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Root Mass Distribution of Winter Wheat as Influenced by Different Tillage Systems in Semi Arid Region

[1,2]A.R. Barzegar, [3]M.H. Mossavi, [4]M.A. Asoodar and [2]S.J. Herbert
[1]Department of Soil Science, College of Agriculture, Shahid Chamran University, Ahwaz, Iran
[2]Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003, USA
[3]Soil and Water Research Institute, Construction-Agricultural Organization of Khuzestan, Ahwaz, Iran
[4]Department of Agricultural Machinery, Ramin Agricultural Complex,
Shahid Chamran University, Ahwaz, Iran

Abstract: The effect of three tillage systems e.g. conventional (CT), minimum (MT) and no tillage (NT) systems on wheat root growth was studied in a silty clay loam soil under flood irrigation system in southwestern of Iran. Root length density and below ground biomass were determined at tillering and anthesis stages of wheat (*Triticum aestivum* L.) growth by soil core sampling and excavation. In tillering stage, root densities of 5-10, 10-20 and 0-30 cm soil depth were significantly different among tillage treatments. The difference was not significant for 0-5 and 20-30 cm depth. In anthesis stage, root densities were significantly different among tillage treatments for all soil layers except for the 20-30 cm depth. Although, the CT treatment resulted in a greater root length density and below ground biomass at tillering stage, the root length density and below ground biomass increased in MT compared to other tillage treatment at anthesis stage. The ratio of below ground biomass to above ground biomass was not significantly different among the tillage treatments. Although grain yield obtained in NT was about 500 kg ha^{-1} greater than other tillage treatments, the differences in grain yield, straw, leaf area index, 1000 grain weight and the seed harvest index among tillage treatments were not statistically significant. The results suggest that the inhibition of root growth by possibly mechanical impedance of soil can be declined in later stage of wheat growth and the reduced tillage system produce wheat root length density equivalent or even higher than the conventional tillage in a semiarid region.

Key words: Root length density, tillage, wheat, yield

INTRODUCTION

Agricultural production systems in the southwestern Iran generally include intensive tillage for seedbed preparation, fertilization and weed control. The intensive tillage systems results in soil compaction and hence impeding root growth[1]. Soil with unsuitable levels of physical properties often have some interrelated problems such as compacted layer, low hydraulic conductivity, water logging and poor aeration. These soils hence present an unfavorable environment for root growth.

Tillage systems influence soil temperature[2], mechanical impedance[3], structural stability[4-6], soil water holding capacity[6], soil bulk density[7], earthworm activity and infiltration rate[8], organic C and N[9] and exchangeable Ca, Mg, P and Zn[10]. These in turn may affect growth and distribution of plant roots[11,12]. Plant roots require adequate nutrition, temperature, aeration and water to grow and function properly. Consequently, tillage may also influence root growth. Since root distribution influences plant water and nutrient uptake, it would be essential to determine the root growth under different tillage systems. For example, Willigen *et al.*[13] indicated that the net P uptake per unit weight of plant was determined by root length uptake kinetics and the root length per unit weight of plant. Similarly Tinker and Nye[14] reported that the root exploitation of the soil increases the adsorption of different nutrients particularly P.

Proper distribution of water[15] and nutrients[9] are important for root growth. Although Barber and Kovar[15] indicated that tillage increased root mass and rooting depth, Cannell *et al.*[16] reported a reverse trend. No-till system may reduce rooting depth[17]. However, some studies[5,6] indicated that the reduced tillage increased soil structural stability which one can expect that exploitation of soils via the cracks can be facilitated. The root length density and its spatial arrangement can be varying also

Corresponding Author: Dr. A.R. Barzegar, Department of Plant and Soil Sciences, University of Massachusetts, Bowditch Hall, Amherst, MA 01003, USA Tel: 413 577 3102 Fax: 413 545 0260 E-mail: barzegar@pssci.umass.edu

with soil structure[18]. Entry *et al.*[19] indicated that the NT treatment resulted in a higher root biomass and root biomass infected with arbescular mycorrhizae. Godwin[3] stated that the effects of tillage on root development and function are the most important role of tillage systems in crop development. The objective of this study was to investigate the influence of different tillage systems on wheat root length density.

