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Tillage Effects on Soil Compactness and Wheat Root Morphology

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ABSTRACT

Tillage systems influence soil physical, chemical and biological characteristics which in turn may alter, root characteristics, growth, and development. A three year study was conducted to investigate the effects of seven tillage systems on some soil (fine-loamy mixed, Typic Haplocambids) physical characteristics and wheat *(Triticum aestivum* L.) root morphology. Tillage treatments included moldboard plowing + disking (MD) as conventional tillage, chisel plowing + disk (CD), chisel plowing + rotary tilling (CR), chisel plowing (twice) + disking (2CD), plowing with a khishchi (a regional rigid cultivator) (KD), as non-inversion methods, and till planting with cultivator combined drill (TP), and no-tillage (NT) as direct drilling methods. Soil texture, bulk density (BD), organic matter (OM) and compactness (CI) were determined. At the depths 0-0.1, 0.1-0.2, 0.2-0.3 and 0.3-0.4m, root mass density (RMD) was obtained, root length density (RLD) was determined and average root diameter (RD), surface area density (RSD), and root fineness (RF) were calculated. A randomized complete block design consisting of four blocks (replications) was used. For all treatments, the upper layer (0-0.lm) contained a higher quantity of RMD, RLD and RSD, but the reverse was observed for the lower layer (0.3-0.4m). The upper layer (0-0. lm) contained almost 46% of the total RMD (average of all treatments), while the second (0.1-0.2m) the third (0.2-0.3m) and fourth (0.3-0.4m) depths contained 23, 18.5 and 12.5% of the total RMD, respectively. The average RLD of four depths for MD, CD, CR and 2CD were significantly ($P \leq 10$)higher than KD, TP and NT systems (24.9, 25.1, 24.2, and 23.8, as compared with 22.3,21.8 and 21.6km m^{-3} , respectively). Results of this study showed that, for the arid soils of central Iran, with weak structure and low organic matter content, as the number of tillage operations increased, root morphological characteristics improved.

Key words: Dry regions, Root morphology, Tillage, Wheat.

INTRODUCTION

Soil management systems including tillage practices, are aimed at altering and minimizing the stress effects of the environment. Soil characteristics such as bulk density and mechanical impedance can be affected by tillage practices, and may markedly alter root growth and distribution (Russell, 1981). Tillage induced effects on root morphology due to changes in soil properties are reported by many investigators (Vepraskas and Wagger, 1990; Kaspar *et al.*, 1991). Vepraskas and Wagger (1990) reported that, chisel plowing loosens dense root-restricting layers within 0.25m of the soil surface while subsoiling can be used for loosening the soil to a depth of almost 0.45m. Chiseling caused root proliferation to a depth of 0.lm and subsoiling to a depth of 0.3 to 0.4m (Vepraskas and Wagger, 1990). Soil compaction (i. e. increase in soil bulk density) alters root growth, primarily as a result of two stresses, mechanical impedance, and anoxia (Trouse, 1971). Mechanical impedance can cause marked morphological alterations within the root system.

According to Barley *et al.* (1970), root elongation rate is clearly influenced by soil mechanical resistance induced by tillage

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practices. Exposing maize roots to 40 KPa of pressure resulted in a 75% reduction in root length, a 50% increase in root diameter and increased root branching (Veen, 1982). Chaudhary *et al.* (1991) concluded that, tillage induced compaction, inhibited lateral spread of wheat roots in the surface soil layers and caused greater downward growth of roots. Kaspar *et al.* (1991) found that the upper 0.15m of inter-rows with wheel-traffic compaction has less than one-half the root length and root weight of untracked inter-rows.

Conventional tillage practice is the most usual way of soil management in Central Iran (Isfahan). Almost no studies have examined the effects of tillage management practices on wheat root morphology in this region. In order to verify the effects of different methods of soil management on wheat root morphological characteristics, a three year experiment was established in 1994 to compare seven types of tillage systems (ranging from conventional to no-till). Root fresh, and dry mass density, root length density, diameter, surface area and fineness were determined. To contrast the plasticity behavior of root with soil in different management systems, organic matter content, bulk density and mechanical strength of the soil were determined too.

