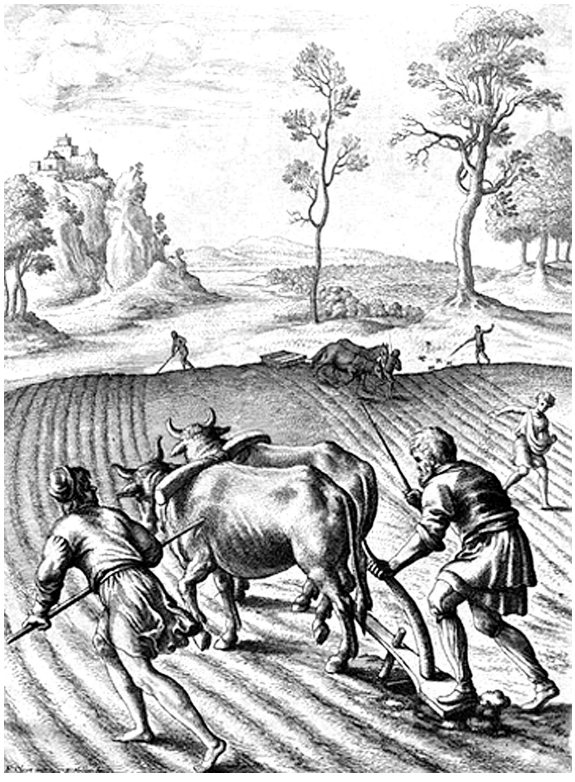
ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY



ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Journal of Agronomy

ISSN 1812-5379
DOI: 10.3923/ja.2018.198.208

Research Article
Effect of Wheat (*Triticum aestivum* L.) Cultivars, Row Spacing and Weed Control Methods on Root Growth

El Sayed Hasan Mohamed Fayed, Saber Abdel Hamed El Sayed Mowafy, Mohamed Elbakry Saleh and Fares Soliman Mohamed Gomaa Salama

Department of Agronomy, Faculty of Agriculture, Zagazig University, Egypt

Abstract

Background and Objective: Wheat (*Triticum aestivum* L.) is the most needed cereal crop in Egypt and due to the wide gap between wheat production and consumption, it was necessary to discover how to maximize wheat productivity in newly cultivated sandy soil as a way of horizontal expansion. Sandy soil suffers essentially from water stress and weed plants invasion, so this study aimed to compare among three wheat cultivars and three row spacing patterns which could provide a better distribution of plants roots at field to for a better uptake of water and minerals minimize the competition between plants, also the study aimed to compare five different weed control methods to decide the best alternative one. **Materials and Methods:** Two field experiments were carried out at the experimental farm of Faculty of Agriculture, Zagazig University in the winter seasons of 2015/2016 and 2016/2017 in new cultivated sandy soil using three Egyptian cultivars and three row spacings (10, 15 and 20 cm) and five different control methods (check, hand weeding, narrow leaf herbicide, broad leaf herbicide, both narrow and broad leaf herbicide). **Results:** The results showed significant differences between wheat cultivars in most of root parameters at different soil depths and layers at various growth stages. Also, studied root parameters showed significant variations between row spacing of wheat in favor of 20 cm row spacing. Root parameters significantly varied due to weed control methods. The response of root number density, root length density, root surface area and root dry weight of wheat differed due to weed control methods, soil depths and layers as well as at different wheat growth stages. On the other hand, roots growth rate was significantly affected by cultivars, row spacing and weed control methods. Simple correlation coefficient between wheat grain yield and root growth parameters was not significant but root number was significant with other root growth parameters. **Conclusion:** The results of this study indicated that root growth is affected by many of agriculture managements, like row spacing and methods of weed control stated that wheat varieties significantly differed in root patterns and the variation in soil moisture may cause this.

Key words: Wheat (*Triticum aestivum* L.), root growth, wheat grain yield, wheat cultivars, row spacing, weed control, agriculture management and narrow leaf herbicide

Citation: El Sayed Hasan Mohamed Fayed, Saber Abdel Hamed El Sayed Mowafy, Mohamed Elbakry Saleh and Fares Soliman Mohamed Gomaa Salama, 2018. Effect of wheat (*Triticum aestivum* L.) cultivars, row spacing and weed control methods on root growth. J. Agron., 17: 198-208.

Corresponding Author: Fares Soliman Mohamed Gomaa Salama, Department of Agronomy, Faculty of Agriculture, Zagazig University, Egypt
Tel: 00201096833545

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

All over the world and also in Egypt, wheat crop is the most important feeding crop. Many ecological and agricultural factors are affecting plants growth and final grain yield, so choosing the high yielding cultivars and the most suitable distribution of wheat plant in the field through the best planting density as well as avoiding weeds harmful distribution and effect are important factors which control the growth and grain yield of wheat plants and foremost affecting the growth and development of roots. Plant roots are the first part of plant which faces the environment and whole plant behavior is depending on. Wheat varieties significantly differed in root patterns and the variation in soil moisture may cause this[1]. Weather condition had influence on root dynamic and nitrogen fertilization effect on root development in the top soil, also, the relation between root weight and root number was not constant in all treatments and soil layers[2]. Root dry weight did not significantly differed in wheat cultivars at various soil layers. Increasing the amounts of N, P and S nutrients were shown to stimulate shoot growth as compared with root growth and then to widen the root-shoot ratio[3]. Nitrogen fertilization had significant effect on root dry weight up to 100 kg/faddan and splitting nitrogen doses decreased root dry weight[4-6]. It was revealed that Root Length Growth (RLG) measured by micro video camera in pressurized-wall minirhizotrones was enhanced in no-tillage than minimum tillage and root growth in upper soil layer was greater than in sup-soil layer. By water logging, root dry weight was decreased significantly after 7 and 14 days and wheat cultivars significantly differed in root system[7].

It has been reported that root number, root length distribution differed substantially between years using soil core samples and there was no genotypic effects in dwarf wheat root depth[8]. Root length density was decreased with soil depth. Few studies were carried out in the area of root system investigation, so this study was aimed to investigate the effect of wheat cultivars, row spacing and weed control methods on the growth of roots.

MATERIALS AND METHODS

Area of study and sampling: Two field experiments were carried out at the experiments field of the Faculty of Agriculture, Zagazig University, at khattara district, Sharqia Governorate during the two winter seasons of 2015/2016 and 2016/2017. The soil is sandy in texture.

Three samples of the plants and at the same time three soil-core samples from each plot were taken using a hand Auger method (455.8 cm^2) until 20 cm soil depth every 15 days at 50, 65 and 80 days after sowing (DAS) for determining root growth parameters[2,4]. Soil-core samples were soaked in water to remove soil particles and in root system labor using glass counting stage[9]. Root numbers at 5 and 10 cm depth were counted and the diameter of main and lateral roots at both soil layers was measured.

