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Phenotyping of wheat genotypes [*Triticum aestivum (L.)*] for root length, root volume and root diameter under North Gujarat condition

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Abstract:

Wheat assumes greater significance among the cereals for being grown over 43 countries across the globe with an area around 222.60 million hectares and production around 720 million tons. Increase size, scale and scope of these wheat traits have been tailored to realize higher economic yield through aerial / above ground parts like stem, leaves, flower and grain parts to strike balance between the source, sink and carbon carriage chain from source to sink. The size and scale of root attributes like length, volume and diameter determines the space and extent of root activities for functional scope of mining nutrients and water from the soil. Wheat genotypes Lok 1 and GW 496 possessed higher root length 14295 and 12352 cm, root volume 188 and 156 cm^3, and root diameter 0.79 and 0.77 mm, respectively. Similarly lower value for root length 3125 and 4571 cm, root volume 34 and 44 cm^3 and root diameter 0.50 and 0.51 mm, respectively were exhibited by wheat genotypes GW 444 and GW 445. The size and scale of root attributes like length, volume and diameter determines the space and extent of root activities for functional scope of mining nutrients and water from soil.

Introduction:

Cereals are indispensable and ubiquitous component of human diet. Cereals belong to monocot family *Poaceae*, which is conspicuously the overarching and cheapest source of food and nutrition. Wheat assumes greater significance among the cereals for being grown over 43rd countries across the globe with an area around 222.60 million hectares and production around 720 million tons (Anonymous, 2015).

The agriculture is confronted with behemoth problems attributed to global warming. Seventy per cent of the food energy is provided by cereals

(Jung *et al.*, 2008). One foreshadow for 2050 has indicated that global warming could reduce wheat yields by 30 per cent in countries like India while its demand in developing world is likely to surge by 60 per cent (Rosegrant and Agcaoili, 2010). Whereas, developed agriculture is facing the problem of sustainability by indiscriminate use of agro-chemical and water. Despite 75 per cent of the globe is water, only 3 per cent of it is fresh water. Out of this, 2.5 per cent is frozen in the form of snow or glaciers. That mean we are left with only 0.5 per cent of the available water for use; and this water too resides in deep aquifers. 80 per cent of the water is used in agriculture (FAO, 2013). Water stress affects 45 per cent of the world's geographic area and is a major constraint in wheat production particularly in semi-arid regions (Amjad *et al.,* 2011). Pragmatically the yielding ability in wheat is manifestation of number of ears per unit area, number of grains per ear and grain weight (Reynolds *et al.,* 2009). It is well documented in literature for anchorage, nutrition, water absorption and slew of other physio-biochemical activities (Bazzaz *et al.,* 2000; Scott, 2008; Fageria *et al.,* 2011 and Reynolds, 2011).

Root Characteristics: Root Length, Volume and diameter

The size and scale of root attributes like length, volume and diameter determines the space and extent of root activities for functional scope of mining nutrients and water from soil. Theoretically, fibrous architecture would be more desirable under irrigated conditions while deep roots are desirable under rainfed conditions to extract nutrients and water from the soil (Wasson *et al.,* 2012 and Sandhu *et al.,* 2015). The mechanical strength of roots entailing spread and bending strength of roots is important for resistance to lodging. It was suggested long ago that roots probably synthesize hormones which are essential for shoot growth like cytokinins (Bishopp *et al.*, 2009), gibberellins (Ubeda-Tomas *et al.,* 2009), and abscisic acid (Luo *et al.,* 2014). It has been suggested that reduced shoot growth of plants whose roots have been subjected to stress such as deficient soil water, deficient aeration, high salinity or low temperature is caused by a change in the amount and kind of growth regulators supplied from the roots (Gou *et al.,* 2010; Saini *et al.,* 2013 and Yoshida *et al.,* 2013). In recent years considerable attention has been given to the possibility that roots of plants in drying soil function as primary sensors of water stress. As the soil dries, it changes root metabolism such as a decrease in cytokinin production, increase in ABA production, and disturbance of nitrogen metabolism, Due to this, it sends biochemical signals to the shoots to have physiological changes such as a decrease in growth, stomatal conductance and rate of photosynthesis; regardless of water status of the leaves

(Martin-Vertedor and Dodd, 2011 and Lobet *et al.,* 2014). The recent development in state of art technologies both in scaling of root attributes has spurred the scientists to undertake studies on root attributes to ascertain nitty-gritties of roots as pragmatic selection criteria for enhancing yield. The literature on these aspects is tersely reviewed.

