Pak. J. Bot., 39(5): 1523-1531, 2007.

GENOTYPIC DIFFERENCES FOR ALLOMETRIC RELATIONSHIPS BETWEEN ROOT AND SHOOT CHARACTERISTICS IN CHICKPEA (*CICER ARIETINUM* L.)

A .GANJEALI[1] AND M. KAFI[2]

[1]Research Center for Plant Science, Ferdowsi University of Mashhad, P.O. Box: 91775-1491, Iran
E-mail: ganjeali@um.ac.ir Fax: 0511-8787670,
[2]Department of Agronomy, Faculty of Agriculture, Ferdowsi University of Mashhad,
P.O. Box: 91775-1163, Iran
Corrresponding: E-mail: m.kafi@ferdowsi.um.ac.ir ,

Abstract

The study was conducted at the Research Greenhouse of Ferdowsi University of Mashhad. Twenty genotypes of chickpea were grown in pots (10×100 cm). Root traits including, total root length (TRL), number of lateral roots (NLR), root area (RA) and ratios of root dry weight (RDW) to root volume (RV) and leaf area (LA) to (RA) only at the seedling stage and root traits such as tap root length (TL), RVand RDW and shoot traits including, height of plant (H), leaf area (LA), leaf dry weight (LDW), stem dry weight (SDW) and root/shoot ratio at the seedling to seed filling were determined. Significant differenece were found in TI, TRL, NLR, RA, RDW at the seedling stage. The triats RV, NLR, RA, RDW and RA showed significant and positive correlation with TRL at the seedling stage. No correlation was found between root traits at the seedling stage with the same traits at the flowering, podding and seed filling stages. In the seedling stage the highest linear regression correlation between TRL and RA (r^2=*0.91*), between TRL and RV (r^2=*0.81*), between RV and RA (r^2=*0.82*) and between TRL and NLR (r^2=*0.84*) were found. The correlation coeffiicent of RV versus H was 0.89, 0.81 and 0.94 at the flowering, podding and seed filling stages, respectively. There was a significant correlation between RDW and RV at the flowering (r^2=*0.55*) and podding stages(r^2=*0.56*). Since RV, RA and RDW are easy to measure and has the highest correlation with the TRL at the seedling stage, therefore we will be able to use from equations produced for TRL estimation in this stage. These parameters are the major criteria for selection of drought resistance.

Introduction

Root and shoot relations and their interactions can be determined and quantified by allometric relationships (Niklas, 1994; Castelan *et al.,* 2002). The information available about the root systems is inadequate when compared to the information gained about the shoot systems. This is because measuring and estimation of root characteristics under field condition is much more difficult than those of shoots (Kashiwagi *et al.,* 2006). In an experiment, maximum variation in root dry weight and root length density between chickpea cultivars occurred in the seedling stage and those variations reduced to 41 days after sowing (Krishnamurthy *et al.,* 1998).

In order to obtain plants with higher seminal roots to improve drought tolerance, the parent material should have more seminal roots (Dorofev & Tyselenko, 1982). However, Hittinger & Engels(1986) noted that the tolerant genotypes have the longest tap root, total root length and the highest root dry weight in 16 days barley plants. They emphasized that length of the longest seminal root appeared to be the most suitable marker in selecting drought resistant plants. Gupta (1984) stated that screening for improvement of primary roots (seminal roots) vigor is an important criterion for selecting drought resistant genotypes. These scientists also emphasized that the number of seminal roots is a highly important trait for screening drought resistant genotypes. In a study of 31 chickpea genotypes, Gupta (1984) reported that in dry condition, genotypes that showed more root length in a particular unit of biomass were more resistant to drought stress.

In many plants genetic differences in root and shoot systems often display in early growth and we can use this trait as a suitable and easy method in breeding programs (Gregory *et al.,* 1988; Richner *et al.*, 1996; Huang *et al.,* 2000). Determination of root characters and gathering whole root from the soil in the field is time consuming and expensive. So, quicker and lower cost methods must be applied in screening and breeding programmes for ideal root and shoot systems. The objective of this study was to examine the differences between roots and shoot characteristics and correlation between 20 genotypes of chickpea in order to apply this relation in future modeling efforts for predicting main root and shoot performance.