MATERIALS AND METHODS

Study Site

The effect of seven tillage systems on soil compactness and wheat root morphology was studied during three years (1994-1996) at the Kabootarabad Research Station Agricultural Research Center, 40km south east of Isfahan (Central Iran). The soil (fine-loamy mixed, Typic Haplocambids) (Calcic Cambisol) at the beginning of the study had a clay loam texture in 0-0.20m surface layer (240g kg^{-1} sand, 400g kg^{-1} silt, and 360g kg^{-1} clay) and a clay texture in the 0.20-0.65m depth (120g kg^{-1} sand, 440g kg^{-1} silt, and 440g kg^{-1} clay). A summary of soil physical and chemical characteristics is given in Table 1.

The field, at least two years prior to applying the treatments was under barley production while cultivated conventionally. Prior to the beginning of the experiment the straw was removed and the previous crop residues, for all except the no-till treatment, were burned. The plots were irrigated and emerged weeds sprayed with paraquat herbicide (1kg ha^{-1}). Experimental plots were 10 m wide by 45m long with borders 6m wide and a main border of 10m width between each two blocks. Tillage treatments include moldboard plowing+disking (MD) as conventional tillage, chisel plowing + disk (CD), chisel plowing+rotary tilling (CR), chisel plowing (twice)+disking (2CD), plowing with a khishchi (a regional rigid cultivator) (KD), and till planting with cultivator combined drill (TP), and no-tillage (NT). Khishchi is a local-made secondary tillage implement used in the region. It carries 15 straight rigid shanks, fixed on a two-row chassis at a spacing of 0.14m with a vertical clearance of 0.35m. Each shank is equipped with a triangular 0.05m wide point with a rake angle of 44^0 .The MD, CD, CR, 2CD and KD systems are called tilled treatments and all except MD would be termed non-inversion tillage systems. The TP and NT are direct drilling systems. The implements for the primary and secondary cultivation were predetermined for each treatment, but the number of secondary tillage operations was chosen according to the soil conditions at the time of land preparation (Hemmat and Khashoei, 1997). The plowing depth in moldboard, chisel and khishchi plowing for the first year was 0.20, 0.20 and 0.15m, respectively, but for the other two years was 0.20, 0.15 and 0.10 m. A winter wheat *(Triticum aestivum* L.) cultivar *Ghods* was seeded at a rate of 180 kg ha^{-1} using a grain drill with a row spacing of 0.12m in the tilled treatments. The row spacing for the cultivator combined-drill was 0.18m. Fertilizer was applied at the rate of 135 kg ha^{-1} N in the form of urea, and 40 kg ha^{-1} P in the form of ammonium phosphate. Half of N, and all of the P fertilizer were applied before the secondary tillage operation and the other half of N was applied at the end of March, the following year. Wheat was planted in November and harvested in July. Land preparation and planting were established, when in a dry soil, followed by irrigation to bring the soil moisture to field capacity. The field was irrigated six times from March to harvest time. To control broadleaf weeds, 2-4-D was applied at a rate of 1.5 1 ha^{-1} in spring, each year.

Determination of Soil Properties

Soil texture, bulk density, and organic matter were determined using the methods of hydrometer (Gee and Bauder, 1986), constant core (Blake, 1986), and digestion (Walkly and Black, 1934), respectively. Other soil physical and chemical properties were determined using the methods suggested by Klute (1986) and Page (1992). The first year prior to beginning of the experiment, soil samples were taken at 0-0.20, and 0.2-0.65m depth (Table 1) and at the end of third year at 0-0.15 and 0.15-0.3m (Table 2). Soil cone index (CI) as the soil mechanical strength or compactness was measured using a digital penetrometer (model SP 1000). The moisture content at the time of CI measurement was 1.1PL (Plastic Limit) (Cassagrande, 1948) at 0-0.l and 0.1-0.2m, and l.2PL at 0.2-0.3 and 0.3-0.4 m, for all the treatments. In each plot 10 points (replications) were used for measuring soil strength, CI at each depth increment was the average of these points. Cone index (MPa) was calculated using the following relation: CI=0.098*(F/A) where F is the force inserting the rod into soil (kgf), and A is the surface are of the cone (cm^2).