Material method

The field experiment was carried out at two locations *viz.,* Centre of Excellence for Research on Wheat (CERW), Vijapur and Agricultural Research Station, Ladol, district Mehsana, Gujarat during 2011-2015.

Experimental sites

Geographical parameters of there two locations *viz.* Vijapur (EI) and Ladol (EII) where experiment was conducted are given in Table 1

Table 1 : Geographical parameters of the experimental sites

Particulars	Vijapur (EI)	Ladol (EII)
North Latitude	23° - 34'	23° - 38'
East Longitude	72° - 45'	72° - 42'
Altitude (m)	126.059	132.294

Plant material

Forty genotypes of *aestivum* wheat were acquired from the germplasm available at the Center of Excellence for Research on Wheat (CERW), Vijapur, Gujarat. They were grown in RBD with two replications at two locations *viz.,* Vijapur and Ladol during 2011-12 and 2012-13. The plot size comprised of one row of 2m length spaced 30cm apart. The plants were excavated at flowering stage by digging a drench with JCB Machine and then after washed the soil with pressurized water. The excavated roots were properly washed and scored for root length, root diameter and root volume using WinRHIZO (Image Analysis System). The most extreme genotypes for higher root length, root volume and root diameter were Lok 1 and GW 496 whereas, GW 444 and GW 445 were scored as lowest for root length, root volume and root diameter. These extreme genotypes were selected and crossed to develop different generations ($F_{1,}$ F_2, BC_1 and BC_2) during 2012-13 and 2013-14. The $F_{1,}$ F_2, BC_1 and BC_2 populations were developed using standard protocols (Table 2).

Table 2 : Schematic summary of different generation used for present study

Sr. No.	Cross designation	P_1	P_2	F_1	F_2	BC_1	BC_2
1.	Lok 1 x GW 445	Lok 1	GW 496	P_1 x P_2	F_1¤	P_1 x F_1	P_2 x F_1
2.	GW 496 x GW 444	GW 496	GW 444	P_1 x P_2	F_1¤	P_1 x F_1	P_2 x F_1

¤ selfing

Hybridization & development of F_1

The Two extreme genotypes for high root length, root volume and root diameter (Lok 1 and GW 496) were crossed to GW 444 and GW 445 having low values for the said root attributes during 2012-13 at Vijapur to obtain two F_1s (Table 2).

Development of F_2, BC_1 and BC_2 population

Seeds of F_1 were sown during 2013-2014 at Vijapur. Seeds of selfed F_1 plant were collected, bulked and used for developing F_2 seed. F_1 plants were also crossed to respective parents to develop BC_1 and BC_2 generation seed (Table 2).

The F_1, F_2, BC_1 and BC_2 plant along with their parents were grown under field condition at two locations *viz.,* Vijapur and Ladol during 2014-2015 in RBD design with two replications. The plot size for each parents, F_1 and BC_1 and BC_2 generations was kept as one row; and for F_2 as 10 rows of 2m length (Table 2).

Screening for root attributes

Five plants of P_1, P_2, F_1, BC_1 and BC_2 generation and 120 plants of F_2 generations of each cross in each replication were excavated at flowering stage by digging a drench all around the experiment with JCB Machine and washing the soil with pressurized water. The excavated roots were properly washed and scored for root length, root diameter and root volume using WinRHIZO (Image Analysis System).