Material and Methods

This study was conducted in 2004 growing season in the Research Greenhouse of the Faculty of Agriculture, Ferdowsi University of Mashhad, Iran. Seeds of 20 conventional Iranian genotypes of chickpea including MCC1, MCC2, MCC4, MCC358, MCC76, MCC392, MCC29, MCC362, MCC30, MCC443, MCC361, MCC40, MCC405, MCC429, MCC447, MCC426, MCC1261, MCC463, MCC458 and MCC32 were grown in sand contained in pots (10×100 cm). Nutrient elements were supplied by using modified Hoagland nutrient solution to each pot. Four seeds were planted in each pot.

The experiment was arranged in a randomized complete block design with three replications. In seedling (20 day after planting), flowering, podding and seed filling stages pots were broken and plants were separated into shoots and roots. Roots were washed and gathered exactly and transferred to a refrigerator immediately after harvesting at each stage. Each shoot was separated into leaf and stem. Leaf area was measured with a leaf area meter. Then roots and shoots were oven dried for 48h at 72˚C and weighed. Root traits including, total root length (TRL), number of lateral roots (NLR), root area (RA), ratios of root dry weight (RDW) to root volume (RV) and LA to RA only at the seedling stage and root traits such as tap root length (TL), RV, RDW and shoot traits including, height of plant (H), leaf dry weight (LDW), stem dry weight (SDW) and root/shoot ratio at seedling to seed filling were measured. Leaf and root areas were measured with a Scanject Delta Scanner connected to a computer for analysis and calculation. Root volume was calculated based on different volumes generated in a determined volume of water. Data were analyzed using Mstat C and Excel software and means were compared by Duncan Multiple Range Test ($p \leq 0.05$). Regression analysis was carried out and correlation coefficients were calculated using JMP software.

Results and Discussions

Seedling stage: Significant differences were observed in TL, TRL and NLR amongst 20 chickpea genotypes (Table 1). TL ranged from 6.8 cm in MCC447 to 15.4 cm in MCC358; TRL ranged from 28.2 cm in MCC447 to 80.8 cm in MCC358 and NLR ranged from 6.3 in MCC1261 to 16.7 in MCC361 genotype. These results indicated that variation in TRL was more than that in TL and NLR, so we will be able to search greater genetic diversity in TRL than the TL and NLR. Higher TRL is an important characteristic for a plant enabling it to absorb more water from different layers of the soil but of course increasing root length is a cost for a plant, which must not be neglected (Gupta, 1984; Gregory, 1988; Sarker & Erikson, 2000; Serraj *et al*., 2004).

Table 1. Mean root characteristics including tap root length (TL), total root length (TRL), number of lateral roots (NLR), root area (RA), root volume (RV), root dry weight (RDW), root to shoot ratio (R/S) and root dry weight to root volume ratio (RDW/RV) at seedling stage of chickpea.

Genotypes	RDW (g)	TL (cm)	TRL (cm)	NLR	RA (cm^2)	RV (cm^3)	R/S	RDW/ RV
MCC358	0.067 a *	15.38 a	80.77 a	16.13 ab	6.94 a	0.71 a	1.05 ab	0.094 b
MCC32	0.059 ab	13.32 abcd	59.77 abc	13.67 ab	5.25 abc	0.45 abc	1.33 a	0.108 b
MCC30	0.056 ab	10.45 abcd	73.12 ab	13.33 ab	4.48 abc	0.56 abc	1.35 a	0.041 b
MCC1261	0.056 ab	8.36 bcd	46.13 abc	6.33 c	4.74 abc	0.36 bc	1.12 ab	0.155 a
MCC361	0.054 ab	10.50 abcd	75.85 ab	16.68 a	5.80 abc	0.55 abc	0.94 cd	0.098 b
MCC76	0.054 ab	9.55 abcd	77.53 a	9.33 bc	5.90 abc	0.56 abc	0.94 cd	0.096 b
MCC463	0.053 ab	9.62 abcd	44.56 abc	15.00 ab	4.63 abc	0.50 abc	1.08 ab	0.106 b
MCC429	0.049 ab	13.92 abc	50.88 abc	15.67 ab	4.57 abc	0.41 abc	0.72 cd	0.119 b
MCC458	0.047 ab	12.30 abcd	58.07 abc	9.66 bc	4.91 abc	0.48 abc	1.30 a	0.097 b
MCC426	0.046 ab	11.52 abcd	57.70 abc	11.67 ab	5.12 abc	0.65 abc	0.84 cd	0.070 b
MCC29	0.043 ab	14.90 ab	65.02 abc	16.00 ab	5.12 abc	0.48 abc	0.72 cd	0.089 b
MCC362	0.041 ab	11.63 abcd	58.72 abc	11.33 ab	4.68 abc	0.43 abc	0.84 cd	0.095 b
MCC1	0.041 ab	10.42 abcd	58.63 abc	13.15 ab	5.42 abc	0.50 abc	0.76 cd	0.082 b
MCC392	0.038 ab	11.25 abcd	49.03 abc	14.00 ab	4.30 abc	0.41 abc	0.75 cd	0.092 b
MCC4	0.037 ab	8.60 abcd	36.75 bc	10.89 bc	3.55 bc	0.35 bc	0.87 cd	0.105 b
MCC2	0.036 ab	10.46 abcd	57.96 abc	12.35 ab	4.38 abc	0.50 abc	0.67 cde	0.072 b
MCC40	0.035 ab	7.66 cd	65.77 abc	11.33 ab	4.55 abc	0.38 bc	0.84 cd	0.092 b
MCC443	0.034 ab	14.30 abc	54.85 abc	15.00 ab	4.88 abc	0.33 c	0.76 cd	0.103 b
MCC405	0.024 b	6.75 d	44.85 abc	16.33 a	3.30 bc	0.31 c	0.47 e	0.077 b
MCC447	0.024 b	6.75 d	28.22 c	9.70 bc	3.18 c	0.30 c	0.73 cd	0.093 b