Agricultural practices: All agricultural practices were done as recommended in newly cultivated sandy soil. Seeds with the same sowing rate for the three cultivars were sown in three row distance as 60 kg/faddan. The plot area was 9 m^2 (3×3 m) each plot contain 30, 20 and 15 rows according the treatments. Potassium sulfate and ordinary superphosphate were applied direct before sowing with rates of 48% K_2O and 15.5% P_2O_5/faddan, respectively. Nitrogen fertilization as ammonium nitrate (33.5% N) at rate of 120 kg N/faddan was divided into five equal doses just before irrigation. The irrigation system was solid state sprinkler irrigation system. Treatments used in this investigation were:

- **Wheat cultivars:** Sakha 94 (v1), Giza 168 (v2), Gemmiza (v3)
- **Row spacing:** About 10 cm between rows (D1), 15 cm between rows (D2), 20 cm between rows (D3)
- **Weed control methods:** Check (W1), hand weeding (W2), narrow leaf herbicide "Traxos 4.5% EC" (W3), broad leaf herbicide "onostar 75% DF" (W4), both narrow and broad leaf herbicide "Pallas 4.5%" (W5)

Studied characters

Root Number Density (RND): Roots, main and laterals were counted at 5 and 10 cm depth in the area of soil-core sample 455.8 cm^2 (Auger area).

Root Length Density (RLD): Root length of both main and lateral roots were estimated by multiplying root number by 5 cm of the soil layer 0-5 and 5-10 cm for both soil layers:

$$RLD = RND \times 5 \text{ cm}$$

Root Surface Area (RSA): Root surface area of main and lateral roots in both soil layer 0-5 and 5-10 cm were determined by multiplying root length in every soil layer and circle area of roots ($2\pi r$):

$$RSA = RLD \times \text{circle area of roots } (2\pi r)$$

Root dry weight (g) (RDW): Roots in each soil layer were dried at 105°C for constant weight.

Root-shoot ratio (RSR): The root-shoot ratio was calculated by dividing root dry weight on shoot dry weight:

$$RSR = \frac{RDW}{SDW} \times 100$$

Root Growth Rate (RGR): Root growth rate estimated belonging root dry weight at the two growth periods of 50-65 days after sowing (DAS) and 65-80 DAS in the soil layer 0-10 cm.

Root Electrical Conductivity (REC) (Ω): As new indirect method for studying root system[10], conductive resistance of counting glass in labor was measured using Avometer (new general Model 500) at 2. The conductive resistance of root varied depending on root volume.

Correlation coefficients between grain yield and roots parameters each other®.

Statistical analysis: Recorded data were subjected to the two-way analysis of variance (ANOVA) of split split-plot design using CoStat-Statistics Software 6.400 package (*, ** indicate to significant at 5 and 1% levels of probability and NS indicate to Non-significance)[11].

RESULTS AND DISCUSSION

Parameters of wheat roots growth measured in this investigation are, root number density, root length density, root surface area, root branching density, root dry weight, root-shoot ratio, electrical conductivity and correlation coefficients between grain yield and root growth parameters each us.

Root number density: The number of main and lateral roots were estimated at soil surface by a soil core (45.58 cm^2) at 5 and 10 cm soil depths as well as the sum of main and lateral roots at both soil depths over plant growth stages in two sowing seasons (Table 1a, b and c). The results showed that number of main and lateral wheat roots at 5 and 10 cm soil depths by wheat varieties increased up to 80 days after sowing (DAS) in the two sowing seasons.

The number of lateral roots was higher at all growth stages by cultivars compared with the number of main roots. The number of main and lateral roots varied significantly among wheat cultivars at the different growth stages up to 80 DAS. This was also true by the total root number density at

Table 1a: Main root number density at 5 and 10 cm depth (45.58 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	Root number density 2015/2016						Root number density 2016/2017					
	5 cm depth			10 cm depth			5 cm depth			10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	7.73^b	8.93^a	9.06^a	3.20^b	3.26^c	3.20^c	8.40^a	9.00^a	8.86^a	3.26^b	2.93^c	3.13^c
Giza 168	7.06^c	8.00^c	8.60^c	1.46^c	3.86^a	3.26^b	8.40^a	8.66^c	8.73^b	2.93^c	3.13^b	3.26^b
Gemmiza 11	8.53^a	8.26^b	8.80^b	3.40^a	3.33^b	3.46^a	8.00^b	8.80^b	8.46^c	3.46^a	3.53^a	3.40^a
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	7.73^b	8.20^b	8.60^b	2.80^a	3.00^c	3.33^b	7.93^b	8.33^c	8.80^b	3.00^c	3.00^c	3.26^b
15	7.93^a	8.26^b	8.60^b	2.60^c	3.33^a	3.13^c	8.20^a	8.80^b	8.33^c	3.53^a	3.13^b	3.13^c
20	7.66^c	8.73^a	9.20^a	2.66^b	3.13^b	3.46^a	8.22^a	9.33^a	8.93^a	3.13^b	3.46^a	3.40^a
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	6.66^e	9.22^a	9.22^b	2.55^c	3.44^b	3.33^b	9.11^b	8.77^c	9.66^a	3.44^b	3.00^d	3.44^a
Hand W	8.44^b	8.33^b	8.77^c	3.00^a	3.11^c	3.22^c	8.00^c	8.77^c	8.55^c	3.11^d	3.11^c	3.33^b
Narrow	7.00^d	9.22^a	9.55^a	2.55^c	3.66^a	3.55^a	9.66^a	9.33^a	9.55^b	4.00^a	3.55^a	3.22^c
Broad	8.77^a	7.22^d	8.11^e	2.88^b	2.66^e	3.11^d	6.33^d	8.22^d	7.44^e	2.55^e	3.11^c	3.00^d
N+B	8.00^c	8.00^c	8.44^d	2.44^d	2.88^d	3.33^b	8.22^c	9.00^b	8.22^d	3.00^c	3.22^b	3.33^b
F test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance, DAS: Days after sowing