Determination of Root Properties

Root morphology was characterized via soil samples, collected at lm distance inside each plot, using a hand held probe (0.15 m diameter at cutting edge). At booting stage of growth (Boots just visible) (Gregoire *et al.,* 1997) each year samples containing roots were taken. After cutting the shoot, the probe was held in a way to have the main root axes located in the center. The probe was hammered to a 0.4m depth then the specified depths (0-0.1, 0.1-0.2, 0.2-0.3 and 0.3-0.4m) being separated.

Three replications out of each plot were used. Soil samples were immediately transferred to the laboratory roots being carefully separated from soil and other residue by gentle washing under a flow of swirling water. After washing and separating the roots from soil, root mass density (RMD) (kg root per m^3 of soil), and root length density (RLD) (km root per m^3 soil) were measured, using modified line intersect method (Newman, 1966). Once the root length was determined, roots were oven dried for 36h at 60^0C for dry root mass density (DRMD) determination. When root specific mass (Mg m^{-3}) assumes unity and all the roots cylindrical, then root diameter (RD) was determined using the equation: $RD=(4*RFW/(RL*3.14))^{1/2}$, where RFW is root fresh weight (kg) and RL root length (m) (Schenk and Barber, 1979). Then root surface area density (RSD) (km^2 root per m^3 soil) was calculated using the equation: RSD= (RL*RD*3.14). Root fineness (RF) was also determined by dividing root length to the root fresh mass. Analysis of variance of the results was conducted using the SAS (SAS, 1985) program, and the means in the results were compared using the Duncan new multiple range test (Steel and Torie, 1986).

RESULTS AND DISCUSSION

Soil General Characteristics

Analysis of variance (ANOVA) indicated that applying different management practices caused a significant change in soil physical properties, thus changing root morphological characteristics accordingly. The magnitude of this influence depended on the

Table 1. Soil texture, bulk density (BD), pH, electrical conductivity (EC), organic matter (OM), available phosphorous (P) and potassium (K) at two soil depths. Measurements taken prior to the start of experiment.

Soil depth (m)	Texture	BD Mg m^{-3}	pH	EC mmhos cm^{-1}	OM	P mg kg^{-1}	K
0-02	Clay-loam	1.42	7.8	0.9	940	22	172
0.2-0.65	Clay	1.51	7.9	1.1	840	14	177

kind of management. Comparing the results of soil physical and chemical properties at the beginning (Table 1), to properties measured at the end of the experiment (Table 2), no change was observed in soil texture, EC, and available P and K (data not shown), but soil pH was lower, especially for NT system (Table 2). It is perhaps due to decomposition of soil organic matter and, thus accumulation of organic acids in the topsoil (Angers and Mehuys, 1989).

Soil Organic Matter, Bulk Density and Strength

Tillage influenced soil organic matter (SOM), due to differences in distributing and storing by physically mixing crop residues and by chemically oxidizing organic matter in soil. The magnitude of SOM in the surface soil (0-0.15m) and for MD system was significantly (at 0.05 probability level) lower than the other treatments, in the third comparing to the first year of the study. Many other studies indicated that, the use of reduced or no-tillage practices better protect the soil resources by protecting SOM compared to the MD (Doran, 1987; Mahboubi *et al*. 1993; Kern and Johnson, 1993; and Paustian *et al.* 1997). At the second depth (0.15-0.30m) no difference on SOM was observed comparing the third to the first year of the experiment but at the third year only CR and 2CD systems had significantly (at 0.05 probability level) higher amount of SOM relating to the other treatments (Table 2).

As the number and magnitude of soil cultivating operations increased higher soil bulk densities were obtained. This could be the result of crashing larger particles (aggregates) and translocating fine particles to the large pores, and also due to a more SOM lost. At the first depth (0-0.15m), MD and

Table 2. Soil bulk density (BD), pH, organic matter (OM), total nitrogen (TN) for seven tillage practices, at two soil depths. Measurements are taken at the end of the third year of experiment.