*Values with the same letter within a column are not significantly different ($p \leq 0.05$).

Significant differences were found among genotypes in RV, RA and RDW (Table 1). The value of RA, RV and RDW was highest in MCC358 and lowest in MCC447 genotype, respectively. Variation range in RV and RA was more stable among the chickpea genotypes. A high root area will increase water and nutrition absorption by developing interaction points for water and elements transportation in root, probability.

There was a remarkable but often no significant differences among 20 genotypes in leaf area per plant. LA ranged from 4.2 cm^2 in MCC429 to 1.6 cm^2 in MCC4 genotypes (Table 2). These results show that LA is nearly uniform among the genotypes at the seedling stage. More assimilate partitioned to the root than the shoot may be the main reason for disappearing genetic differences in early growth of plants.

Change in leaf dry weight was similar to leaf area pattern and it was highest and lowest in MCC429 and MCC4 genotypes, respectively (Table 2). Variation range for this character is small but with increasing plants age, genetic differences will be more significant and genotypes differences will increase.

The highest stem dry weight was observed in MCC429 genotype and had a significant difference with MCC392, MCC405, MCC447, MCC463 and MCC458 genotypes, but not significant with the rest ($p \leq 0.05$). SDW reduced from 0.029 g (highest) in MCC429 genotype to 0.01 g (lowest) in MCC458 genotype (Table 2). In legumes, faster root growth rate due to more assimilate partitioning to the root than the shoot in early growth stages might be the main reason for uniformly shoot characters in the seedling stage (Gregory, 1988).

Table 2. Mean shoot characteristics including, height of seedling (H), leaf dry weight (LDW), stem dry weight (SDW), leaf area (LA) and leaf area to root area ratio (LA/RA) at seedling stage of chickpea.

Genotypes	LA (cm^2/plant)	H (cm)	LDW (g/plant)	SDW (g/plant)	LA/RA (cm^2/cm^2)
MCC429	4.190* a	11.27 a	0.039 a	0.029 a	0.922 a
MCC32	3.930 a	8.36 cd	0.029 a	0.024 ab	0.748 ab
MCC1261	3.510 ab	9.15 bcd	0.027 a	0.023 ab	0.740 ab
MCC361	3.150 ab	9.43 abcd	0.031 a	0.019 b	0.543 ab
MCC405	3.100 ab	9.70 abcd	0.031 a	0.018 b	0.941 a
MCC392	2.970 ab	9.07 bcd	0.032 a	0.018 b	0.691 ab
MCC29	2.920 ab	10.08 abcd	0.037 a	0.022 ab	0.570 ab
MCC426	2.900 ab	9.93 abcd	0.031 a	0.019 b	0.567 ab
MCC443	2.590 ab	10.52 ab	0.025 a	0.023 ab	0.531 ab
MCC458	2.560 ab	8.30 cd	0.026 a	0.010 c	0.524 ab
MCC358	2.530 ab	9.40 abcd	0.032 a	0.026 ab	0.364 b
MCC447	2.370 ab	11.30 a	0.019 b	0.019 b	0.744 ab
MCC40	2.360 ab	10.52 ab	0.023 ab	0.026 ab	0.518 ab
MCC362	2.330 ab	9.91 abcd	0.027 a	0.021 ab	0.498 ab
MCC1	2.260 ab	9.61 abcd	0.029 a	0.024 ab	0.416 ab
MCC2	2.230 ab	9.87 abcd	0.029 a	0.022 ab	0.516 ab
MCC30	2.200 ab	10.40 abc	0.027 a	0.023 ab	0.340 b
MCC76	2.100 ab	3.03 e	0.031 a	0.026 ab	0.356 b
MCC463	1.690 b	8.21 d	0.029 a	0.020 b	0.365 b
MCC4	1.620 b	2.39 e	0.019 b	0.023 ab	0.457 ab