WinRHIZO (Image Analysis System)

WinRHIZO is a non-statistical method for measuring root morphology. It calculates total root length from a one pixel thinned image by multiplying the number of pixels by pixel size, and calculates average diameter by dividing the projected area of the imaged object by the total length. Surface area is calculated from root diameter and length assuming the root has a round cross-section (Regent Instruments, Win/MacRHIZO V 5.0A User's Guide, Regent Instruments,Québec,) It is unlike other image analysis systems as it detects areas of root overlap and makes corrections for them, and assigns root lengths to predefined diameter classes, thus providing diameter distributions of the total root system (Fig.1, Fig.2, Fig 3 and Fig.4).

Image a

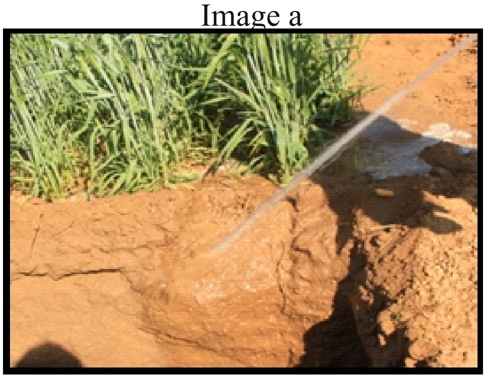

Image b

Image c

Fig. 1 : Phenotyping of root attribute:

a-c: Excavation of root from soil with pressurized water

Image d

Image e

Fig. 2: Phenotyping of root attribute:
d-e: Washing root for 2-3 times with clean water

Image f

Image g

Fig. 3: The excavated roots scored for root length, root diameter and root volume using WinRHIZO (Image Analysis System) **(f-g)**

