

Root Development at Different Growth Stages of Wheat and Barley Cultivars Grown in Tubes under Field Environmental Conditions

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Authors' contributions

This work was carried out in collaboration between both authors. Authors HA and AT designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors HA and AT managed the literature searches and analyses of the study performed the spectroscopy analysis. Author HA managed the experimental process and author AT identified the species of the plant. Both authors read and approved the final manuscript.

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ABSTRACT

This work was conducted to investigate root length and biomass developments at three different growth stages of GS 31 (stem elongation), GS 69 (complete of anthesis) and GS 92 (full grain maturity) of two cultivars for each of bread wheat (*Triticum aestivum* cv. Konya 2002 and Gerek 79), durum wheat (*Triticum durum* cv. Çeşit 1252 and Kunduru 1149) and barley (*Hordeum vulgare* conv. *distichon* cv. Larende and Karatay 94) that were grown under irrigated and non-irrigated field conditions during 2011-2012 and 2012-2013 growing seasons. It was found significant differences for genotype, year and growth stage with regard to root length and biomass. Average root length of cereal genotypes at GS 31, GS 69 and GS 92 reached up to 204.7, 236.1 and 230.3 cm, respectively. According to species, at GS 69 average root length of bread wheat, durum wheat and

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barley was found 226.0, 237.0 and 227.0 cm, respectively. Barley root was as long as wheat, even barley had larger root system depending on different growth stages than wheat. For bread wheat, durum wheat and barley, 86.5, 77.3 and 92.5% of the root length and 31.9, 37.0 and 33.9% of root biomass were respectively formed up to the stage of stem elongation. The results showed that a considerable part of root length constituted up to GS 31, however that of root biomass was between GS 31 and GS 92. In conclusion, root length and root biomass developments were considerably affected by plant growth stages, genotypes, and environmental conditions.

Keywords: Bread wheat; durum wheat; barley; root length; root biomass; growth stage.

1. INTRODUCTION

Roots have a basic importance for absorption of water and nutrients and for their translocation to shoot. However, researchers generally have avoided study of root systems because root research requires a lot of time and intensive labor. There is also the difficulty to interpret environmental interactions between root and shoot traits.

Different aspects among the researchers exist about how crops have roots. Deep rooted genotypes could take up water and nutrient from deeper soil layers, increasing yield of plants above ground [1,2,3]. Since root size is subject to environmental conditions, crops should have an ideal root system. Crops with large root systems take up much water and nutrient, but competition in root dry matter production by using more assimilates from the shoot may cause a decline in yield [4]. A smaller root system may be useful through water use efficiency where water is insufficient [5]. Root biomass is a significant trait and indicator of root size [6,7]. Accordingly, improvement in grain yield and quality is possible to be well known developments in root traits in different growth stages and in factors affecting it.

This work aimed to investigate developments in root length and biomass of durum wheat, bread wheat and barley cultivars during the different growth stages under field environmental conditions.

2. MATERIALS AND METHODS

2.1 Experimental Site, Soil and Weather Conditions

This research was conducted in Konya, Central Anatolian Region, Turkey, during 2011–2012 and 2012–2013 growing seasons. The research field is located at 38°15'58"N 32°24'23"E at altitude of 1061 above mean sea level. The soilless media as soil consisted of the mixture of peat (70%)

and perlite (30%). Soil samples were taken before sowing and analyzed for some chemical and physical parameters. The soil was used in both years. In the first year, soil at the experimental area has a loam texture and is slightly acidic, high in organic matter, and calcareous. It is adequate for K₂O, Zn, and Cu and high for Mg. In addition, P₂O₅ and Mn is found in the soil as very high. In the second year, soil has a loam texture and is slightly alkaline, very low in organic matter and calcareous. It is adequate for Mg and Zn, and very low for Cu, K₂O and P₂O₅. Mn is found as adequate. One more fertilization was applied to plots in the second year, not to expose plants to nutrient deficiency.