*Values with the same letters within a column are not significantly different ($p \leq 0.05$).

Significant differences were found in root to shoot (R/S) ratio among the genotypes. MCC30 and MCC405 genotypes showed the highest and the lowest R/S ratio, respectively (1.35 vs 0.47) (Table 1). Gregory (1988) in studying chickpea seedlings reported that R/S ratio decreased from 0.83 in the seedling stage to 0.13 at the time of maturity. Conversely, in maize Derieux *et al*., (1989) found that R/S ratio decreased until 2-leaf stage. It seems that, at the transition to autotrophic growth, shoot growth strongly dominates to root growth, because the first assimilate are preferentially used for leaf growth. In early growth stages, root system in grain legumes usually is heavier than that in cereals, therefore, R/S is also higher in this stage.

Since, leaf area largely determines the light interception and transpiration, root surface area is an important trait for the uptake of nutrients and water, so LA/RA ratio is a better measure of the functional relationships between shoot and root than are dry-matter based ratios (Stamp, 1984). There was a significant difference for LA/RA in the 20 genotypes and MCC405 that had lowest R/S ratio, showed the highest LA/RA (Table 2). Lower root area in MCC405, might be the main reason for high LA/RA. The lowest LA/RA was observed in MCC30.

Root dry weight/Root volume (RDW/RV in MCC4, MCC443, MCC463, MCC1261 and MCC32 genotypes was higher than the other genotypes, but only MCC1261 showed a significant difference with the rest (Table 1). RDW/RV as a useful criterion for evaluation of drought resistant genotypes may be considerable. We could not find any similar study in the literature.

Flowering to seed filling stages: Significant differences were observed in TL, RDW and R/S ratio among the 20 genotypes at the flowering stage. The highest and the lowest TL belonged to MCC426 and MCC392. RDW ranged between 0.60 g in MCC426 and 0.3 g in MCC2 and R/S ratio ranged from 1.4 in MCC76 to 0.6 in MCC2 genotypes (Table 3). Despite that the MCC358 had the highest TL, RV and RDW at the seedling stage (Table 1), but these traits were the highest in MCC426 at the flowering stage. Significant differences were found in TL, RDW and R/S ratio at the podding stage (Table 3). R/S ratio were the highest in MCC76 genotype in flowering to seed filling stages and generally this ratio decreased from seedling to maturity in all genotypes. These results are in agreement with those of Gregory (1988).

Genotypes significantly showed variation in LA, LDW and SDW on different growth stages (Table 4). More genotypic diversity on shoot than the root traits after the seedling stage were found. There are a 1.3, 2.6 and 2.2 fold difference between the highest and the lowest values for LA, LDW and SDW, respectively at the flowering stage (Table 4). The higher TRL, TL and RDW in the seedling stage were probably reflected in greater LA, LDW and SDW at the flowering stage. Generally we found more genotypic differences in shoot traits at flowering to seed filling than the seedling stage.

Different strategies for continuous assimilates transporting to the roots and increasing leaf area duration or blocking assimilates transporting and shifted that to the sinks (growing seed), are the strategies that might be used by genotypes. Different strategies conducting by different genotypes during different growth stages possibly are the reasons for unstable trend in a particular trait. Vincent & Gregory (1986) reported that, there are high genotypic differences in root traits of chickpea genotypes, but these traits may be unstable at further stages. So in order to screen a trait, selection must be done at the phenology of growth, which is most effective.