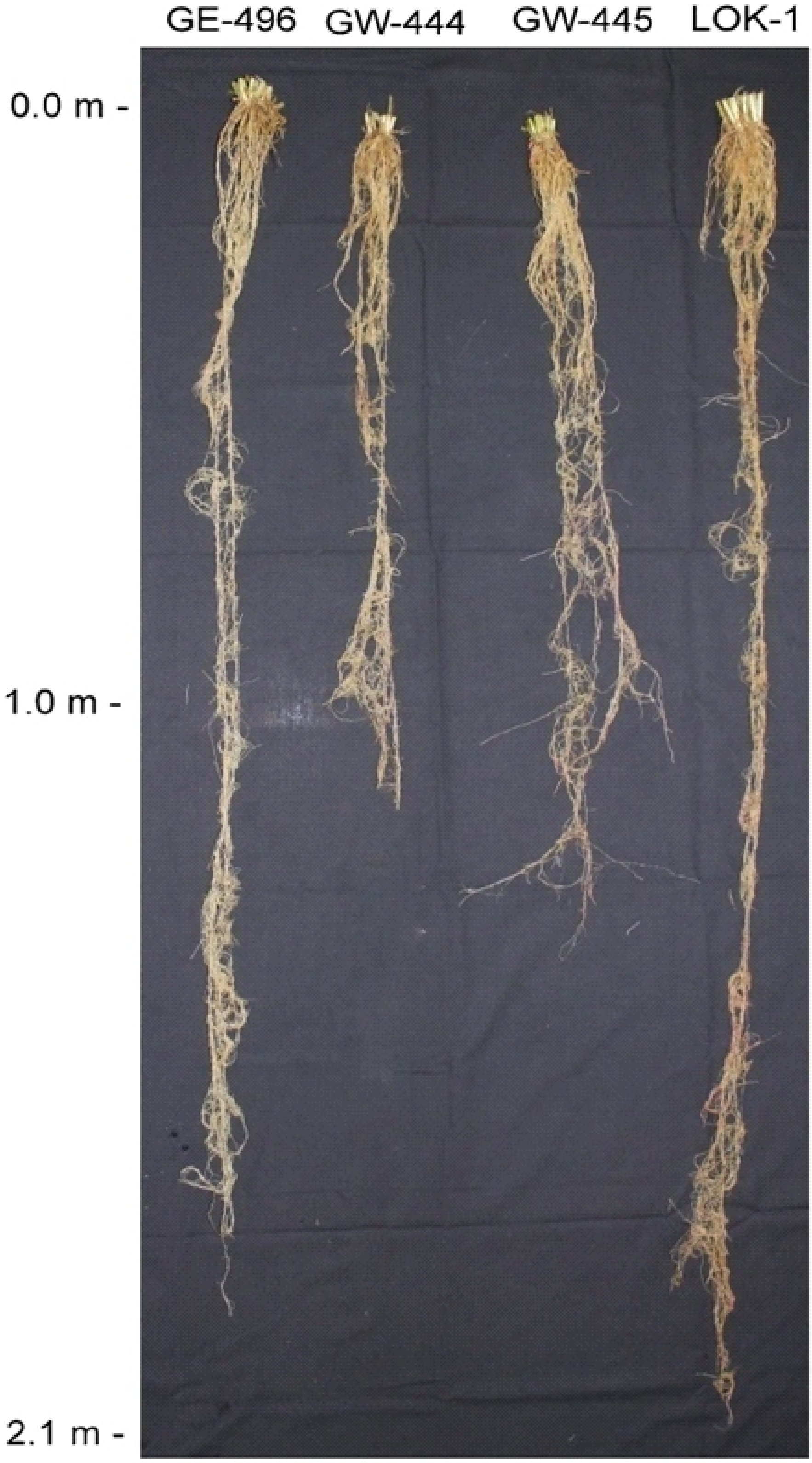

Fig. 4 : Root system architecture (RSA) of four parent *viz.,* GW496, GW 444, GW 445 and Lok1 used in this study.

Preparing roots for scanning

The roots were excavated by washing the soil debris by applying pressurized water. Dead roots were manually removed from vital roots by washing 2-3 times with clean water. Roots were floated in water in acrylic trays on the scanner by using forceps and arranged to reduce overlap and crossing of roots.

Scanning roots

WinRhizo is used with a mandated scanner, which allows the roots to be lit from above and below while being scanned. WinRhizo prompted a text file that can be easily opened in standard spreadsheet programs. Root data in each section were recorded using a digital image analysis system (WinRhizo Software., Regent Instruments Inc., Canada). A transparent 10 x 15 cm tray was used to immerse the roots in water to separate them and to avoid overlap. Data were recorded using a simple scanning interface.

Statistical analysis

Analysis of variance

The average of the individual trait for each treatment in each replication was subjected to analysis of variance for randomized block design. The ANOVA for ascertaining variability among generation is given in Table 3.

Table 3 ANOVA for comparison among generations

Source	d.f.	M.S.	EMS
Replication	(r-1)	M_r	$\sigma^2 e + f\sigma^2_r$
Generations	(g-1)	M_g	$\sigma^2 e + r\sigma^2_g$
Error	(r-1) (g-1)	M_e	$\sigma^2 e$

Where,
g = number of generation,
r = number of replication

Result:

Phenotyping of root attributes

The analysis of variance exhibited significant differences among the genotypes for all the root traits (Table 4). Mean values for root length, root volume and root diameter ranged from 3125 to 14295 cm, 34 to 188 cm^3, and 0.50 to 0.79 mm, respectively. In general, the genotypes with the longer roots also evinced the higher root length, root volume and root diameter. *Aestivum* wheat genotypes Lok 1 and GW 496 possessed higher root length 14295 and 12352 cm, root volume 188 and 156 cm^3 and root diameter 0.79 and 0.77 mm, respectively. Similarly lower value for root length 3125 and 4571 cm, root volume 34 and 44 cm^3) and root diameter 0.50 and 0.51 mm, respectively were exhibited by wheat genotypes GW 444 and GW 445.