The climate of the Konya can be defined as semiarid continental. The monthly averages of soil and environmental meteorological data during the 2011-2012 and 2012-2013 experimental seasons and long term are given in Table 1 and Fig. 1, respectively.

According to the meteorological data in the region, there was 299.6 mm in the long term (2003-2013), 217.4 mm in the first year and 302.9 mm in the second year for rainfall, 11.7°C for the long term temperature, 10.4°C in the first year and 12.5°C in the second year for average annual temperature. In different soil depths (5, 10, 20, 50 ve 100 cm), soil temperature in the second year had commonly greater than that in the first year (Fig. 1)

2.2 Field Experiment and Plant Materials

The experiment was designed according to randomized complete block design with four replications. Field soil was dug about 2 m by a backhoe. We used 72 cylindrical PVC tubes about 200 cm in long and 12 cm in diameter during per growth stages (4 replications × 3 tubes per cultivar × 6 cultivars). The tubes were replaced to soil in 2 meter deep. Seeds were sown on November 11, 2012 and October 10,

2013 in the first year and second year, respectively. A plant in each tube was grown, followed by seedling emergence. We used two cultivars for each of bread wheat (*Triticum aestivum* cv. Konya 2002 and Gerek 79), durum wheat (*Triticum durum* cv. Çeşit 1252 and Kunduru 1149) and barley (*Hordeum vulgare* conv. *distichon* cv. Larende and Karatay 94), respectively of which one each for irrigated and dry (non-irrigated) field conditions. Plots were thoroughly watered before sowing in order to provide emergence. In spring, plants were watered with drip irrigation system at stem elongation (GS 31) and post flowering (anthesis) (GS 69) stages for the first year, while with one more watering at the tillering stage for the second year. During all irrigation applications, a fertilizer solution including 37.5 g urea (46% N), 64 g microelements (Cu, Fe, Mn and Zn), 11.8 cc humic acid for 216 tubes was applied with irrigation water through drip irrigation system. Also, at sowing, the fertilizer DAP (18% N, 46% P₂O₅) 130 kg ha⁻¹, was applied as topdressed to all tubes.

2.3 Measurement and Harvesting

Measurement and counting of roots were made at stages of GS 31 (stem elongation), GS 69 (complete of anthesis; post flowering) and GS 92 (full grain maturity). Root media with nylon cover was taken out from PVC tubes and then nylon cover was cut. Roots were washed with pressurized water, root length was measured as maximum root length of the longest root on a flat and then roots were dried in a forced oven at 80°C for 48 hour to record root biomass [8].

2.4 Statistical Analysis

The data were analyzed according to the randomized complete block model of ANOVA. Differences between means were assessed with the Least Significant Difference (LSD) test at $p = 0.01$ or 0.05 levels of significance. Statistical analyses were performed using the MSTAT-C statistical software package.

3. RESULTS AND DISCUSSION

Results of the variance analysis for the root length and root biomass of wheat and barley cultivars are given in Table 2 while the mean values of each group in the Table 3 and Table 4.

While the differences between the cultivars and years during stem elongation, the post flowering and full grain maturity in terms of root length were regarded considerable at $P < 0.01$ and the interaction of year and cultivar was considered important at $P < 0.01$ (Table 2).

The differences between the cultivars and years during stem elongation and full grain maturity in terms of root biomass were regarded considerable at $P < 0.01$, the interaction of year x cultivar was considered important at $P < 0.01$, however in the post flowering stage, the differences between the cultivars and the interaction of year x cultivar were considered important at $P < 0.05$ and the differences between the years were found important at $P < 0.01$ (Table 2).