Tillage Treat.	BD Mgm^{-3}	PH	OM mg kg^{-1}	TN mg kg^{-1}
Depth 0-0.15 m				
MD[a]	1.57a	7.5 a	850 a	55 a
CD	1.45b	7.4 a	1050 b	50 a
CR	1.46b	7.3 a	960 b	54 a
2CD	1.63a	7.4 a	960 b	64 b
KD	1.5ab	7.4 a	920 a	64 b
TP	1.52ab	7.4 a	1050 b	60 ab
NT	1.46b	7.2 b	1090 b	66 b
Depth 0.15-0.30 m				
MD	1.66 a	7.5 a	800 a	35 a
CD	1.54 a	7.4 a	820 a	47 b
CR	1.58 a	7.4 a	670 b	48 b
2CD	1.46 b	7.4 a	660 b	47 b
KD	1.62 a	7.5 a	860 a	54 b
TP	1.47 b	7.4 a	900 a	53 b
NT	1.49 b	7.5 a	860 a	55 b

[a] Moldboard + disk, CD = chisel + disk, CR = chisel + rotary, 2CD = chisel (twice) + disk, KD = khishchi, TP = till planting with cultivator combined drill, NT = no-tillag. Means in each column and for each depth, followed by the same letter are not significantly different (P<0.05).

2CD systems had significantly (at 0.05 probability level) higher (almost 10%) figures of BD as compared to the other treatments (Table 2). Yang and Wandr (1999) by comparing the amount of SOM and BD for no-tillage (NT), disk tillage (DT) and moldboard plow (MP) concluded that the use of NT practices increased SOM concentrations in top few centimeters (0-0.05m), and BD in top 0.30m as compared to the DT and MD systems. Voorhees (1992) hypothesized that a no-tillage system may result in higher bulk

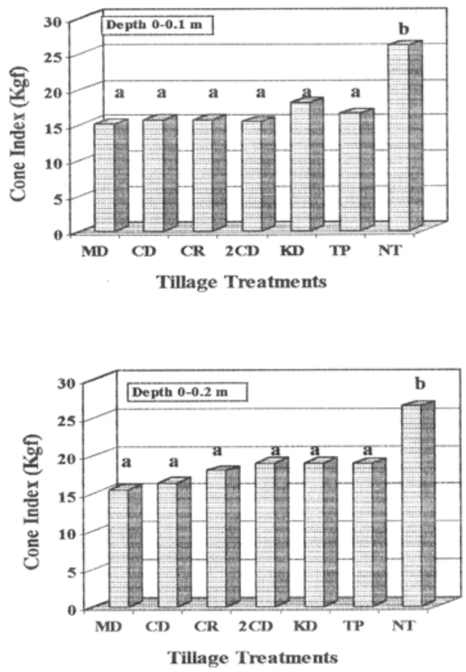

Figure 1. Cone index (CI) taken in seven tillage systems (means of 10 points) at 0-0.1 and 0-0.2 m layers. Means with the same letter are not significantly different (P<0.05). DM= moldboard + disk, CD= chisel +disk, CR= chisel + rotary, 2CD= chisel (twice) + disk, KD= khishchi, TP= till planting with cultivator combined drill, NT= no-tillage.