Table 4 : Mean performance of root length, root volume and root diameter of different genotypes of wheat over two locations *viz.*, Vijapur (EI) and Ladol (EII)

Genotypic Designation	Root Length (cm)	Root Volume (cm^3)	Root Diameter (mm)
GW-11	6987	67	0.76
GW-173	8107	80	0.69
GW-273	1139	114	0.44
GW-322	11696	116	0.54
GW-366	9876	92	0.61
GW-418	9350	92	0.59
GW-426	8532	79	0.65
GW-427	6978	68	0.64
GW-428	8696	86	0.57
GW-430	9807	96	0.48
GW-432	7413	74	0.57
GW-433	9985	100	0.75
GW-438	8355	82	0.51
GW-439	9489	94	0.52
GW-440	5086	50	0.53
GW-441	9817	96	0.54
GW-444	3125	34	0.50
GW-445	4571	44	0.51
GW-496	12352	156	0.77
LOK-1	14295	188	0.79
VA 2010-10	8280	80	0.76
VA 2010-14	8526	82	0.79
VA 2010-18	6908	66	0.72
VA 2010-19	6163	60	0.68
VA 2010-20	6515	62	0.73
VA 2011-02	9069	88	0.43
VA 2011-05	5303	50	0.4
VA 2011-10	5870	57	0.5

VA 2011-13	8449	83	0.53
VA 2011-16	9110	85	0.54
VA 2011-20	9146	88	0.82
VA 2011-22	9783	91	0.61
VA 2011-23	6714	68	0.45
VA 2011-25	6808	67	0.54
VA 2011-26	7908	78	0.54
VA 2011-32	5736	59	0.6
VA 2011-33	5301	51	0.53
VA 2011-34	5603	50	0.6
VA 2012-02	7683	74	0.72
VA 2012-03	5780	56	0.71
Average	**8014.5**	**80.08**	**0.60**
Range	**3125-14295**	**34-188**	**0.50-0.79**
CD $_{(0.05)}$	**467.43**	**14.75**	**0.03**
SE_M(±)	**163.41**	**5.16**	**0.01**
CV %	**2.88**	**8.67**	**2.04**

The analysis of variance for individual character was carried out for each character in both the crosses and is presented in Table 5. The mean sum of square due to treatment was significant in both the crosses at both the locations *viz.,* Vijapur and ladol.

Root Length

Environment I (Vijapur)

Result shown there was a significant differences between parental lines (P_1 and P_2) of cross Lok 1 x GW 445 for mean values of root length (Table 6). The mean performance of root length in parents of cross Lok 1 x GW 445 was 4452 cm in GW 445 and 14245 cm in Lok 1. The mean performance of F_1 generation was 11245 cm. The F_2 generation showed wide gamut of variation for root length from 5630 cm to 14879 cm with an overall average of 11478 cm. The average root length of BC_1 and BC_2 was 14589 cm and 10356 cm, respectively.

The mean performance of root length of parents in cross GW 496 x GW 444 was 3012 cm in GW 444 and 12528 cm in GW 496. The mean performance of F_1 generation was 10487 cm.

Table 5 Analysis of variance for generation means of two crosses for different characters at Vijapur (EI) and Ladol (EII)

Source	Lok 1 x GW 445		GW 496 x GW 444	
	Vijapur (EI)	Ladol (EII)	Vijapur (EI)	Ladol (EII)
Root Length				
Replication (1)	55763.54	5155201.64	45900.95	83361.11
Treatment (5)	35215985.92*	31404590.77*	23306160.94*	21881311.26*
Error (5)	200936.761	6041875.159	149117.823	106917.628
Root Volume				
Replication (2)	1.12	2.58	400.98*	7.42
Treatment (5)	5183.97*	4702.33*	3178.26*	4228.62*
Error (10)	36.704	35.096	55.139	115.746
Root Diameter				
Replication (2)	0.00*	0.00	0.00	0.01*
Treatment (5)	0.02*	0.02*	0.03*	0.00*
-Error (10)	0.000	0.001	0.001	0.001

t = 0.05

Table 6 Mean performance of six generation of two crosses of wheat for root length, root volume and root diameter