Table 1. Precipitation and temperature during 2011–2012, 2012–2013 growth seasons and long term period from 2003 to 2013 in Sarayonu, Konya*

Months	Temperature (°C)			Precipitation (mm)		
	LT	2011-12	2012-13	LT	2011-12	2012-13
September	18.4	17.9	19.4	15.4	2.8	6.8
October	12.4	9.3	14.6	36.6	41.2	8.0
November	6.0	3.3	7.3	29.0	11.0	32.2
December	1.6	1.9	3.6	40.3	26.0	80.0
January	-0.3	-2.7	1.3	34.1	63.0	33.0
February	1.0	-2.9	4.8	23.1	9.0	21.0
March	5.5	2.6	6.9	26.4	16.0	18.0
April	10.5	12.8	10.6	27.3	6.4	38.5
May	15.8	14.8	17.1	29.9	42.0	61.0
June	20.5	21.2	20.1	29.2	0.0	4.4
July	24.3	24.6	22.3	6.8	0.0	0.0
August	23.5	21.5	22.5	1.6	0.0	0.0
Mean	11.7	10.4	12.5	–	–	–
Total	–	–	–	299.6	217.4	302.9

LT: Long Term

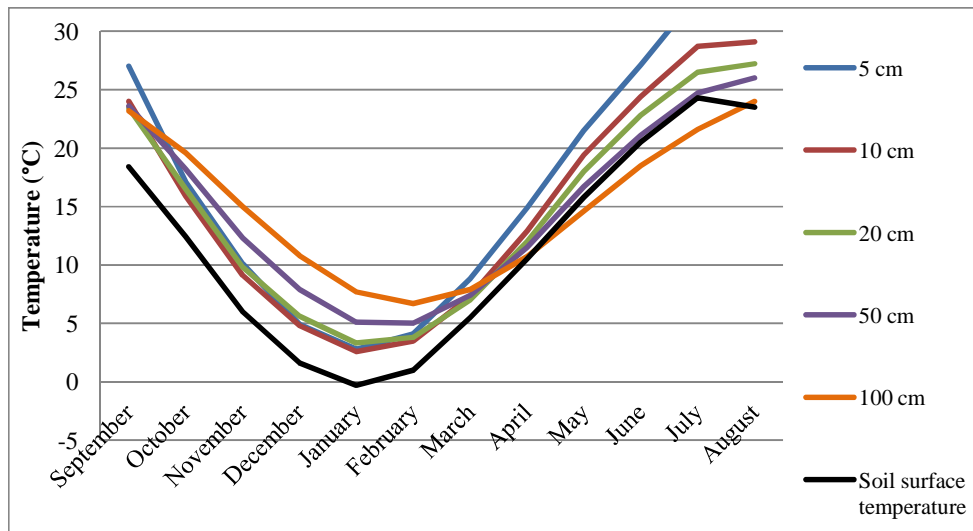


Fig. 1. Temperatures in different soil depths (5, 10, 20, 50 and 100 cm) and soil surface in long term (2003–2013) of Sarayonu, Konya

Table 2. Results of ANOVA for root length and root biomass in different growth stages of wheat and barley genotypes

S	DF	Root length			Root biomass		
		GS 31	GS 69	GS 92	GS 31	GS 69	GS 92
		M.S.	M.S.	M.S.	M.S.	M.S.	M.S.
R	3	9.9	86.0	15.8	0.017	0.561	0.316
Y	1	85885.9**	3230.8**	6088.5**	0.472**	26.107**	33.785**
G	5	793.2**	336.3**	271.6**	0.170**	1.336*	2.365**
Y*G	5	1136.4**	252.3**	285.4**	0.079**	1.236*	1.696**
E	33	24.8	60.2	48.5	0.015	0.401	0.104
G	47						
CV (%)		2.43	3.28	3.03	7.69	20.01	8.74