Table 1b: Lateral root number density at 5 cm and 10 cm depth (45.58 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	Root number density 2015/2016						Root number density 2016/2017					
	5 cm depth			10 cm depth			5 cm depth			10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	88.80^{b}	121.33^{a}	143.93^{b}	22.46^{b}	35.86^{b}	43.75^{b}	125.33^{a}	145.20^{a}	147.00^{a}	36.26^{b}	50.13^{c}	55.20^{b}
Giza 168	85.93^{b}	114.60^{b}	140.46^{c}	13.93^{c}	30.40^{c}	36.48^{c}	113.20^{b}	140.53^{b}	141.53^{b}	31.26^{c}	55.46^{b}	56.20^{b}
Gemmiza 11	97.60^{a}	116.60^{b}	152.53^{a}	26.66^{a}	40.66^{a}	50.42^{a}	112.40^{b}	146.13^{a}	153.46^{a}	41.00^{a}	62.66^{a}	64.46^{a}
F test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	94.00^{a}	114.86^{b}	145.46^{b}	21.86^{a}	34.00^{b}	41.48^{b}	117.00^{b}	145.80^{b}	148.86^{b}	35.40^{b}	57.20^{a}	59.46^{a}
15	84.3^{b}	119.26^{a}	144.53^{b}	21.00^{b}	36.46^{a}	43.75^{a}	121.20^{a}	145.26^{b}	148.86^{b}	36.53^{a}	54.13^{b}	55.06^{b}
20	94.00^{a}	118.80^{a}	146.93^{a}	20.20^{b}	36.46^{a}	44.12^{a}	117.66^{b}	149.80^{a}	150.26^{a}	36.60^{a}	56.93^{a}	59.33^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	89.66^{d}	125.55^{b}	151.22^{a}	20.11^{b}	37.11^{b}	46.76^{b}	126.00^{b}	146.00^{b}	151.33^{a}	35.88^{b}	59.22^{a}	61.44^{a}
Hand W	92.44^{c}	113.22^{c}	141.44^{c}	26.44^{a}	37.55^{b}	48.82^{a}	114.77^{c}	146.11^{b}	149.11^{b}	36.11^{b}	52.00^{c}	54.11^{d}
Narrow	80.33^{e}	127.33^{a}	151.88^{a}	19.77^{c}	40.11^{a}	45.32^{b}	137.55^{a}	148.00^{a}	149.88^{b}	40.55^{a}	54.66^{b}	55.77^{c}
Broad	96.77^{a}	106.33^{d}	144.44^{b}	20.55^{b}	30.44^{d}	39.27^{c}	108.55^{d}	143.66^{c}	144.77^{c}	33.44^{d}	56.11^{b}	58.55^{b}
N+B	94.66^{b}	115.77^{c}	139.22^{d}	18.22^{c}	33.00^{c}	39.60^{c}	106.33^{d}	136.00^{d}	135.88^{d}	34.88^{c}	58.44^{a}	59.22^{b}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, $^{a\,b,c,d}$The order of significance from higher to lower, NS: Non-significance, DAS: Days after sowing

Table 1c: Total root number density at 5 cm and 10 cm depth (45.58 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	Root number density 2015/2016						Root number density 2016/2017					
	5 cm depth			10 cm depth			5 cm depth			10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	96.53^{b}	130.26^{a}	152.99^{b}	25.66^{b}	39.12^{b}	46.95^{b}	133.73^{a}	154.20^{a}	155.86^{b}	39.52^{b}	53.06^{c}	58.33^{c}
Giza 168	92.99^{c}	122.60^{c}	149.06^{c}	15.39^{c}	34.26^{c}	39.74^{c}	121.60^{b}	149.19^{b}	150.26^{c}	34.19^{c}	58.59^{b}	59.46^{b}
Gemmiza 11	106.13^{a}	124.86^{b}	161.33^{a}	30.06^{a}	43.99^{a}	53.88^{a}	120.40^{c}	154.93^{a}	161.92^{a}	44.46^{a}	66.19^{a}	67.86^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	101.73^{a}	123.06^{b}	154.06^{b}	24.66^{a}	37.00^{b}	44.81^{b}	124.93^{c}	154.13^{b}	157.66^{b}	38.40^{b}	60.20^{a}	62.72^{a}
15	92.23^{b}	127.52^{a}	153.13^{c}	23.60^{b}	39.79^{a}	46.88^{a}	129.40^{a}	154.06^{b}	157.19^{c}	40.06^{a}	57.26^{b}	58.19^{b}
20	101.66^{a}	127.53^{a}	156.13^{a}	22.86^{b}	39.59^{a}	47.58^{a}	125.88^{b}	159.13^{a}	159.19^{a}	39.73^{a}	60.39^{a}	62.73^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	96.32^{c}	134.77^{b}	160.44^{a}	22.66^{c}	40.55^{b}	50.09^{b}	135.11^{b}	154.77^{b}	160.99^{a}	39.32^{b}	62.22^{a}	64.88^{a}
Hand W	100.88^{b}	121.55^{c}	150.21^{b}	29.44^{a}	40.66^{b}	52.04^{a}	122.77^{c}	154.88^{b}	157.66^{b}	39.22^{b}	55.11^{c}	57.44^{d}
Narrow	87.33^{d}	136.55^{a}	161.43^{a}	22.32^{c}	43.77^{a}	48.87^{c}	147.21^{a}	157.33^{a}	159.43^{a}	44.55^{a}	58.21^{b}	58.99^{c}
Broad	105.54^{a}	113.55^{d}	152.55^{b}	23.43^{b}	33.10^{d}	42.38^{d}	114.88^{d}	151.88^{c}	152.21^{c}	35.99^{d}	59.22^{b}	61.55^{b}
N+B	102.66^{b}	123.77^{c}	147.66^{c}	20.66^{d}	35.88^{c}	42.93^{d}	114.55^{d}	145.00^{d}	144.10^{d}	37.88^{c}	61.66^{a}	62.55^{b}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d}The order of significance from higher to lower, NS: Non-significance, DAS: Days after sowing

5 and 10 cm depths in the two seasons. It is important to mention that wheat cultivars in general produced higher numbers of total roots density at 5 cm depth (Table 1c) the significant differences in root number density may due to the genetic variations between wheat cultivars.

Concerning the effect of row spacing on root number density (Table 1a, b and c), the results revealed that root number density of main, lateral and total roots increased with increasing wheat growth up to 80 DAS. On the other hand, root number density at 5 and 10 cm by main, lateral and

total roots was significantly higher by planting wheat in 20 cm row spacing, specially by increasing wheat growth up to 65 and 80 DAS (Table 1a, b and c).

Due to the effect of weed control methods on root number density, the results showed significant differences in root number density at all growth stages and soil depths in the tow sowing seasons. Overall, the highest values of root number density at most growth stages and soil layers of main and lateral and total root number in both seasons were given by using narrow leaf herbicide (Traxos). Similar results may be found by many researchers[2,5,9], as the distribution of roots in the different soil depths.