Sr. No.	Cross designation	Vijapur (EI)						Ladol (EII)					
		P_1	P_2	F_1	F_2	BC_1	BC_2	P_1	P_2	F_1	F_2	BC_1	BC_2
Total Root Length (cm)													
1.	Lok 1 x GW 445	14245	4452	11245	11478	14589	10356	14458	4885	12254	12457	14998	10548
2.	GW 496 x GW 444	12528	3012	10487	9215	13478	9223	12115	3589	10544	11544	13458	10012
Root volume													
1.	Lok 1 x GW 445	186	44	160	172	170	158	192	49	185	177	188	165
2.	GW 496 x GW 444	155	32	155	150	141	140	162	38	159	150	161	144
Average Root Diameter													
1.	Lok 1 x GW 445	0.78	0.52	0.69	0.72	0.79	0.69	0.83	0.59	0.80	0.79	0.84	0.77
2.	GW 496 x GW 444	0.78	0.51	0.60	0.70	0.80	0.65	0.75	0.52	0.72	0.71	0.76	0.68

The F_2 generation showed wide gamut of variation for root length that varied from 4336 cm to 12894 cm with an overall average of 9215 cm. The average root length of BC_1 and BC_2 was 13478 cm and 9223 cm, respectively.

Environment II (Ladol)

In this case, There was significant differences between parental lines (P_1 and P_2) of Lok 1 x GW 445 for mean value of root length (Table 6). The mean performance of root length in parents of cross Lok 1 x GW 445 was 4885 cm in GW 445 and 14458 cm in Lok 1. The mean of F_1 generation was 12254 cm. The F_2 generation showed wide gamut of variation for root length from 5446 cm to 15023 cm with an overall average of 12457 cm. The average root length of BC_1 and BC_2 was 14998 cm and 10548 cm, respectively.

The mean performance of root length in parents of cross GW 496 x GW 444 was 3589 cm in GW 444 and 12115 cm in GW 496. The mean performance of F_1 generation was 10544 cm. The F_2 generation showed wide range of variation for root length from 4233 cm to 13224 cm with an overall average of 11544 cm. The average root length of BC_1 and BC_2 was 13458 cm and 10012 cm, respectively.

Root Volume

Environment I (Vijapur)

Significant differences between parental lines (P_1 and P_2) of Lok 1 x GW 445 and GW 496 x GW 444 for mean values of root volume (Table 6). The mean performance of root volume in parents of cross Lok 1 x GW 445 was 44 cm^3 in GW 445 and 186 cm^3 in Lok 1. The mean of F_1 generation was 160 cm^3. The F_2generation showed wide gamut of variation for root volume from 52 cm^3 to 190 cm^3 with an overall average of 172 cm^3. The average root volume of BC_1 and BC_2 was 170 cm^3 and 158 cm^3, respectively.

The mean performance of root volume in parents of cross GW 496 x GW 445 was 32 cm^3 in GW 445 and 155 cm^3 in GW 496. The mean of F_1 generation of crosses was 155 cm^3. The F_2 generation showed wide gamut of variation for root volume from 40 cm^3 to 165 cm^3 with an overall average of 150 cm^3. The average root volume of BC_1 and BC_2 was 141 cm^3 and 140 cm^3, respectively.

Environment I (Ladol)

Significant differences between parental lines (P_1 and P_2) of Lok 1 x GW 445 and GW 496 x GW 444 for mean value of root volume (Table 6). The mean performance of root volume in parents of cross Lok 1 x GW 445 was 49 cm^3 in GW 445 and 192 cm^3 in Lok 1. The mean of F_1 generation was 185 cm^3. The F_2 generation showed wide gamut of variation for root volume from 60 cm^3 to 210 cm^3 with an overall average of 177 cm^3. The average root volume of BC_1 and BC_2 was 188 cm^3 and 165 cm^3, respectively.

The mean performance of root volume in parents of cross GW 496 x GW 444 was 38 cm^3 in GW 444 and 162 cm^3 in GW 496. The mean of F_1 generation was 159 cm^3. The F_2 generation showed wide range of variation for root volume from 42 cm^3 to 170 cm^3 with an overall average of 150 cm^3. The average root volume of BC_1 and BC_2 was 161 cm^3 and 144 cm^3, respectively.