** $P < 0.01$, * $P < 0.05$, S: Sources, R: Replicaiton, Y: Year, G: Genoteype, E: Error, G: General

3.1 Root Length

In the stage of stem elongation of the first year, root length was observed to range from 157.5 to 169.4 cm for bread wheat cultivars, 137.7 to 160.8 cm for durum wheat cultivars and 173.7 to 175.2 cm for barley cultivars, while in the second year, it was from 253.1 to 263.8 cm for bread wheat cultivars, 240.2 to 267.3 cm for durum wheat cultivars and 228.5 to 229.1 cm for barley cultivars. From the two years average, Konya 2002, an irrigated cultivars of bread wheat, was found to have longer root length (216.6 cm) than Gerek 79 (205.3 cm), a non-irrigable cultivar. Similarly, durum wheat cultivar, Çeşit 1252 (214.0 cm), developed for irrigable conditions was observed to have longer root than Kunderu 1149 (189.0 cm). While there was no considerable difference between the irrigable and non-irrigable barley cultivars (201.1 cm and 202.2 cm) (Table 3).

Root length, measured during the post flowering stage in the first year of study, fluctuated between 248.7 and 257.2 cm in bread wheat, 239.3 and 239.8 cm in durum wheat and 237.8 and 243.1 cm in barley, while in second year, it was 229.3 and 232.4 cm for bread wheat, 219.8 and 244.4 cm for durum wheat and 219.5 and 222.3 cm for barley. According to the two-year averages, at the post flowering stage, bread wheat cultivars were found to have longer root systems than durum wheat and barley, but there was no considerable difference observed between two cultivars. While a non-irrigable durum wheat cultivar, Kunderu 1149 (241.8 cm) had longer roots than the irrigable cultivar, Çeşit 1252 (229.8 cm).

There was no remarkable difference between two barley cultivars during the stage of post flowering (Table 3). It has been shown that the root length of winter wheat reached up to 2 m at

the end of May [9] and that the wheat root system was not prevented from growing by the plough pan and the roots could be deep down up to 2.4 m. It has been stated that maximum root depth of winter wheat is 0.8 m in heavily argillaceous soil [9]; Miao et al. [10] reveals that root depth is 3.7 and can even reach up to 5 m in the Plateau Loess which is a non-irrigable semi dry land in China, while it is 1.6-1.8 m deep in the south of China where the rate of precipitation is higher [11].

During the maturity, the root length, in the first year ranged from 239.8 to 247.2 cm for bread wheat and 247.4 to 252.5 cm for durum wheat, while the case was 229.5 to 232.9 cm in barley cultivars. In second year, root length differed between 208.4 and 210.3 cm in bread wheat, 224.2 and 225.6 cm in durum wheat and 222.7 and 222.9 cm in barley. In accordance with the average values of two years, at the maturity stage the durum wheat was measured to have longer root systems than the cultivars of bread wheat and barley, yet there was no noteworthy difference between the cultivars. While the difference between two durum wheat cultivars mattered at the stage of post flowering, after this stage an increase was observed in the root length of irrigable cultivar, Çeşit 1252. Yet, root length during the maturity stage was observed to be quite close to each other (Table 3). The primary root length of the cultivar Kunduru 1149 is found to be longer than other bread and durum wheat cultivars [12]. According to the results shown from the study, while Kunduru 1149 was the shortest root length during the stem elongation stage among bread and durum wheat cultivars in each year of the study, it was observed to have a longer root length in each year during the stage of maturity. Botwright Acuna and Wade [13] stated in a study they carried out in order to detect the root depth and the interaction of genotype x environment in wheat genotypes that the interaction of genotype x environment in regions having different soil conditions affects root length considerably. Researchers observed that roots could deepen up to 2 m in sandy soil.

Bread wheat, durum wheat and barley during stem elongation had higher root length in the second year compared to the first by such properties 58.0, 70.3 and 31.2% respectively. The response to the climatic in terms of root length during the stage of stem elongation can be ordered as durum wheat > bread wheat > barley respectively. In the second year of the

study compared to the first year, it is possible that both the ground surface and the soil (5, 10, 20, 50 and 100 cm) temperatures follow a higher trend from the sowing to the stem elongation stage, in this process roots continue to grow and thus plants have a deeper root system (Table 3). As a matter of fact, Sharrat [14] revealed in the study carried out under controlled conditions in order to research the effect of the temperatures in different depth of barley root on both their root and shoot growth that the density of the root length showed a trend of increase with the increase in the soil temperature.