Root length density: Root length density of main, lateral and total root length of wheat cultivars at the different growth stages of wheat in the tow seasons is presented in Table 2a, b and c. Data concerning root length density showed significant differences between wheat cultivars at all growth stages and soil depth in the tow seasons. Root length density as well as root number density took the same trend at the different growth stages of wheat plants. Where, the number of main roots at 5 cm depth was higher than that at 5-10 cm depth. Also, the number of lateral and total roots was higher at the soil layer 0-5 cm depth than that of soil layer 5-10 cm depth. So, the overall, total root length density by Gemmiza 11 wheat cultivar was significantly higher than by the other cultivars. That was true at all soil layers and growth stages in the two seasons (Table 2a, b and c).

Planting wheat in different row spacing showed significant variation on root length of main and lateral roots as well as the total of main and lateral roots (Table 2a, b and c). Root length density at soil layer 0-5 cm depth was higher compared with that at soil layer 5-10 cm depth at various growth stages by main and lateral roots as well as total roots in the two seasons. This is true because the higher number of roots in the soil layer 0-5 cm depth compared with that in soil layer 5-10 cm depth. Root length of main lateral roots of wheat plants grown in 20 cm row spacing was significantly higher in general compared with these grown in other row spacing. These results took the same trends mentioned in studies carried out by other researchers[2,8].

Concerning the response of root length by main, lateral and total roots in both soil layer (0-5 and 5-10 cm depth) in the two seasons as affected by weed control methods (Table 2a, b and c), The results showed that root length of main, lateral and total roots was significantly higher when weeds was controlled using narrow or broad leaf herbicides separately in the tow seasons and at different growth stages.

Root surface area (cm^2): Root surface area was estimated for the total root length in the soil layer 0-10 cm depth including

Table 2a: Main root length density at soil depth of 0-5 and 5-10 cm (228 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	2015/2016						2016/2017					
	0-5 cm depth			5-10 cm depth			0-5 cm depth			5-10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	38.65^{b}	44.65^{a}	45.30^{a}	16.00^{b}	16.30^{c}	16.00^{c}	42.00^{a}	45.00^{a}	44.30^{a}	16.30^{b}	14.65^{c}	15.65^{c}
Giza 168	35.30^{c}	40.00^{c}	43.00^{c}	7.30^{c}	19.30^{a}	16.30^{b}	42.00^{a}	43.30^{c}	43.65^{b}	14.65^{c}	15.65^{b}	16.3^{b}
Gemmiza 11	42.65^{a}	41.30^{b}	44.00^{b}	17.00^{a}	16.65^{b}	17.30^{a}	40.00^{b}	44.00^{b}	42.30^{c}	17.30^{a}	17.65^{a}	17.00^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	38.65^{b}	41.00^{c}	43.00^{b}	14.00^{a}	15.00^{c}	16.65^{b}	39.65^{b}	41.65^{c}	44.00^{b}	15.00^{c}	15.00^{c}	16.30^{b}
15	39.65^{a}	41.30^{b}	43.00^{b}	13.00^{c}	16.65^{a}	15.65^{c}	41.00^{a}	44.00^{b}	41.65^{c}	17.65^{a}	15.65^{b}	15.65^{c}
20	38.30^{c}	43.65^{a}	46.00^{a}	13.30^{b}	15.65^{b}	17.30^{a}	41.10^{a}	46.65^{a}	44.65^{a}	15.65^{b}	17.30^{a}	17.00^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	33.30^{e}	46.10^{a}	46.10^{b}	12.75^{c}	17.20^{b}	16.65^{b}	45.55^{b}	43.85^{c}	48.30^{a}	17.20^{b}	15.00^{d}	17.20^{a}
Hand W	42.20^{b}	41.65^{b}	43.85^{c}	15.00^{a}	15.55^{c}	16.10^{c}	40.00^{d}	43.85^{c}	42.75^{c}	15.55^{c}	15.55^{c}	16.65^{b}
Narrow	35.00^{d}	46.10^{a}	47.75^{a}	12.75^{c}	18.30^{a}	17.75^{a}	48.30^{e}	46.65^{a}	47.75^{b}	20.00^{a}	17.75^{a}	16.10^{c}
Broad	43.85^{a}	36.10^{d}	40.55^{e}	14.40^{b}	13.30^{e}	15.55^{d}	31.65^{a}	41.10^{d}	37.20^{e}	12.75^{e}	15.55^{c}	15.00^{d}
N+B	40.00^{c}	40.00^{c}	42.20^{d}	12.20^{d}	14.40^{d}	16.65^{b}	41.10^{c}	45.00^{b}	41.10^{d}	15.00^{d}	16.10^{b}	16.65^{b}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

Table 2b: Lateral root length density at soil depth of 0-5 cm and 5-10 cm (228 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	2015/2016						2016/2017					
	0-5 cm depth			5-10 cm depth			0-5 cm depth			5-10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	444.00^{b}	606.65^{a}	719.65^{b}	112.30^{b}	179.30^{b}	218.75^{b}	626.65^{a}	726.00^{a}	735.00^{b}	181.30^{b}	250.65^{c}	276.00^{c}
Giza 168	429.65^{c}	573.00^{c}	702.30^{c}	69.65^{c}	152.00^{c}	182.40^{c}	566.00^{b}	702.65^{b}	707.65^{c}	156.30^{c}	277.30^{b}	281.00^{b}
Gemmiza 11	488.00^{a}	583.00^{b}	762.65^{a}	133.30^{a}	203.30^{a}	252.10^{a}	562.00^{c}	730.65^{a}	767.30^{a}	205.00^{a}	313.30^{a}	322.30^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	470.00^{a}	574.30^{c}	727.30^{b}	109.30^{a}	170.00^{b}	207.40^{c}	585.00^{c}	729.00^{b}	744.30^{b}	177.00^{b}	286.00^{a}	297.30^{a}
15	421.50^{b}	596.30^{a}	722.67^{c}	105.00^{b}	182.30^{a}	218.75^{b}	606.00^{a}	726.30^{c}	744.30^{b}	182.65^{a}	270.65^{b}	275.30^{b}
20	470.00^{a}	594.00^{b}	734.65^{a}	101.00^{c}	182.30^{a}	220.60^{a}	588.30^{b}	749.00^{a}	751.30^{a}	183.00^{a}	284.65^{a}	296.65^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	448.30^{d}	627.75^{b}	756.10^{b}	100.55^{b}	185.55^{b}	233.8^{b}	630.00^{b}	730.00^{b}	756.65^{a}	179.40^{b}	296.10^{a}	307.20^{a}
Hand W	462.20^{c}	566.10^{d}	707.20^{d}	132.20^{a}	187.75^{b}	244.10^{a}	573.85^{c}	730.55^{b}	745.55^{c}	180.55^{b}	260.00^{e}	270.55^{e}
Narrow	401.65^{e}	636.65^{a}	759.40^{a}	98.85^{c}	200.55^{a}	226.60^{c}	687.75^{a}	740.00^{a}	749.40^{b}	202.75^{a}	273.30^{d}	278.85^{d}
Broad	483.85^{a}	531.65^{e}	722.20^{e}	102.75^{b}	152.20^{d}	196.35^{d}	542.75^{d}	718.30^{c}	723.85^{d}	167.20^{d}	280.55^{c}	292.75^{c}
N+B	473.30^{b}	578.85^{c}	696.10^{c}	91.10^{d}	165.00^{c}	198.00^{d}	531.65^{e}	680.00^{d}	679.40^{e}	174.40^{c}	292.20^{b}	296.10^{b}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