MATERIALS AND METHODS

Field procedures: This study was conducted in an ongoing long-term tillage-crop rotation study initiated in fall 2000. The site is located at Ramin Agricultural Research Station (48° 53'E and 31° 35'N) 25 km Northeast of Ahwaz with average altitude of 50 m. The soil used in this study is a silty clay loam which is representative of a large area of arable land in the Khuzestan Province in Iran. The soil is classified as a fine loamy clayey, carbonatic typic torrifluvent. The climate is characterized by a cold and rainy winter and a hot and dry summer. Mean annual rainfall is 224 mm, with approximately 90% of rain (on average) falling between November and March. The cropping sequence in the experimental site, for the last 25 years, was winter wheat and summer fallow.

A Randomized Complete Block Design with treatments arranged as a split plot was utilized. The treatments consisted of Conventional Tillage (CT), Minimum Tillage (MT) and No Tillage (NT). In CT, moldboard plowing with 25 cm depth followed by two disking to a depth of 10 cm was used. MT consisted of disc plowing to a depth of 15 cm followed by disc harrowing to a depth of 10 cm. Treatments were replicated three times and individual plots were 40 m long, 14 m wide and were 3 m apart. The site was tilled and sown to winter wheat in December 2001. The row spacing was 18 cm. Experimental plots received 50 kg ha^{-1} urea (46% N) and 175 kg ha^{-1} diammonium phosphate broadcast before planting. Plots also received 150 kg ha^{-1} urea as top dress when plants were at anthesis stage. To control weeds for NT plots, paraquat (Gramaxon) was used at the rate of 2l ha^{-1} before sowing. All plots received 2l ha^{-1} of 2-4-D at the tillering stage. Prior to planting, composite soil samples were taken from 0-5, 5-10, 10-20 and 20-30 cm of topsoil, then air dried and sieved. The soil bulk density was estimated by taking the intact soil cores from the soil layers down to the 30 cm depth with a 10 cm diameter steel coring sampler.

At tillering and anthesis stages, root length density and dry matter weight were determined from 7 cm diameter excavated samples obtained in the row and midway between two rows on three consecutive plants in each plot. The cores were taken from 0-5, 5-10, 10-20 and 20-30 cm depth, bagged and refrigerated. Wheat top growth was also measured at the time of root excavation. Wheat from three 1 m^2 areas within each plot was harvested in early June 2001. To minimize the edge effect, a 0.5 m buffer zone was designated along the edge of each plot. Grain yield was adjusted to a 120 g kg^{-1} moisture content basis. Also measured were grain yield, straw yield, leaf area index, biomass at the grain filling stage, 1000 grain weight and seed harvest index.

Three intact soil cores were taken from the soil layers down to the 30 cm depth with a 10 cm diameter steel coring sampler. The bulk density of the soil at two stages of wheat growth, namely tillering and anthesis was measured using the total weight and volume of all intact cores taken from each depth.

Laboratory procedures: The soil core, including soil and roots, was removed and immersed in water overnight and the soil attached to roots was removed by sieving to pass a 0.5 mm opening. Roots were collected and washed. Roots were washed manually. Subsamples of roots were dried for 48 h at 60-65°C and the dry weight was determined. Roots were conserved in Glycerin solution at 5°C. Root length was measured by determining the length of the root in a shallow tray of water using the line intersection method[20]. A 0.5 cm grid was used. Roots of known length were randomly placed on the grid to determine the accuracy of the measurement. Root length density was calculated as the quotient between root length and volume of sample.

The dry matter weight of the above ground biomass was determined after drying at 70°C for 72 h. Soil texture was determined by the pipette method[21]. The concentration of organic matter was determined using the potassium dichromate oxidation method.

Statistical analysis: An analysis of variance for a split-split plot design was performed to evaluate the significance of tillage treatment effects on root mass distribution using the SAS statistical package for analysis of variance[22].