It was also pointed out in the study that, at stage of maturity, 93.2, 85.0 and 88.9% of the average root length of bread wheat, durum wheat and cultivars of barley were formed during the stage of stem elongation, respectively. While the root lengths of non-irrigated bread and durum wheat cultivars were formed more after the stage of stem elongation, barley cultivars had values close to each other (Table 3). In the first year of the study, root length of all cultivars increased till the post flowering stage, but subsequent to this phase, root length of bread wheat and barley cultivars decreased while an increase in the durum wheat cultivars was observed. While maximum root length was observed in the second year of the study to be during the stage of stem elongation and then decreased, but the increase in Kunduru 1149 was still seen. The root length of the cultivars with regard to the average of two years showed a trend of increase until the stage of post flowering, but after this stage, a decrease was observed in the root length of all cultivars except Çeşit 1252, which is among the durum wheat (Table 3).

Barracough et al. [15] reported that the root length of wheat and barley depended on the cultivar of the plant, soil and the availability of soil water and nutrients and they also revealed that plants with longer height had longer root. Borg and Grimes [16] showed the maximum root length of barley is between 150 and 290 cm under suitable conditions, while the case is 150 – 300 cm for wheat. According to the average results obtained from the two-year study, root length of wheat and barley was determined to range in 189.0 to 216.6 cm and 201.1 to 202.2 cm during the stage of stem elongation, while 229.8 to 243.2 cm and 228.7 to 232.7 cm at post flowering stage, and 224.1 to 239.0 cm and 226.2 to 227.8 cm during the stage of maturity, respectively.

Table 3. Root length at different growth stages of wheat and barley cultivars

Cultivars	Growth stages								
	Stem elongation			Complete of anthesis			Maturity		
	2011-12	2012-13	Mean	2011-12	2012-13	Mean	2011-12	2012-13	Mean
Konya 2002	169.4 ef**	263.8 a	216.6 A**	248.7 ab**	232.4 cde	240.5 A**	247.2 a**	210.3 de	228.7BC**
Gerek 79	157.5 g	253.1 b	205.3 B	257.2 a	229.3 de	243.2 A	239.8 ab	208.4 e	224.1 C
Çeşit 1252	160.8 fg	267.3 a	214.0 A	239.8 bcd	219.8 e	229.8 B	247.4 a	224.2 c	235.8 AB
Kunduru 1149	137.7 h	240.2 c	189.0 C	239.3 bcd	244.4 abc	241.8 A	252.5 a	225.6 c	239.0 A
Larende	173.7 e	228.5 d	201.1 B	237.8 bcd	219.5 e	228.7 B	229.5 bc	222.9 cd	226.2 C
Karatay 94	175.2 e	229.1 d	202.2 B	243.1 a-d	222.3 e	232.7 AB	232.9 bc	222.7 cd	227.8 BC
Mean	162.4 **	247.0	204.7	244.3 **	227.9	236.1	241.5 **	219.0	230.3
LSD		9.6	6.8		15.0	10.6		13.5	9.5