Root Diameter

Environment I (Vijapur)

Significant differences between parental lines (P_1 and P_2) of Lok 1 x GW 445 and GW 496 x GW 444 for mean values of root diameter (Table 6). The mean performance of root diameter in parents of cross Lok 1 x GW 445 was 0.52 mm in GW 445 and 0.78 mm in Lok 1. The mean of F_1 generation was 0.69 mm. The F_2 generation showed wide gamut of variation for root diameter from 0.54 mm to 0.83 mm with an overall average of 0.72 mm. The average root diameter of BC_1 and BC_2 was 0.79 mm and 0.69 mm, respectively.

The mean performance of root diameter in parents of cross GW 496 x GW 444 varied from 0.51 mm in GW 444 and 0.78 mm in GW 496. The mean of F_1 generation was 0.60 mm. The F_2 generation showed wide gamut of variation for root volume from 0.56 mm to 0.75 mm with an overall average of 0.70 mm. The average root volume of BC_1 and BC_2 was 0.80 mm and 0.65 mm, respectively.

Environment I (Ladol)

Significant differences between parental lines (P_1 and P_2) of Lok 1 x GW 445 and GW 496 x GW 444 for mean values of root diameter (Table 6). The mean performance of root diameter in parents of cross Lok 1 x GW 445 was 0.59 mm in GW 445 and 0.83 mm in Lok 1. The mean of F_1 generation was 0.80 mm. The F_2 generation showed wide gamut of variation for root diameter from 0.63 mm to 0.90 mm with an overall average of 0.79 mm. The average root diameter of BC_1 and BC_2 was 0.84 mm and 0.77 mm, respectively.

The mean performance of root volume in parents of cross GW 496 x GW 444 was 0.52 mm in GW 444 and 0.75 mm in GW 496. The mean of F_1 generation was 0.72 mm. The F_2 generation showed wide gamut of variation for root volume from 0.56 mm to 0.81 mm with an overall average of 0.71 mm. The average root volume of BC_1 and BC_2 was 0.76 mm and 0.68 mm, respectively.

Discussion:

From the overall experiment, It can be said that the underground parts of the plants have greater say in accessing, mobilizing, utilizing and converting the water and nutrients into economic products. However, their study is too tedious and deterrent to be executed under normal course. The oscillating extreme climatic events, capricious pattern of rains attributed to climate change that often culminate either in drought or deluge and consequently losses of large properties including soil and life of farmers that are too irresistible to neglect root studies any more (Cao *et al.,* 2010; Zaman-Allah *et al.,* 2011 and Carvalho *et al.,* 2014). Off late, good number of studies have been spurred that have indicated enormous genotypic differences for root attributes (Maccaferri *et al.,* 2011) and their role in stress-adaptive features in field performance across environments (Araus *et al.,* 2003a'b; Garcia del Moral *et al.,* 2003 and Royo *et al.,* 2010). Yet, roots are still an enigmatic black box requiring intricate tasks like excavation to evaluate their role in adaptation to hostile environments (Petrarulo *et al.,* 2009, Zhuo-Kun *et al.,* 2010, Hamada *et al.,* 2012, Christopher *et al.,* 2013 and Zhang *et al.,* 2013).