Table 2c: Total root length density at soil depth of 0-5 cm and 5-10 cm (228 cm^2) as affected by wheat cultivars, row spacing and weed control treatments

	2015/2016						2016/2017					
	0-5 cm depth			5-10 cm depth			0-5 cm depth			5-10 cm depth		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety												
Sakha 94	482.65^{b}	651.30^{a}	764.95^{b}	128.30^{b}	195.60^{b}	234.75^{b}	668.65^{a}	771.00^{b}	779.30^{b}	197.60^{c}	265.30^{c}	291.65^{c}
Giza 168	464.95^{c}	613.00^{c}	745.30^{c}	76.95^{c}	171.30^{c}	198.70^{c}	608.00^{b}	745.95^{c}	751.30^{c}	170.95^{b}	292.95^{b}	297.30^{b}
Gemmiza 11	530.65^{a}	624.30^{b}	806.65^{a}	150.30^{a}	219.95^{a}	269.40^{a}	602.00^{c}	774.65^{a}	809.60^{a}	222.30^{a}	330.95^{a}	339.30^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing (cm)												
10	508.65^{a}	615.30^{b}	770.30^{b}	123.30^{a}	185.00^{b}	224.05^{c}	624.65^{c}	770.65^{b}	788.30^{b}	192.00^{b}	301.00^{a}	313.60^{b}
15	461.15^{b}	637.60^{a}	765.67^{c}	118.00^{b}	198.95^{a}	234.40^{b}	647.00^{a}	770.30^{b}	785.95^{c}	200.30^{a}	286.30^{b}	290.95^{c}
20	508.30^{a}	637.65^{a}	780.65^{a}	114.30^{c}	197.95^{a}	237.90^{a}	629.40^{b}	795.65^{a}	795.95^{a}	198.65^{a}	301.95^{a}	313.65^{a}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Weed control												
Control	481.60^{d}	673.85^{b}	802.20^{b}	113.30^{c}	202.75^{b}	250.45^{b}	675.55^{b}	773.85^{b}	804.95^{a}	196.60^{b}	311.10^{a}	324.40^{a}
Hand W	504.40^{c}	607.75^{d}	751.05^{d}	147.20^{a}	203.30^{b}	260.20^{a}	613.85^{c}	774.40^{b}	788.30^{c}	196.10^{b}	275.55^{d}	287.20^{e}
Narrow	436.65^{e}	682.75^{a}	807.15^{a}	111.60^{c}	218.85^{a}	244.35^{c}	736.05^{a}	786.65^{a}	797.15^{b}	222.75^{a}	291.05^{c}	294.95^{d}
Broad	527.70^{a}	567.75^{e}	762.75^{c}	117.15^{b}	165.50^{d}	211.90^{d}	574.40^{d}	759.40^{c}	761.05^{d}	179.95^{d}	296.10^{b}	307.75^{c}
N+B	513.30^{b}	618.85^{c}	738.30^{e}	103.30^{d}	179.40^{c}	214.65^{d}	572.75^{d}	725.00^{d}	720.50^{e}	189.40^{c}	308.30^{a}	312.75^{b}
F-test	*	*	*	*	*	*	*	*	*	*	*	*
Interaction												
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

main and lateral roots at the various growth stage of wheat plants as affected by wheat varieties, row spacing and weed control methods in the two seasons (Table 3a, b).

Root surface area of wheat plants in the soil layer 0-10 cm showed significant variations at all growth stages by main and lateral roots as well as by total roots. Overall, Gemmiza 11

Table 3a: Root surface area (cm^2) in soil layer 0-10 cm depth (456 cm^3) as affected by wheat cultivars, row spacing and weed control treatments (1st season)

	2015/2016								
	Main roots (0-10)			Lateral roots (0-10)			Total		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety									
Sakha 94	12.01[b]	13.40[a]	13.47[a]	34.94[b]	49.36[a]	58.93[b]	46.95[b]	62.75[a]	72.41[b]
Giza 168	9.36[c]	13.03[b]	13.03[b]	31.36[c]	45.53[b]	55.56[c]	40.72[c]	58.56[c]	68.59[c]
Gemmiza 11	13.11[a]	12.74[c]	13.47[a]	39.02[a]	49.38[a]	63.73[a]	52.13[a]	62.12[b]	77.20[a]
F-test	*	*	*	*	*	*	*	*	*
Row spacing (cm)									
10	11.57[a]	12.31[c]	13.11[b]	36.38[a]	46.74[b]	58.70[c]	47.95[a]	59.05[b]	71.81[c]
15	11.57[a]	12.74[b]	12.89[c]	33.06[c]	48.90[a]	59.12[b]	44.64[c]	61.63[a]	72.01[b]
20	11.34[b]	13.03[a]	13.91[a]	35.86[b]	48.75[a]	59.99[a]	47.20[b]	61.79[a]	73.90[a]
F-test	*	*	*	*	*	*	*	*	*
Weed control									
Control	10.12[e]	13.91[b]	13.79[b]	34.47[d]	51.08[b]	62.17[a]	44.59[d]	64.99[b]	75.96[b]
Hand W	12.57[b]	12.57[c]	13.18[c]	37.33[a]	47.34[c]	59.74[c]	49.90[e]	59.91[c]	72.92[c]
Narrow	10.50[d]	14.16[a]	14.40[a]	31.43[e]	52.58[a]	61.92[b]	41.93[a]	66.73[a]	76.32[a]
Broad	12.80[a]	10.86[e]	12.33[e]	36.84[b]	42.95[a]	57.68[d]	49.64[b]	53.80[e]	70.02[d]
N+B	11.47[c]	11.96[d]	12.94[d]	35.44[c]	46.71[d]	56.15[e]	46.92[c]	58.67[d]	69.08[e]
F-test	*	*	*	*	*	*	*	*	*
Interaction									
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, [a,b,c,d,e]The order of significance from higher to lower, NS: Non-significance

Table 3b: Root surface area (cm^2) in soil layer 0-10 cm depth (456 cm^3) as affected by wheat cultivars, row spacing and weed control treatments (1st season)