**P<0.01

Table 4. Root biomass at different growth stages of wheat and barley cultivars

Cultivars	Growth stages								
	Stem elongation			Complete of anthesis			Maturity		
	2011-12	2012-13	Mean	2011-12	2012-13	Mean	2011-12	2012-13	Mean
Konya 2002	1.87 ab**	1.48 de	1.68 AB**	2.76 c*	2.35 c	2.56 C*	5.39 a**	2.29 e	3.84 B**
Gerek 79	1.93 a	1.53 cde	1.73 A	3.78 b	2.78 c	3.28 AB	4.38 b	2.28 e	3.33 C
Çeşit 1252	1.83 ab	1.49 de	1.66 AB	3.74 b	2.09 c	2.91 BC	3.07 cd	2.65 de	2.86 D
Kunduru 1149	1.34 e	1.35 e	1.34 C	5.16 a	2.41 c	3.78 A	4.57 b	3.04 cd	3.80 B
Larende	1.55 cde	1.55 cde	1.55 B	3.90 b	2.57 c	3.23 AB	5.40 a	3.54 c	4.47 A
Karatay 94	1.75 abc	1.68 bcd	1.72 A	4.08 b	2.37 c	3.22 AB	4.38 b	3.33 c	3.85 B
Mean	1.71 **	1.51	1.61	3.90**	2.43	3.17	4.53**	2.85	3.69
LSD		0.24	0.17		0.91	0.64		0.62	0.44

**P<0.01, *P<0.05

3.2 Root Biomass

In the first year of the research, root biomass was found to range in 1.87 to 1.93 g for bread wheat, 1.34 to 1.83 g in the durum wheat and 1.55 to 1.75 g for the barley during the stage of stem elongation, while in year, it was 1.48 to 1.53 g for bread wheat, 1.35 to 1.49 g for durum wheat and 1.55 and 1.68 g for barley. In terms of the average root biomass of both years, while bread wheat cultivars, Konya 2002 and Gerek 79 were in the same group with 1.68 and 1.73 g respectively, durum wheat cultivars, Çeşit 1252 and Kunduru 1149 took place in different groups with their values of 1.66 and 1.34 g. In accordance with these results, Çeşit 1252 being an irrigable cultivar had higher root biomass than non-irrigable cultivar, Kunduru 1149. As for Karatay 94 being a non-irrigable barley cultivar with root biomass (1.72 g), which second was higher than irrigable cultivar, Larende (1.55 g) (Table 4).

Noulas et al. [17] revealed that while the rate of roots grown after flowering spring wheat was found to be 1–22% of the total root until the physiological development and that 50% of the total nitrogen was absorbed after flowering. According to the results gathered from this study, the rate of roots grown after flowering showed differences among genotypes. In accordance with these findings, Konya 2002 and Gerek 79 as the bread wheat cultivars had an increase rate of 50.0% and 1.5%, respectively, while it was found 1.4% decrease in Çeşit 1252 and 0.5% increase in Kunduru 1149 as the durum wheat cultivars. There was also an increase rate of 38.4% in Larende and 19.6% in Karatay 94, which are barley cultivars. Miralles et al. [18] have stated that the difference in the root weight is more than the root length.

In the post flowering stage, in the first year of the research, root biomass was determined to range between 2.76 to 3.78 g for bread wheat, 3.74 to 5.16 g for durum wheat and 3.90 to 4.08 g for barley, while the case, in second year, was 2.35 to 2.78 g for bread wheat, 2.09 to 2.41 g for durum wheat and 2.37 to 2.57 g for barley. As the average results of both years, root biomass of bread wheat cultivars, Konya 2002 and Gerek 79 was measured to be 2.56 g and 3.28 g respectively, whereas durum wheat cultivars, Çeşit 1252 and Kunduru 1149 as 2.91 g and 3.78 g, respectively. Accordingly, non-irrigable bread wheat cultivar, Gerek 79 was found to be more root biomass than the irrigable cultivar,

Konya 2002 and the root biomass of non-irrigable durum wheat cultivar Kunduru 1149 was more than irrigable cultivar Çeşit 1252. While the both barley cultivars, Larende and Karatay 94 had root biomass very closely to each other as 3.23 g and 3.22 g respectively (Table 4). In the first year of the research, during the stage of maturity, root biomass ranged between 4.38 to 5.39 g for bread wheat, 3.07 to 4.57 g for durum wheat and 4.38 to 5.40 g for barley, while in the second year, the case was 2.28 to 2.29 g for bread wheat, 2.65 to 3.04 g for durum wheat and 3.33 to 3.54 g for barley. As the average value of both years, the root biomass of the irrigable bread wheat cultivar Konya 2002 (3.84 g) was greater than that of non-irrigable cultivar Gerek 79 (3.33 g). Besides, root biomass of non-irrigable durum wheat cultivar Kunduru 1149 (3.80 g) was more than that of irrigable cultivar Çeşit 1252 (2.86 g). Larende (4.47 g), developed to irrigable conditions had more root biomass than non-irrigable cultivar Karatay 94 (3.85 g) (Table 4). In a study carried out on barley, it was revealed that the deeper it was, the less the root biomass became and varied in different locations and different years [19]. In this study, it was also found that the root biomass of Kunduru 1149 and Larende did not change in the second year of the study compared to the first year and there was a decrease in other cultivars.