Correlations between root and shoot characters at the seedling stage are shown in Fig. 1. There was positive and high significance correlation between root characteristics. The highest linear regression correlation (r^2=0.91) belongs to RA versus TRL, so we will expect that total root length would be estimated with a minimum error by this equation $y = -9.23+13.37x$ (Fig 1a). Weak correlation between RA and LA ($r^2=0.35$) and between RDW and LDW ($r^2= 0.38$) indicated that assimilates partitioning to root and to the shoot is unbalanced and roots are the more strong sink for obtaining assimilates than the shoot in the seedling stage. Gregory (1988) showed that root dry weight as a fraction of whole plant biomass (Root plus Shoot) reduced from 0.5 - 0.9 in early growth to 0.13 at maturity. Serraj *et al*., (2004) observed linear relationships between root dry weight and shoot dry weight at 35 days after sowing and for shoot biomass and seed yield at maturity. Stem dry weight (SDW) had no significant correlation with height of seedling ($r^2=0.14$). These results indicated that, height and stem diameter are independent of SDW at the seedling stage. Results from regression analysis showed that there isn't significant correlation between RDW and TL at the seedling stage ($r^2= 0.12$), It seems likely that tap root length, is independent of root dry weight at the seedling stage. It must be noted that in early growth stage, R/S ratio in grain legumes is more than that in cereals (Gregory *et al*., 1988). Serraj *et al*., (2004) reported a significant genetic variation among genotypes of chickpea for root dry weight and shoot dry weight at 35 days after plantation.

Table 3. Mean root characteristics including root dry weight (RDW), tap root length (TL) and root/shoot ratio at flowering, podding and seed filling stages in 20 genotypes of chickpea grown in sand culture.

	Flowering stage				Podding stage				Seed filling stage		
Genotype (MCC number)	RDW (g)	TL (cm)	R/S	Genotype (MCC number)	RDW (g)	TL (cm)	R/S	Genotype (MCC number)	RDW (g)	TL (cm)	R/S
426	0.60* a	91.7 a	1.0 a-d	358	0.59 a	88.0 ab	0.9 a-c	426	0.85 a	108.8 ab	0.46 bc
358	0.56 ab	84.3 ab	1.0 a-d	447	0.57 a	86.0 ab	0.8 a-c	4	0.77 ab	90.8 cd	0.64 a-c
1261	0.55 a-c	79.5 ab	1.1 a-c	429	0.56 a	79.0 bc	0.9 a-c	29	0.65 bc	114.0 a	0.56 a-c
30	0.52 a-d	83.3 ab	1.1 a-c	1261	0.55 a	98.2 a	0.8 a-c	443	0.62 b-d	93.8 b-d	0.61 a-c
429	0.49 a-d	80.0 ab	0.9 a-d	426	0.52 ab	91.0 ab	0.9 a-c	361	0.60 b-d	96.3 b-d	0.40 bc
29	0.49 a-d	80.9 ab	1.0 a-d	361	0.52 ab	91.7 ab	0.8 a-c	358	0.59 b-e	89.6 d	0.44 bc
76	0.49 a-d	73.1 ab	1.4 a	76	0.52 ab	87.3 ab	1.2 a	463	0.59 b-e	100.4 a-d	0.37 bc
40	0.49 a-d	73.2 ab	1.3 ab	362	0.50 a-c	99.7 a	0.8 a-c	405	0.54 c-e	99.7 a-d	0.32 c
1	0.47 a-e	81.6 ab	1.0 a-d	463	0.49 a-c	101.3 a	0.8 a-c	447	0.53 c-e	100.7 a-d	0.60 a-c
32	0.45 a-e	79.8 ab	0.9 a-d	32	0.49 a-c	101.3 a	0.9 a-b	458	0.53 c-f	100.5 a-d	0.47 bc
447	0.41 b-e	74.9 ab	0.8 cd	40	0.43 a-c	87.2 ab	0.9 a-b	76	0.49 c-f	106.0 ab	0.90 a
458	0.41 b-e	72.3 b	1.0 a-d	4	0.42 a-c	98.0 a	0.7 a-c	40	0.49 c-f	105.3 ab	0.48 bc
362	0.39 b-e	76.6 ab	0.9 a-d	1	0.40 a-c	78.8 bc	1.0 ab	32	0.48 c-f	88.3 d	0.64 a-c
361	0.38 c-e	69.8 b	0.9 a-d	29	0.40 a-c	87.3 ab	0.9 a-c	1	0.46 c-f	102.0 a-d	0.70 ab
463	0.38 c-e	83.3 ab	1.0 a-d	405	0.40 a-c	92.7 ab	0.8 a-c	1261	0.46 c-f	106.1 ab	0.58 a-c
443	0.37 c-e	82.3 ab	1.0 a-d	458	0.40 a-c	64.6 c	0.8 a-c	392	0.45 c-f	93.6 b-d	0.70 ab
392	0.37 c-e	67.8 b	0.8 cd	30	0.38 a-c	92.3 ab	0.7 a-c	30	0.43 d-f	97.8 b-d	0.52 a-c
405	0.35 de	72.2 b	0.9 a-d	443	0.32 bc	64.5 c	0.6 bc	362	0.39 ef	109.1 ab	0.46 bc
4	0.31 e	75.0 ab	1.0 a-d	2	0.31 bc	87.7 ab	0.5 c	2	0.39 ef	100.5 a-d	0.37 bc
2	0.29 e	78.3 ab	0.6 d	392	0.28 c	92.1 ab	0.5 c	429	0.30 f	72.1 e	0.39 bc