	2016/2017								
	Main roots (0-10)			Lateral roots (0-10)			Total		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety									
Sakha 94	12.81[a]	13.11[b]	13.18[a]	50.74[a]	61.33[b]	63.49[b]	63.55[a]	74.44[b]	76.67[b]
Giza 168	12.45[c]	12.96[c]	13.18[a]	45.36[c]	61.54[b]	62.09[c]	57.81[c]	74.50[b]	75.26[c]
Gemmiza 11	12.59[b]	13.55[a]	13.03[b]	48.17[b]	65.56[a]	68.43[a]	60.76[b]	79.11[a]	81.46[a]
F-test	*	*	*	*	*	*	*	*	*
Row spacing (cm)									
10	12.01[c]	12.45[c]	13.25[b]	47.85[c]	63.74[b]	65.41[b]	59.87[c]	76.19[b]	78.67[b]
15	12.89[a]	13.11[b]	12.59[c]	49.53[a]	62.61[c]	64.03[c]	62.42[a]	75.72[c]	76.63[c]
20	12.47[b]	14.06[a]	13.55[a]	48.44[b]	64.91[a]	65.81[a]	60.91[b]	78.97[a]	79.36[a]
F-test	*	*	*	*	*	*	*	*	*
Weed control									
Control	13.79[b]	12.94[d]	14.4[a]	50.83[b]	64.44[a]	66.81[a]	64.62[b]	77.37[b]	81.21[a]
Hand W	12.21[c]	13.06[c]	13.06[c]	47.38[c]	62.21[d]	63.81[c]	59.59[c]	75.26[c]	76.87[c]
Narrow	15.01[a]	14.16[a]	14.03[b]	55.92[a]	63.64[b]	64.57[b]	70.94[a]	77.79[a]	78.61[b]
Broad	9.76[d]	12.45[e]	11.47[e]	44.58[d]	62.73[c]	63.84[c]	54.34[e]	75.18[c]	75.32[d]
N+B	12.33[c]	13.43[b]	12.69[d]	44.34[d]	61.05[e]	61.26[d]	56.67[d]	74.48[d]	73.95[d]
F-test	*	*	*	*	*	*	*	*	*
Interaction									
Cultivars*Row spacing	*	*	*	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*	*	*	*

*Significant at 5% level of probability, [a,b,c,d,e]The order of significance from higher to lower, NS: Non-significance

cultivar had the highest roots surface area during growth stages by main, lateral and total roots. Surface area of lateral roots was higher compared with main roots due to higher number and length of lateral roots.

Wheat plants growth at different row spacing revealed significant variations in root surface area of main, lateral and total roots at various growth stages (Table 3a, b). Root surface area was higher by planting wheat at 10 cm spacing at the first

growth stage (50 DAS) by main and lateral roots as well as total roots but at late growth stages of 60 and 80 DAS, the highest root surface area was found by row spacing of 20 cm. To explain these results, it may be due to that at first growth stage the canopy of plants was small and by late growth stage, the canopies of plants increased and decreased the penetration of light by increasing the shading of plants.

Weed control methods had significant effects on root surface area of main, lateral and total roots at various growth stages in the two seasons (Table 3a and b). Using narrow or broad leaf herbicides to control weeds by wheat plants reflect significantly higher roots surface area at various growth stages of main and lateral roots compared with other weed control methods.

Root dry weight (g): Root dry weight as affected by wheat cultivars variation, row spacing and weed control methods is shown in Table 4. Root dry weight significantly varied at different growth stage, where wheat cultivar Sakha 94 had the highest root dry weight at the first growth sample (50 DAS), while wheat cultivars Giza 168 and Gemmiza 11 produced the highest root dry weight at the second and third growth stage in the two seasons, respectively.

Concerning the effect of row spacing on root dry weight of wheat cultivars (Table 4), it can be concluded that the highest root dry weight was obtained by growing wheat plants in 15 cm between rows at the three growth stages. It is obviously to explain that the density of plants inner rows was lower than at 20 cm between rows. It also means that, the competition among weed plants was low.

Root dry weight of wheat cultivars responded significantly to weed control methods (Table 4), where the highest root dry weight produced by all weed control methods compared with non weed controlled specially, at late stage of wheat plants. Weed control methods minimized the competition between weeds and wheat plants. These results may be confirmed with those obtained by other investigators[4-6,12].

Root/shoot ratio: Root/shoot ratio of wheat cultivars as affected by row spacing and weed control methods was presented in Table 5. Results of root/shoot ratio showed significant differences between wheat cultivars. The highest root/shoot ratio was found by wheat cultivar Sakha 94 in both growing seasons especially, at growth stage of 65 DAS.

Row spaces had significant effects on root/shoot ratio at the different growth stages except at the first growth stage in 1st season (Table 5). The highest values of root/shoot ratio

Table 4: Root dry weight (g) as affected by wheat cultivars, row spacing and weed control treatments

	Root dry weight (g)					
	2015/2016			2016/2017		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety						
Sakha 94	0.34^{a}	0.34^{b}	0.47^{c}	0.34^{a}	0.32^{c}	0.47^{c}
Giza 168	0.25^{b}	0.41^{a}	0.52^{b}	0.26^{b}	0.41^{a}	0.54^{b}
Gemmiza 11	0.21^{c}	0.34^{b}	0.57^{a}	0.21^{c}	0.35^{b}	0.60^{a}
F-test	*	*	*	*	*	*
Row spacing (cm)						
10	0.26^{a}	0.42^{a}	0.58^{a}	0.25^{c}	0.42^{a}	0.51^{a}
15	0.25^{b}	0.29^{b}	0.52^{b}	0.30^{a}	0.24^{c}	0.51^{a}
20	0.26^{a}	0.42^{a}	0.47^{c}	0.26^{b}	0.39^{b}	0.49^{b}
F-test	*	*	*	*	*	*
Weed control						
Control	0.22^{c}	0.25^{d}	0.56^{b}	0.25^{d}	0.22^{c}	0.51^{e}
Hand W	0.28^{a}	0.49^{a}	0.44^{d}	0.28^{b}	0.43^{a}	0.44^{d}
Narrow	0.27^{a}	0.47^{b}	0.63^{a}	0.27^{c}	0.43^{a}	0.67^{a}
Broad	0.27^{a}	0.39^{c}	0.45^{d}	0.28^{b}	0.43^{a}	0.49^{c}
N+B	0.25^{b}	0.26^{d}	0.53^{c}	0.29^{a}	0.24^{b}	0.54^{b}
F-test	*	*	*	*	*	*
Interaction						
Cultivars*Row spacing	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*
Row spacing*Weed con.	*	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d}The order of significance from higher to lower, NS: Non-significance