In the second year of the research, a decrease was found in the root biomass of all cultivars between the stages of flowering and maturity. In the second year compared to the first year, in terms of the average values of wheat and barley cultivars, there were found to be decreasing rates of in the root biomass as 11.7% for stem elongation, 37.7% for post flowering and 37.1% for maturity (Table 4).

In a study conducted by Tahir et al. [20], it was revealed that root biomass fell because of the root temperature or the temperature of ground surface. According to the results acquired from the study, differences between cultivars root biomass were observed and there was also a higher rate of decrease in the second year compared to the first year, and that is considered due to fact that not only ground surfaces but also root temperatures were higher in the second year and conditions of the soil. Ford et al. [21] revealed that the root biomass obtained by the cleaned roots was the balance weight between the rotten and the new roots. This entails that an increase in the root weight does not necessarily mean root development. In the study, according

to maturity values, 43.8 and 52.0% of the root biomass in bread wheat cultivars Konya 2002 and Gerek, 79.58.0 and 35.3% of that in durum wheat cultivars Çeşit 1252 and Kunduru 1149, and 34.7 and 44.7% of that in barley cultivars Larende and Karatay 94, formed during the stage of stem elongation. In addition, a significant rate of root biomass of the bread wheat and barley cultivars grown under non-irrigable conditions was formed during the stage of the stem elongation, compared to the irrigable ones. Kunduru 1149, which is a non-irrigable cultivar of durum wheat, formed much more of its root biomass after stem elongation stage (Table 4). Gregory [9] [10] revealed that under field conditions the total root biomass of winter wheat reached the maximum level (105 g m^{-2}) during the stage of flowering and showed a decreasing trend after flowering. Barraclough and Leigh [22] stated that root weight and length of the winter wheat roots increased swiftly until flowering and Ford et al. [21] found that the biomass of winter wheat roots did not vary between GS 63 (flowering) and GS 85 (forming starch). According to the results acquired through this study, the maximum root biomass of durum wheat in the first year of the research formed at the stage of post flowering, while the case was at the stage of maturity in bread wheat and barley cultivars. As for the second year of the study, the maximum root biomass of bread wheat formed at the stage of post flowering, while the case was at the stage of maturity in durum wheat and barley cultivars. In accordance with such data, in bread and durum wheat cultivars there were always increases and decreases observed as of the post flowering stage, while in the cultivars of barley, a consistent rate of increase in the root biomass in both years (Table 4).

4. CONCLUSIONS

Research results showed that average root length of cereal species at GS 31, GS 69 and GS 92 reached up to 204.7, 236.1 and 230.3 cm, respectively. Root lengths of bread wheat, durum wheat and barley at GS 92 were 226.0, 237.0 and 227.0 cm, respectively. The longest root system was observed in durum wheat. In the study, Kunduru 1149 had longer root system than other genotypes, which might be used as genetic material in breeding programs to develop deep-rooted genotypes. Barley root length developed as much as wheat.

This study showed that there was increase in the root biomass of some cultivars, however

decrease in some of them after flowering. Root biomass of genotypes increased when growth stages advanced. Infact, increase in root biomass is a balanced weight between newly forming root and decaying root .

These results showed that root length and root biomass were significantly affected by different growth stages, genotypes, and environmental conditions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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