* Values with the same letters within a column are not significantly different ($P \leq 0.05$).

Table 4. Mean shoot characterisics including leaf area (LA), leaf dry weight (LDW), stem dry weight (SDW) at the flowering, podding and seed filling stages in 20 genotypes of chickpea grown in sand culture.

	Flowering stage				Podding stage				Seed filling stage		
Genotype (MCC number)	LA (cm^2/plant)	LDW (g/plant)	SDW (g/plant)	Genotype (MCC number)	LA (cm^2/plant)	LDW (g/plant)	SDW (g/plant)	Genotype (MCC number)	LA (cm^2/plant)	LDW (g/plant)	SDW (g/plant)
426	41* a	0.32 a	0.30 a	1261	79 a	0.42 ab	0.39 ab	426	171 a	0.97 a	0.76 ab
458	34 ab	0.23 b-d	0.18 g-i	463	72 ab	0.37 bc	0.26 d-h	361	144 ab	0.78 b	0.86 a
429	34 ab	0.31 a	0.26 b-c	2	62 a-c	0.32 c-f	0.27 d-h	463	118 bc	0.67 bc	0.81 ab
29	34 ab	0.27 a-c	0.21 d-g	362	62 a-c	0.34 b-d	0.35 a-d	443	113 b-d	0.54 cd	0.66 a-c
2	33 ab	0.27 a-d	0.22 c-e	361	61 a-c	0.48 a	0.24 e-h	4	113 b-d	0.53 cd	0.57 b-d
30	32 ab	0.26 a-d	0.22 c-e	4	59 b-d	0.31 c-g	0.28 c-h	458	106 c-e	0.56 cd	0.61 a-d
447	31 ab	0.28 ab	0.27 ab	392	57 b-e	0.27 c-h	0.29 c-g	29	105 c-f	0.47 de	0.55 b-d
392	30 ab	0.28 ab	0.24 b-d	30	51 c-f	0.26 d-h	0.40 a	358	103 c-f	0.52 cd	0.53 b-d
358	30 ab	0.26 a-d	0.27 ab	426	46 c-g	0.33 c-e	0.26 d-h	40	91 c-g	0.51 cd	0.76 ab
463	30 ab	0.21 b-e	0.16 hi	32	45 c-h	0.27 d-h	0.33 a-e	392	88 c-h	0.41 de	0.56 b-d
32	29 ab	0.23 b-d	0.22 c-e	429	43 c-i	0.31 e-g	0.30 c-g	405	81 c-i	0.44 de	0.72 ab
1261	29 ab	0.25 a-d	0.24 b-d	443	40 d-i	0.24 d-h	0.29 c-h	362	78 d-g	0.38 de	0.62 a-d
1	28 b	0.26 a-d	0.25 b-d	358	39 e-i	0.29 c-h	0.34 a-d	76	73 e-g	0.36 de	0.36 d
443	27 bc	0.21 b-e	0.20 e-h	447	39 e-i	0.29 c-h	0.37 a-c	1	73 e-g	0.39 de	0.55 b-d
361	26 bc	0.22 b-d	0.21 d-g	405	33 f-i	0.24 e-h	0.26 d-h	2	66 fg	0.43 de	0.66 a-c
362	25 bc	0.21 b-e	0.20 e-h	458	32 f-i	0.27 d-h	0.22 f-h	1261	59 g-j	0.37 de	0.62 a-d
76	23 bc	0.19 de	0.18 g-i	40	29 g-i	0.23 f-h	0.20 gh	32	56 g-j	0.42 de	0.57 b-d
40	22 bc	0.20 c-e	0.19 e-i	76	28 g-i	0.23 g-h	0.30 c-g	30	51 h-j	0.41 de	0.81 ab
405	21 bc	0.20 c-e	0.18 g-i	29	26 h-i	0.22 g-h	0.20 h	429	48 ij	0.29 e	0.4 cd
4	16 c	0.14 e	0.15 i	1	24 i	0.20 h	0.20 gh	447	39 j	0.27 e	0.79 ab

* Values with the same letters within a column are not significantly different ($P \leq 0.05$).