RESULTS AND DISCUSSION

Soil properties: Selected physical properties of experimental site just prior to the experiment are given in Table 1. The electrical conductivity of soil extracts ranged from 2.1 to 3.3 dS m^{-1}. The soil texture was silty clay loam with range of clay content from 34 to 36%. The concentration of organic matter decreased from 12 to 9 g kg^{-1} as the soil depth increased (Table 1).

Table 1: Selected physical properties of soil

Soil depth (cm)	^{a}O.M (g kg^{-1})	^{b}BD (Mg m^{-3})	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})
0-5	12.1	1.55	354	546	108
5-10	10.0	1.60	336	520	144
10-20	9.5	1.64	358	530	132
20-30	9.0	1.64	348	528	140

^{a}O.M., organic matter; ^{b}BD, bulk density

Table 2: Statistical analysis of the effect of different tillage treatments on root length density (cm cm^{-3}) of different soil layers

	Soil depth (cm)							
	Tillering				Anthesis			
F-test	0-5	5-10	10-20	20-30	0-5	5-10	10–20	20-30
Replicate	ns	ns	ns	ns	ns	ns	ns	*
Tillage systems	*	*	*	ns	ns	ns	*	*
^{a}CV (%)	21.0	18.1	23.8	19.9	13.7	18.0	26.3	23.6

^{a}CV, coefficient of variation

Table 3: Statistical analysis of effect of tillage treatments on root dry weight (mg cm^{-3}) at different soil layers

	Soil depth (cm)							
	Tillering				Anthesis			
F-test	0-5	5-10	10-20	20-30	0-5	5-10	10–20	20-30
Replicate	ns	ns	ns	ns	ns	ns	ns	ns
Tillage systems	*	*	*	ns	*	ns	*	*
^{a}CV (%)	17.5	28.3	18.3	21.2	9.0	17.6	18.3	19.0

^{a}CV, coefficient of variation

Table 4: Statistical analysis of effect of tillage treatments on root and shoot dry weights and the root:shoot at anthesis stage

F-test	Root	Shoot	Root:Shoot
Replicate	ns	ns	ns
Tillage systems	ns	ns	ns
^{a}CV (%)	13.5	14.2	21.7

^{a}CV, coefficient of variation

Soil bulk density (measured at two stages of wheat growth) was not significantly different among tillage treatments. CT treatment generally had a lower bulk density during the early stages of corn growth[5]. These results are consistent with Blevins *et al.*[23], who showed no differences in bulk density among tillage systems for corn production. However, some studies reported that primary tillage operations had a transitory influence on soil physical properties because of soil setting after wetting and drying cycles occurred[24]. Wetting and drying cycles occurred during the growing months because of the rainfall pattern and also due to irrigation. Recently, Katsvairo *et al.*[8] reported some physical properties of a 6-year tillage, crop rotation and management systems. They indicated that tillage and crop rotation had no significant effect on soil bulk density.

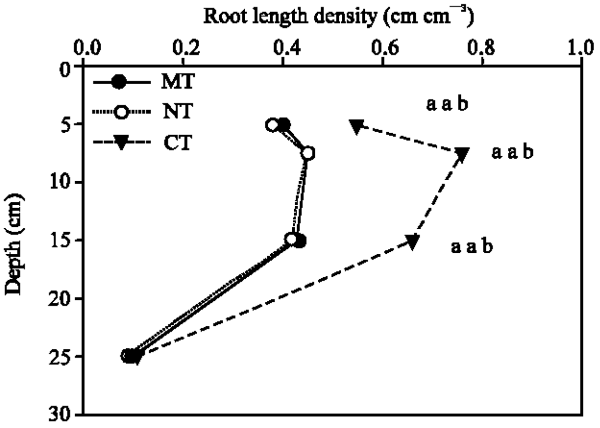

Fig. 1: Root length density of winter wheat at tillering stage as influenced by tillage systems. MT, minimum tillage; NT, no tillage; CT, conventional tillage. Different letters at each depth indicate significant differences ($p<0.05$)