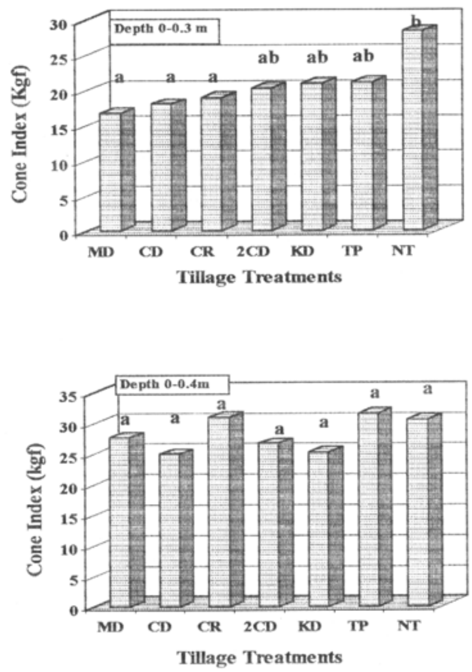

Figure 2. Cone index (CI) taken in seven tillage systems (means of 10 points) at 0-0.3 and 0-0.4 m layers. Means with the same letter are not significantly different (P<0.05). DM= moldboard + disk, CD= chisel +disk, CR= chisel + rotary, 2CD= chisel (twice) + disk, KD= khishchi, TP= till planting with cultivator combined drill, NT= no-tillage.

densities due to incomplete amelioration of compacted soil over the winter. Bauer and Black (1981) reported that cultivating could loose the topsoil for a specific period of time then, due to heavy traffic (Soane *et al.,* 1982), the soil will be compacted again.

Soil strength and bulk density are two major soil physical factors known to affect crop root development (Taylor, 1974; Jones, 1983), in turn amount and type of SOM is a parameter influencing soil strength properties and rooting characteristics (Gerard *et al.* 1982). Figures 1 and 2 show the effect of seven tillage systems on soil strength as shown by cone index. Despite higher amount of SOM on the surface for NT relative to the other systems, the cone index figures at the surface layers were significantly higher (Figures 1 and 2). This is basically due to the nature of the soil in the region, with high amount of clay and low amount of OM (around 1%), which provides a thick layer of sealing on the surface. There were no significant differences in CI among other tillage treatments. This indicates that as far as root penetration is concerned, a kind of cultivation in autumn or winter, for this soil is obligatory. According to Karlen (1990) soil compaction is considered to be the more serious problem limiting the adoption of no-till system. Hajabbasi and Hemmat (2000) concluded that although, adopting no-till system in this region improves SOM and consequently aggregation, but due to an initial weak structure and still low organic matter, a complete or at least partial amelioration of soil in winter is necessary. At depth 0-0.40m there were no differences observed among the treatments for CI, indicating that a higher CI for NT as compared to the other systems, at the surface layer, equalized at the lower depths.

Root Morphological Characteristics

Change in soil physical properties (e. g. soil strength and pore space) resulting from compaction directly affected the root growth characteristics. Analysis of Variance (ANOVA) at P≤1 level of probabilities showed that there were no differences in root fresh and dry mass, root length and fineness and root surface area among the three years of study, thus all the data presented here are the means of three years. The effects of tillage practices on root morphological characteristics will be discussed consecutively.

Root Mass Density

The influence of tillage systems on root fresh and dry masses within treatments, depths and years, followed almost similar trends, thus only fresh root mass density will be discussed here. Quantitatively, root dry mass was almost 14% that of root fresh mass. Due to suitable moisture content and aeration (because of irrigation), the soil in this experiment was believed physically appropriate for root growth in the top 0.10 m The relative proportion of root mass density (RMD) for treatments, at depths 0-0.1, 0.1-0.2, 0.2-0.3, and 0.3-0.4m, were respectively 46, 23, 19, and 13% (Table 3). Kaspar *et al.* (1991) also reported that almost 65% of root weight were proliferated in the upper layer (0-0.15 m) of an untracked row of a silt-clay loam soil in Iowa, while root fresh weight in the tracked row, with a higher mechanical impedance, was about 45% of total RMD. The average (over four depths) RMD for different tillage treatments are shown in Table 3.

The MD system with 3.28 and TP and NT with 2.71 and 2.76 kg m^{-3} had respectively the highest and the lowest amounts of RMD (average of four layers). At 0-0. 1m no significant difference was obtained among the treatments, while at the other depths generally as the number of cultivating operations increased, RMD was increased too. Newell and Wilhelm (1987) discussed that tillage systems alter the soil environment, thus providing a potential for affecting root distribution within the soil profile. On a clay-loam soil, Bauder *et al.* (1985) also, felt that reduced or no-tillage systems would lead to an increase in the development of root restricting soil layers.