Different responses and strategies implemented by genotypes at different growth stages might be the main reason for non-significant correlation between root traits at different growth stages. Because RV, RA and RDW are easy to measure at the seedling stage and have the highest correlation with the TRL, we can, therefore, use the regression equations to estimate TRL at the seedling stage. This trait is the major criterion for selection of drought resistant genotypes. TRL observed and estimated by regression equations with variables such as RA (a), RV (b), RDW(c) and NLR (d) at the seedling stage are shown in Fig. 2. In all equations, there were no significant differences between estimated and observed TRL values. Therefore, we will be able to estimate root characters based on other characters by regression equation that have been produced in this experiment. We can also comprise estimated and observed values that were measured by direct methods together.

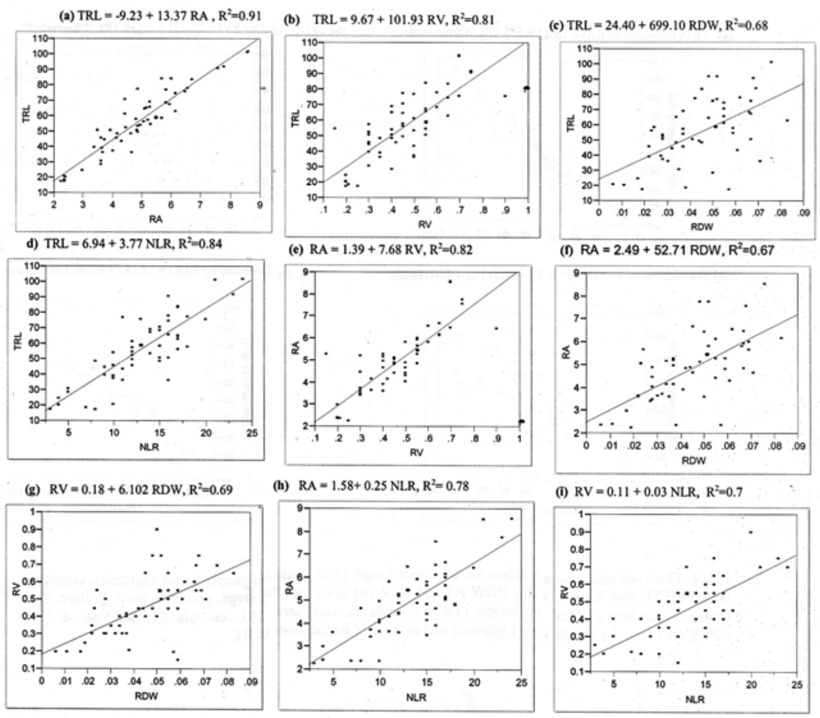

Fig. 1. Relationships amongst chickpea root characteristics including: total root length (TRL) (cm/plant), root area (RA) (cm^2/plant), root volume (RV) (cm^3/plant), root dry weight (RDW) (g/plant) and number lateral roots (NLR).

It seems that at the autotrophic growth or early growth stage, root growth strongly dominates to shoot growth and assimilates are preferentially used for root growth. Due to the phenology of growth, the genotypes showed different responses, so we didn't find uniform changes for root traits at different growth stages among the genotypes for introducing high performance genotypes throughout the growing season. So in order to screen a trait, selection must be done at the phenology of growth, which is most effective. In chickpea seedlings, there is a high significant linear regression between total root length (TRL) with another root characters such as root area (RA), root volume (RV), number of lateral roots (NLR) and root dry weight (RDW). Since RV, RA and RDW are easy to measure and have high correlation with the TRL, we can, therefore use the regression equations to estimate TRL. TRL is an important criterion for selection of drought resistant genotypes. A linear regression of root traits at the seedling stages with flowering, podding and seed filling stages showed non-significant correlation. Different responses and strategies conducted by genotypes at different growth stages might be the main reason for these different reactions.