Root growth: Wheat root length density at tillering stage under different tillage systems is shown in Fig. 1. Roots were much denser in 0-5 and 5-10 cm depth for all tillage treatments. The CT had the highest root length density in 0-5 and 10-20 cm depth. The root length density of MT and NT treatments were similar. In reduced tillage systems, roots of wheat were more concentrated at the shallower depths than the CT tillage treatment (Table 2). This difference in root distribution can be attributable in part to the slower preliminary growth of plants in reduced tillage systems due to competition of weeds. Ozpinar[25] indicated that weed density in mouldboard plow was significantly lower than the reduced tillage with either rototiller or disc. Root dry weight of wheat in various soil

Table 5: Yield and yield components of winter wheat as influenced by tillage treatments

Tillage[a]	Gy[b] (kg ha^{-1})	LAI[c]	Straw (kg ha^{-1})	1000 Gw[d] (g)	Biomass[e] (kg ha^{-1})	SHI[f]
NT	4367	0.32	9372	42.2	11602	1.85
MT	3750	0.27	9424	43.1	9189	1.96
CT	3925	0.28	10817	42.1	10502	2.07
LSD$_{0.05}$	723	0.09	1377	3.9	2263	0.37

[a] NT, no tillage; MT, minimum tillage; CT, conventional tillage; [b] Grain yield, [c], leaf area index; [d], grain weight, [e], measured at grain filling stage; [f], seed harvest index.

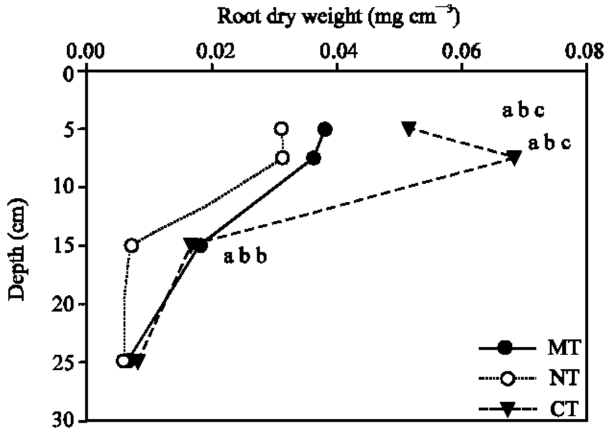

Fig. 2: The effect of tillage systems on the wheat root dry weight distribution at tillering stage. MT, minimum tillage; NT, no tillage; CT, conventional tillage. Different letters at each depth indicate significant differences ($p<0.05$)

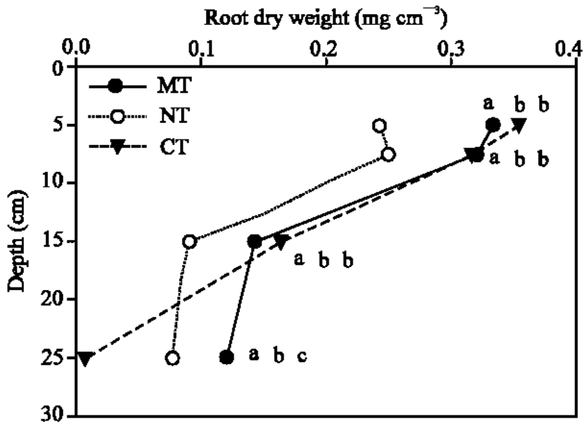

Fig. 4: The effect of tillage systems on the wheat root dry weight distribution at anthesis stage. MT, minimum tillage; NT, no tillage; CT, conventional tillage. Different letters at each depth indicate significant differences ($p<0.05$)

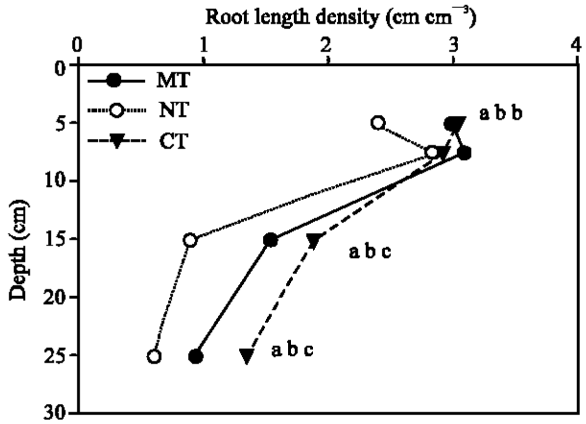

Fig. 3: Root length density of winter wheat at anthesis stage as influenced by tillage systems. MT, minimum tillage; NT, no tillage; CT, conventional tillage. Different letters at each depth indicate significant differences ($p<0.05$)