Table 5: Root/shoot ratio as affected by wheat cultivars, row spacing and weed control treatments

	Root/shoot ratio					
	2015/2016			2016/2017		
Treatments	50 DAS	65 DAS	80 DAS	50 DAS	65 DAS	80 DAS
Variety						
Sakha 94	0.48^{a}	0.45^{a}	0.20^{b}	0.55^{a}	0.44^{a}	0.27^{a}
Giza 168	0.36^{b}	0.38^{b}	0.22^{a}	0.41^{c}	0.37^{b}	0.23^{c}
Gemmiza 11	0.36^{b}	0.29^{c}	0.20^{b}	0.45^{b}	0.35^{c}	0.24^{b}
F-test	*	*	*	*	*	*
Row spacing (cm)						
10	0.39	0.37^{b}	0.22^{a}	0.45^{b}	0.42^{a}	0.25^{a}
15	0.39	0.34^{c}	0.21^{b}	0.53^{a}	0.33^{c}	0.23^{b}
20	0.39	0.42^{a}	0.18^{c}	0.44^{c}	0.40^{b}	0.21^{c}
F-test	NS	*	*	*	*	*
Weed control						
Control	0.37^{d}	0.31^{d}	0.24^{a}	0.42^{d}	0.33^{c}	0.27^{a}
Hand W	0.41^{b}	0.47^{a}	0.17^{e}	0.46^{b}	0.44^{a}	0.18^{e}
Narrow	0.39^{c}	0.43^{b}	0.22^{b}	0.42^{d}	0.43^{a}	0.27^{b}
Broad	0.37^{a}	0.40^{c}	0.21^{c}	0.44^{c}	0.40^{b}	0.23^{c}
N+B	0.44^{a}	0.24^{e}	0.19^{d}	0.61^{a}	0.33^{c}	0.21^{d}
F-test	*	*	*	*	*	*
Interaction						
Cultivars*Row spacing	*	*	*	*	*	*
Cultivars*Weed control	*	*	*	*	*	*
Row spacing*Weed con.	NS	*	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

where found by narrow row spaces between wheat plants in 2nd season and at late growth stage in 1st season. This may be due to the reduction of shoot growth by narrow growing plants.

In relation to the effect of weed control methods on root/shoot ratio of wheat cultivars (Table 5), the results showed significant variations in root/shoot ratio at all growth stages of wheat plants but without clearly trend of those results. At the growth stage of 65 DAS, root/shoot ratio was higher by hand weeding; while, by the controlled one root/shoot ratio was higher at late growth stage (80 DAS), where the competition of weeds reached its maximum effect causing higher reduction in shoot growth of wheat plants.

In these trends, it was reported that root-shoot ratio varied according to variations on the ecological and agricultural factors[12].

Root growth rate: Root growth rate was estimated belong to root dry weight (Table 6). It was found that root growth rate was higher at the second growth period (65-80 DAS) than at the first one (50-65 DAS) in both growing seasons. Root growth rate was significantly affected by wheat cultivars variation, row spacing and weed control methods at all growth stages in both seasons.

It can be concluded that wheat cultivar Gemmiza 11 surpassed the other two cultivars in root growth rate at the base of root dry weight. Concerning row spaces, root growth rate was higher by narrow planting spaces at the second growth period (65-80 DAS) in both seasons.

There were significant variations due to different row spacing which may affected the penetration of light between rows but there were no clear trends for the effect of row spacing on root growth rate.

Root electrical conductivity (Ω): Data of root electrical conductivity (Ω), which was measured by Avometer as new and indirect method for studying root system must be confirmed by other direct methods were shown in Table 7.

The results concerning the effect of wheat cultivars, row spacing and weed control methods on root electrical conductivity showed significant variation on the ability of roots to conductivity or resistance due to different cultivars or row spacing and weed control methods.

Roots were more conductive by wheat cultivar Giza 168, plants grown at 10 cm between rows and by applying a broad leaves herbicide (Onostar) to control weeds. Our observation revealed that the low values of electrical conductivity means that the root volume was higher expressed as root dry weight or length.

Table 6: Root growth rate belong to root dry weight as affected by wheat cultivars, row spacing and weed control treatments

Treatments	2015/2016		2016/2017	
	50-65 DAS	65-80 DAS	50-65 DAS	65-80 DAS
Variety				
Sakha 94	0.001^{b}	0.094^{b}	0.001^{b}	0.103^{b}
Giza 168	0.012^{a}	0.082^{c}	0.011^{a}	0.097^{c}
Gemmiza 11	0.012^{a}	0.111^{a}	0.011^{a}	0.112^{a}
F-test	*	*	*	*
Row spacing (cm)				
10	0.012^{a}	0.091^{b}	0.012^{a}	0.084^{b}
15	0.004^{b}	0.123^{a}	0.001^{b}	0.142^{a}
20	0.013^{a}	0.074^{c}	0.012^{a}	0.081^{b}
F-test	*	*	*	*
Weed control				
Control	0.003^{b}	0.154^{a}	0.003^{b}	0.153^{a}
Hand W.	0.012^{a}	0.064^{e}	0.013^{a}	0.071^{d}
Narrow	0.014^{a}	0.092^{c}	0.014^{a}	0.102^{b}
Broad	0.011^{a}	0.083^{d}	0.014^{a}	0.087^{c}
N+B	0.004^{b}	0.132^{b}	0.004^{b}	0.150^{a}
F-test	*	*	*	*
Interaction				
Cultivars*Row spacing	*	*	*	*
Cultivars*Weed control	*	*	*	*
Row spacing*Weed con.	*	*	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

Table 7: Root electrical conductivity (Ω) as affected by wheat cultivars, row spacing and weed control treatments

Treatments	2015/2016	2016/2017
Variety		
Sakha 94	116.26^{c}	116.73^{c}
Giza 168	125.00^{a}	125.13^{a}
Gemmiza 11	121.46^{b}	118.46^{b}
F-test	*	*
Row spacing (cm)		
10	122.86^{a}	124.40^{a}
15	122.06^{b}	123.46^{b}
20	117.80^{c}	112.46^{c}
F-test	*	*
Weed control		
Control	112.77^{d}	106.44^{e}
Hand W.	122.00^{c}	118.55^{c}
Narrow	112.66^{d}	115.22^{d}
Broad	132.44^{a}	127.77^{b}
N+B	124.66^{b}	132.55^{a}
F-test	*	*
Interaction		
Cultivars*Row spacing	*	*
Cultivars*Weed control	*	*
Row spacing*Weed con.	*	*

*Significant at 5% level of probability, ^{a,b,c,d,e}The order of significance from higher to lower, NS: Non-significance

Correlation between root characters and grain yield: Correlation coefficients between grain yield of wheat and root parameters each other were presented in Table 8. The results