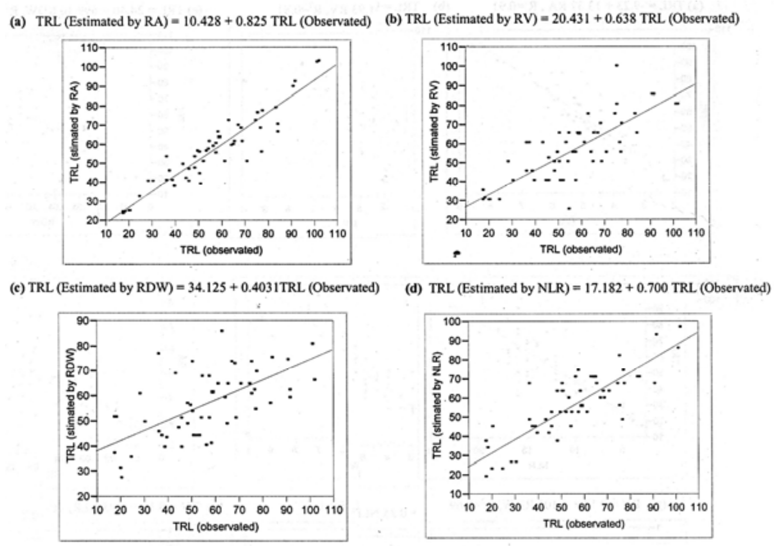

Fig. 2. Observed and estimated values for total root length (TRL) based on simple linear regression equations, between TRL and RA (a), RV(b), RDW (c) and NLR (d) at the seedling stage, grown in sand culture. Root characters including: total root length (TRL) (cm/plant), root area (RA) (cm^2/plant), root volume (RV) (cm^3/plant), root dry weight (RDW) (g/plant) and number of lateral roots (NLR).

References

Castelan, M., P. Vivin and J.P. Gaudillere. 2002. Allometric relationships to esitimate seasonal above ground vegetative and reproductive biomass of (*Vitis vinifera* L.). *Ann. Bot*., 89: 401-408.

Derieux, M., R, Bourdu, J.B. Duburcq and H. Boizard. 1989. Early growth of maize seedlings at low temperatures (In French, with English abstract.). *Agronomie*, 9: 207-212.

Dorofev, V.F. and A.M. Tyslenko. 1982. Number of seminal roots in spring wheat in the course of selecting pairs for hybridization. *Veestnik Seleskokhozyaistvennoi nauki*, 8: 50-56.

Gregory, P.J. 1988. Root growth of Chickpea, faba bean, lentil and pea and effcets of water and salt stresses. PP. 857-867. In: *World Crops: Cool Season Food Legumes*. (Eds.): R.J. Summerfield Kluwer Academic Publishers.

Gupta, U.S. 1984. Crop improvement for drought resistonce. *Curr. Agric*., 8: 1-15.

Hettinger, B. and J.M.M. Engels. 1986. Screening methods for drought resistance in indigenous Ethiopian barely. II. The use of Plexiglass container. *PGRC/E-ILCA Germplasm Newsl*., 3: 26-30.

Huang, B. and H. Gao. 2000. Root physiological characteristics associated with drought resistance in tall fescue cultivar. *Crop Sci*., 40: 196-203.

Kashiwagi, J., L. Krishnamurty, J.H. Croouch and R. Serraj. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L.) under terminal drought stress. *Field Crops Res*., 95: 171-181.

Krishnamurty, L., O. Ito, C. Johansen and N.P. Saxena .1998. Length to weight ratio of chickpea roots under under progressively receding soil moisture condition in a verti soil. *Field Crops Res*., 58: 177-185.

Niklas, K.J. 1994. *Plant Allometery. The Scaling of Form* and *Process*. Chicogo, USA. The University of Chicogo Press.

Richner, W., A. Soldati and P. Stamp. 1996. Shoot to Root relation in field grown maize seed lings. *Agron. J*., 88: 56-61.

Sarker, A and W. Eriksin. 2000. Drought tolerance in lentil: Root parameters. 3rd International Crop Science Congress 2000. Hamburg Germany.

Serraj, R., L. Krishnamurty, J. Kashiwagi, J.K. Kumar, S.Chandra and J.H. Crouch. 2004. Variation in root traits of chickpea (*Cicer aretinum* L.) grown under terminal drought. *Field Crops Res*., 88: 115-127.

Stamp, P. 1984. Chilling tolerance of young plants demonstrated on the example of maize (*Zea mays* L.). *Adv. Agron. Crop Sci*., 29: 7 (Suplemens to J. Agron. Crop. Sci.). Paul. Berlin.

Vincent, C. and P. J. Gregory. 1986. Differences in the growth and development of chickpea seedling roots. *Exp. Agric*., 22: 233-242.

(Received for publication 20 June 2007)