depths followed a similar trend as root length density where CT treatment produced the highest root dry weight at 0-5 and 5-10 cm depth (Fig. 2 and Table 3). The difference in root weight among tillage systems showed a reducing trend with increasing soil depth. No significant difference in root dry weight was found at 20 cm depth. In a warm weather condition such as Southern Iran, in tillering stage unlike cold and temperate regions is relatively short. Therefore, roots are not well developed at this depth, regardless of tillage systems.

A large concentration of roots at shallower depth of the CT treatment is in agreement with observation reported by other researchers[26]. This could be due to lower bulk density of the plowed soil in the CT treatment. Without soil mixing it might be possible that the nutrients become more concentrated near the soil surface. Tillage systems alter soil physical properties including soil bulk density[5], soil penetration resistance[27], soil organic matter[4] and soil structural stability[6]. Wheat roots respond to these changes, shifting their roots to the areas in the soil that are more conductive to growth. The external pressure of the soil consists of the pressure required to deform the soil, plus a component of frictional resistance between the root and soil[27]. Conservation tillage systems tend to increase the root concentration in the surface layer[17].

In anthesis stage, root densities of CT and MT at 0-5 and 5-10 cm were not significantly different. The NT treatment however, had the lowest root length density in all soil depths (except 5-10 cm depth) compared to the other two tillage treatments (Fig. 3). However, the root distribution of NT was higher at 0-5 and 5-10 cm depth compared to other tillage treatments. The root dry weights of CT and MT treatments were not significantly different in all soil layers except at 20-30 cm depth in which the MT treatment had the highest root dry weight compared to the other tillage treatments (Fig. 4). Several studies have revealed that reduced root length density was related to soil physical conditions[26, 27]. The CT treatment had the lower bulk density at tillering stage compared to other tillage treatments. Whereas at the anthesis stage, the order of bulk density of tillage treatment was MT<NT<CT (data not shown). Mechanical strength of soil increases as soil bulk density increases and root growth decreases[24]. The statistical analysis of root length density and root dry weight are indicated in Table 2 and 3, respectively. High coefficient of variation of Tables 2 and 3 can be due to interactions between root system structure and soil conditions. This has been reported by other authors[28]. The influences of tillage treatments on above-ground biomass and shoot: root ratio was not significantly different (Table 4). The shoot: root ratio is generally affected by nutrient status of soil, climatic conditions[11], etc.

It was apparent that plants continued to produce roots during reproductive development in the MT treatment compared to CT treatment. This partitioning of carbon to root growth during the anthesis stage is probably a detriment to above-ground biomass. A higher root mass per unit leaf area results in a higher water uptake capacity per unit transpiring leaf area[29]. This supports higher stomata conductance and hence higher photosynthesis and transpiration rates[30]. Water uptake depends to a greater extent on the root surface area[29].

Wheat plants under no-till had a greater yield compared to the other tillage treatments. However, the yield difference was not statistically significant (Table 5). Halvorson *et al.*[31] compared the grain yield of winter wheat under different tillage systems in a dryland region of United States and indicted that no-till resulted in higher grain yield compared to CT and minimum tillage. Although the dry matter of weeds was not measured one explanation for non-significant results occurred between tillage treatments, could be due to greater incidence of weeds in the NT treatment. Our results of wheat yield are consistent with those of Pikul *et al.*[32], who found no consistent differences due to tillage for winter wheat yield despite measurable changes in soil properties.

Tillage treatments changed the root distribution pattern of winter wheat. CT treatment increased root length density in the top 10 cm depth at the tillering stage. However, NT and MT treatments increased both root length density and the below ground biomass at the anthesis stage.

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