Root Length Density

Root length density (RLD) varied from depth to depth within the tillage treatments, but the average values for four depths with regard to tillage systems were more consistent. As the number of operations increased RLD was increased too (Table 4). Generally,

Table 3. Wheat fresh root mass density (kg m^{-3}) in soil cores taken in different tillage systems at four depths, averaged across three years.

	Depth (m)				
Treatments	0-10	0.1-0.2	0.2-0.3	0.3-0.4	Mean
MD[a]	5.10 a	3.08 ab	2.44 ab	1.35 b	3.00 ab
CD	5.51a	3.19 a	2.63 a	1.79 a	3.28 a
CR	6.16 a	2.40 bc	2.21 ab	1.33 b	3.02 ab
2CD	5.31 a	2.64 ab	1.83 b	1.85 a	2.91 ab
KD	5.55 a	2.70 ab	1.89 ab	1.22 b	2.84 ab
TP	5.09 a	2.46 b	2.01 ab	1.28 b	2.71 b
NT	5.01	2.24 c	2.20 ab	1.60 ab	2.76 b
Mean [b]	5.39 a	2.67 b	2.19 c	1.49 d	

[a] Moldboard + disk, CD= chisel + disk, CRchisel + rotary, 2CDchisel (twice) + disk, KD= khishchi, TP= till planting with cultivator combined drill, NT=no-tillage. Means in each column followed by the same letter are not significantly different (P< 0. 10). [b] Means in this row followed by the same letter are not significantly different (P<0.05).

Table 4. Wheat root length density (km m^{-3}) in soil cores taken in different tillage systems at four depths, averaged across three years.

	Depth (m)				
Treatments	0.0.1	0.1-0.2	0.2-0.3	0.3-0.4	Mean
MD[a]	39.7 ab	27.7 a	20.0 a	11.8 bc	24.9 a
CD	38.3 ab	27.1 a	19.6 a	15.4 b	25.1 a
CR	44.1 a	21.8 ab	18.5 a	12.2 c	24.2 a
2CD	39.8 ab	23.5 ab	15.1 a	16.9 a	23.8 a
KD	40.3 ab	21.9 ab	16.6 a	10.4 c	22.3 b
TP	38.6 ab	21.7 ab	15.8 a	11.1 c	21.8 b
NT	35.6 b	20.1 b	16.8 a	14 ab	21.6 b
Mean [b]	39.5 a	23.4 b	17.5 c	13.2 d	

[a] Moldboard ± disk, CD= chisel + disk, CR= chisel + rotary, 2CD=chisel (twice) + disk, KD= khishchi, TP= till planting with cultivator combined drill, NT=no-tillage. Means in each column followed by the same letter are not significantly different ($P<0.10$). [b] Means in this row followed by the same letter are not significantly different ($P<0.05$).

reduced or no-till cultivating systems (NT, PT, and KD) had resulted in a lower root length density, as compared to the conventional and non-inversion tillage systems (Table 4). Within all of the treatments RLD was the highest at the first depth (0-0.lm) (42%), while at 0.1-0.2, 0.2-0.3, and O.3-0.4m this proportion was 25, 19 and 14%. As mentioned for RMD, this is probably due to favorable conditions at the first layer of the soil. Not all the researchers agreed in this manner. Ehlers *et al.* (1983) reported that despite greater bulk density under minimum tillage, as compared to the conventional, barley root growth increased in the 0. l2m of the soil. Barber (1984) found that although total corn root weight declined, root length density was greater in the surface 0.1m of soil in the corn row under minimum tillage. Unlike Oussible *et al.* (1992) who reported root weight density of wheat was not affected by compacted soil, but length density was significantly reduced, this study showed that, root mass and length density were both significantly affected by different tillage managements. Thus there must be some different changes in anatomy and/or morphology for genotypes of a specific crop or different crop roots growing in unfavorable soil environmental (e. g. compaction, restricted moisture) conditions or at various times of growing season. Chaudhary and Prihar (1974) found that conventional tillage encouraged earlier and deeper penetration of corn roots into the soil profile than did no-tillage, but no-tillage had more roots in the top 0.20m of soil during early growth stages. Garcia *et al.* (1988) reported that irrigation enhanced root growth and development in the soil surface. Newell And Wilhelm (1987) concluded that irrigation can enhance shallower root growth as compared to dry-land farming.