Table 8: Correlation coefficients between wheat grain yield and root parameters

Correlations	Grain yield	Total root No. in 5 cm depth	Total root No. in 10 cm depth	Total root length in 0-5 cm depth	Total root length in 5-10 cm depth	Total root surface area	Root dry weight
1st season							
Grain yield		0.124^{NS}	0.138^{NS}	0.162^{NS}	0.251^{NS}	0.161^{NS}	0.305^{NS}
Total root No. in 5 cm depth	0.124^{NS}		0.653*	0.156^{NS}	0.692*	0.926**	0.589*
Total root No. in 10 cm depth	0.138^{NS}	0.653^{*}		0.09^{NS}	0.286^{NS}	0.88**	0.154^{NS}
Total root length in 0-5 cm depth	0.162^{NS}	0.156^{NS}	0.09^{NS}		0.598*	-0.105^{NS}	-0.156^{NS}
Total root length in 5-10 cm depth	0.251^{NS}	0.692*	0.268^{NS}	0.598*		0.635*	0.568*
Total root surface area (cm^2)	0.161^{NS}	0.926**	0.88**	-0.105^{NS}			0.519*
Root dry weight (g)	0.305^{NS}	0.589*	0.154^{NS}	-0.156^{NS}	0.568*	0.519*	
2nd season							
Grain yield		0.01^{NS}	0.086^{NS}	0.055^{NS}	0.293^{NS}	0.031^{NS}	0.016^{NS}
Total root No. in 5 cm depth	0.01^{NS}		0.24^{NS}	0.82^{**}	0.572*	0.894**	0.133^{NS}
Total root No. in 10 cm depth	0.086^{NS}	0.24^{NS}		0.499^{NS}	0.144^{NS}	0.607*	0.269^{NS}
Total root length in 0-5 cm depth	0.055^{NS}	0.82**	0.499^{NS}		0.334^{NS}	0.888**	0.56^{NS}
Total root length in 5-10 cm depth	0.293^{NS}	0.572^{NS}	0.144^{NS}	0.334^{NS}		0.452^{NS}	-0.175^{NS}
Total root surface area (cm^2)	0.031^{NS}	0.894^{**}	0.607^{*}	0.888**	0.452^{NS}		0.354^{NS}
Root dry weight (g)	0.016^{NS}	0.133^{NS}	0.269^{NS}	0.56^{NS}	-0.175^{NS}	0.354^{NS}	

*,**Significant at 5 and 1% levels of probability, NS: Non-significance

revealed that grain yield of wheat was not significantly associated with each of total root number density, total root length, total root surface area and root dry weight; but grain yield was more associated with root number density at soil depth of 10 than 5 cm. Also, grain yield was highly associated with root length density at soil layer 5-10 cm than that at soil layer 5-10 cm. On the other hand, grain yield was more associated with root dry weight than other root growth parameters. Root dry weight contributed with ($r^2 = 0.093$) in grain yield under this study.

CONCLUSION

It could be concluded that root system parameters which present a true impression of wheat plants growth and development significantly affected be the variation of wheat cultivars, the variation row spacings and weed control. The results of roots parameters were significantly affected by wheat cultivars. The distribution of wheat roots was decreased with increasing soil depth. Row spacings affected root distribution until with the same seeding rates of wheat cultivars. Weed control methods affected significantly on behavior f roots parameters.

SIGNIFICANCE STATEMENT

This study assured the true and significant role of root system and its relation to plant behavior through choosing the most adaptable cultivar and its distribution at field which as translated into competition as well as applying an efficient method of weed control. That can be beneficial for applying the most suitable agricultural practices which maximize the role of root system on performing its function. Hence, wheat grain yield at the end of a successful growth period would be the maximum looking forward to overcome the gap between production and consumption. This study will help researchers to uncover the critical areas of root system and its relation to the plant growth that many researchers were not able to explore. Thus a new theory on the relation between root growth parameters and plant grain yield may be arrived at.

REFERENCES

1. Hurd, E.A., 1968. Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agron. J., 60: 201-205.
2. Franken, H. and E.H.M. Fayed, 1983. Zur Wurzdbildung Bei Winter Weizen in Abhangigkeit von Bodentiefe und N-Dungung. In: Root Ecology and its Practical Application: International Symposium Gumpenstein, Bohm, W., L. Kutschera and E. Lichtenegger (Eds.). Bundesanstalt Gumpenstein, Irdning, pp: 453-462.
3. Steineck, O., 1983. Der Einfluss der Hauptnahrstoffe Auf Die Wurzelbildung. In: Root Ecology and its Practical Application: International Symposium Gumpenstein, Bohm, W., L. Kutschera and E. Lichtenegger (Eds.). Bundesanstalt Gumpenstein, Irdning, pp: 44-99.
4. Fayed, E.H.M., 1992. Response of wheat cultivars to nitrogen rates and time of application in newly reclaimed sandy soil. Egypt. J. Applied Sci., 7: 506-528.
5. Bassiouny, A.U., E.H.M. Fayed, M.H. Iskander and A.H.M. Bassiouny, 1993. Yield and root growth of wheat as influenced by sowing rate and nitrogen fertilization. Egypt. J. Applied Sci., 8: 1-18.

6. Merrill, S.D., A.L. Black and A. Bauer, 1996. Conservation tillage affects root growth of dryland spring wheat under drought. Soil Sci. Soc. Am. J., 60: 575-583.
7. Marashi, S.K. and G.S. Chinchanikar, 2012. Evaluation of root system and mineral content in wheat cultivars under waterlogging stress. Int. J. Applied Agric. Res., 7: 37-44.
8. Hodgkinson, L., I.C. Dood, A. Binley, R.W. Ashton, R.P. White, C.W. Walts and W.R. Whalley, 2017. Root growth in field-grown winter wheat: Some effects of soil conditions, season and genotype. Eur. J. Agron., 91: 74-83.
9. Fayed, E.H.M., 1987. Root growth of wheat as affected by organic manure, nitrogen fertilization and its relation to grain yield. Egypt. J. Applied Sci., 1: 391-401.
10. Chloupek, O., 1977. Evaluation of the size of a plant's root system using its electrical capacitance. Plant Soil, 48: 525-532.
11. Cardinali, A. and G.P. Nason, 2013. Costationarity of locally stationary time series using costat. J. Stat. Software, 55: 1-22.
12. Steen, E., 1983. The Net Stocking Method for Studying Quantitative and Qualitative Variation with Time of Grass Roots. In: Root Ecology and its Practical Application: International Symposium Gumpenstein, Bohm, W., L. Kutschera and E. Lichtenegger (Eds.). Bundesanstalt Gumpenstein, Irdning, pp: 63-74.