0.251	-0.255	0.144	-0.084	1.000**	-0.138	1				
Shoot Biomass	**Irrigated**	0.112	0.038	0.027	-0.158	-0.068	-0.070	0.452*	-0.070	1			
	Drought	-0.110	0.372*	-0.371*	0.302	-0.240	0.318	-0.218	0.318	-0.030	1		
Root Shoot biomass ratio	**Irrigated**	0.147	-0.232	0.720**	-0.119	0.504**	-0.022	-0.280	-0.022	-0.565**	-0.298	1	
	Drought	-0.023	-0.146	0.234	0.359	0.214	0.010	-0.013	0.010	-0.154	-0.622**	0.206	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

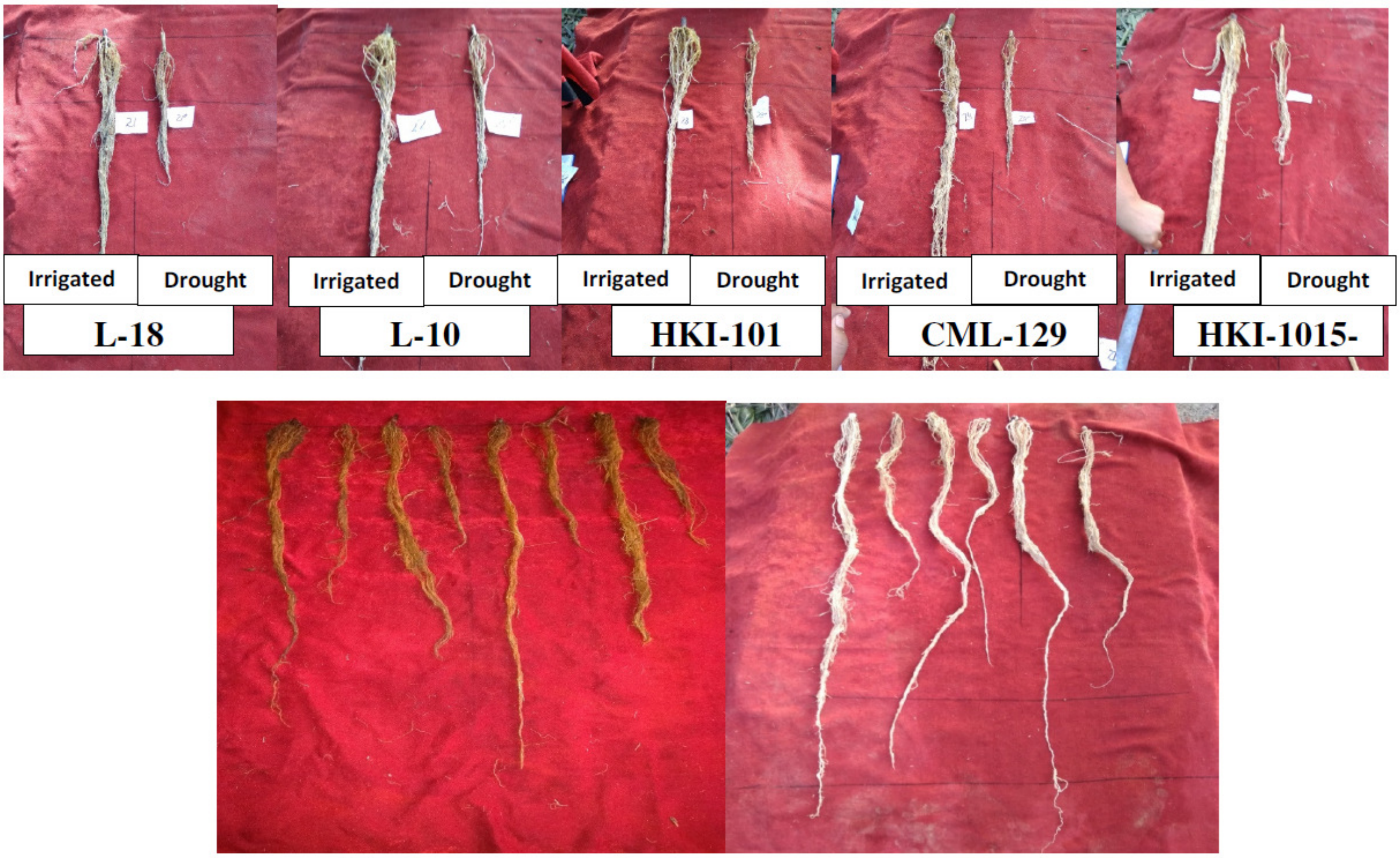

Fig. 1 : Comparison of roots of Maize (*Zea mays* L.) genotypes under drought and irrigated conditions.

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