Phenotyping of root length, root volume and root diameter

Three attributes of roots *viz.,* root length, root volume and root diameter were ascertained in 40 genotypes. There were significant genotypic differences among the genotypes for root length, root volume and root diameter (Table 5). This indicated that genotypes with customized root attributes can be selected for different growing situations. It was further observed that genotypes with good root length also evinced better root volume and root diameter. This further indicated explicitly that there are ample chances for selection of genotypes with good root length, root volume and root diameter. This is pertinent from enhancing productivity of wheat under different situations (Fitter, 2002; Nardini *et al.,* 2002; Comas *et al.,* 2013; Jeong *et al.,* 2013 and Yildirim *et al.,* 2015). The crosses between extreme genotypes *viz.,* Lok 1 and GW 496 (good for all the three attributes of root) with GW 445 and GW 444 (poor for all the three attributes of root) were made and different populations (F_1, F_2, BC_1 and BC_2) were evolved. The mean values of six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) of two crosses of wheat for root length, root volume and root diameter in Table 6. The differences in mean values of parents of each cross were conspicuous for root length, root volume and root diameter at both the locations. In both the crosses, F_1s evinced partial dominance for longer root length and higher root diameter as indicated by their mean values tilted towards longer root length and higher root diameter from the mid parental value both at Vijapur and Ladol location. However, for root volume, the values of F_1s were closer to the parent having high root volume in both the crosses at both the locations suggesting that this character is controlled by dominant gene action. The mean values of the backcross generations BC_1 and BC_2, in both the crosses at both the locations authenticated the gene action observed in F_1s. The mean values of F_2s for root length varied from 4336 cm to 15023 cm in cross Lok 1 x GW 445 and from 4233 cm to 13224 cm in cross GW 496 x GW 444. The upper values of root length in both the crosses exceeded the better parent for root length in both the crosses. This indicated that there are reasonable chances to get transgressive segregants for root length. Similarly for root diameter and root volume too, the values of F_2s defied the threshold of the parent for respective root traits. This is of great significance both for increasing yield and adaptability as root length, root volume and root diameter have been reported to manifest better productivity, adaptability; and better nutrient uptake and use efficiency in wheat (Bahrman *et al.,* 2004); *Brassica napus; (*Wissuwa, 2003; Shimizu *et al.,* 2004, Yi *et al.,* 2005 and Xiangsheng *et al.,* 2010);maize (Mollier and Pellerin, 1999 and Chun *et al.,* 2005) and rice (Yang *et al.,* 2010 and Arai-Sanoh *et al.,* 2014). The significance of different root attributes in relation to drought resistance via better access to water in soil has also been reported by Comas *et al.* (2013). They held out that in environments with late season water deficits, root diameters in targeted seminal roots saved soil water deep in the soil profile for later use at crop maturation and thereby resulted in improved yields. Key morphological traits looked like influencing total root length, root volume and root number (Fitter, 2002 and Nardini *et al.,* 2002). In consonance to the results of the present study, Yildirim *et al.* (2015) also reported importance of root length in yield. They further reported that roots have direct contact with the soil and are responsible for accessing nutrients and water and thereby manifested better yield and tolerance to abiotic stresses. Dreccer *et al.* (2002) in their simulation study in wheat suggested that even a small increase of just 2 per cent in rooting depth would increase wheat yield in the low-rainfall condition, and that preserving water in deeper layers during early growth increased yield by increasing the amount of water available at, and after anthesis. Jeong *et al.* (2013) reported that transgenic rice plants had increased root diameter and this resulted in increase in yield up to 26 per cent. Kashiwagi *et al.* (2015) reported that root depth conferred yield advantages in chickpea grown under terminal drought stress.

Conclusion:

The experimental material entailed *Triticum aestivem* (L.) highest root length, root volume and root diameter line Lok 1 and GW 496 that was crossed to a lowest root length, root volume and root diameter line GW 444 and GW 445 to develop F_1 and subsequently F_2, BC_1 and BC_2 populations. The phenotyping of root length, root volume and root diameter was done by trench method and later analyzed by WinRHIZO (Image Analyzer Software). Wheat genotypes Lok 1 and GW 496 possessed higher root length (14295 and 12352 cm, respectively), root volume (188 and 156 cm^3, respectively) and root diameter (0.79 and 0.77 mm, respectively). Similarly lower value for root length (3125 and 4571 cm, respectively), root volume (34 and 44 cm^3, respectively) and root diameter (0.50 and 0.51 mm, respectively) were exhibited by wheat genotypes GW 444 and GW 445. There were significant differences for mean values of root length, root volume and root diameter between parental lines (P_1 and P_2) of Lok 1 x GW 445 and GW 496 x GW 444. The F_1 of Lok 1 x GW 445 and GW 496 x GW444 crosses had root length (11245 and 10487 cm), root volume (160 and 155 cm^3) and root diameter (0.69 and 0.60 mm), respectively. The F_2 individuals also showed a variation of root length (11478 and 9215 cm), root volume (172 and 150 cm^3) and root diameter(0.72 and 0.70 mm), respectively.

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