Root Fineness

Root fineness (RF) represents root diameter, a higher value of RF denoting a thinner root. Compared to the other tillage practices, at 0-0. lm depth, a reduction in root length to root fresh mass occurred in the CD and NT systems, which is an indication of thicker and shorter roots in that layer. At the first depth (0-0.lm) MD system had significantly (at 0.10 probability level) higher amount of root fineness (7.8 km kg^{-3}) compared to the CD and NT systems, which had the lowest values (6.9 and 7.1 km kg^{-3} respectively). At this depth the other tillage systems exhibited similar RF. At the depths 0.1-0.2, 0.2-0.3 and 0.3-0.4m no significant difference was observed among the treatments. Although, soil physical condition changes induced by tillage systems were not the same (Figures 1 and 2, Tables 3 and 4), RF (average of four depths) was not significantly different among the treatments (Table 5). This proves the theory that when soil conditions constrain root activity in one parts of the root system (root length or diameter), increased activity occurs in other parts of that system. This compensatory response has been observed for anoxia (Schumacher and Smucker, 1984), temperature and water uptake (Crossett *et al.,* 1975)*,* nutrients (Hajabbasi and Schumacher, 1994; Drew and Saker, 1978) and compaction (Garcia *et al.* 1988; Oussible *et al*. 1992; and Kaspar *et al.* 1991). All these soil characteristics could be affected by soil management practices. Oussible *et al*. (1992) also, reported a reduction in RF in the tillage induced compacted zones. Similar results were observed by Goss (1977); Schuurman (1965)*;* and Castillo *et al.* (1982) who demonstrated that high penetration resistance promoted root thickness causing considerable proliferation of fine lateral roots near the tips of the impeded roots.

Table 5. Root fineness (km kg^{-3}) in soil cores taken in different tillage systems at four depths, averaged across three years.

	Depth (m)				
Treatments	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	Mean
MD[a]	7.8 a	9.0 a	8.2 a	9.0 a	8.5 a
CD	6.9 b	8.5 a	7.7 a	8.6 a	8.0 a
CR	7.2 ab	9.1 a	7.9 a	9.4 a	8.4 a
2CD	7.5 ab	9.0 a	8.0 a	9.4 a	8.5 a
KD	7.3 ab	8.3 a	8.8 a	8.3 a	8.2 a
TP	7.6 ab	9.1 a	7.8 a	8.8 a	8.1 a
NT	7.1 b	8.9 a	8.0 a	8.7 a	8.2 a
Mean [b]	7.35 a	8.85 b	8.06 ab	8.89 b	

[a] Moldboard + disk, CD= chisel + disk, CR=chisel + rotary, 2CD=chisel (twice) + disk, KD= khishchi, TP= till planting with cultivator combined drill, NT=no-tillage. Means in each column followed by the same letter are not significantly different (P< 0.10). [b] Means in this row followed by the same letter are not significantly different (P<0.05).

Root Surface Area Density

Root surface area (RSD), a component proportional to root length and diameter, is the most important morphological characteristic influencing plant water and nutrient uptake (Barber, 1984). The relative distribution of wheat root decreased as depth increased. The average (over all of the treatments) proportion of RSD was the highest at the first depth (0-0.lm) (45%)*,*while at 0.1-0.2, 0.2-0.3, and 0.3-0.4m this proportion was 23, 19 and 13%. The highest magnitude of RMD and RLD of the CR system resulted in the larger root surface area (0.132km^2 m^{-3}) of this treatment as compared to NT system (0.107 km^2 m^{-3}) with the lowest RMD and RLD. There were no significant differences (at 0.10 probability level) among the other treatments, at this layer. Although no-till cultivating systems (NT and PT) result in a thicker root diameter (Table 5), but due to a smaller RLD (Table 4), application of these methods results in a lower root length density, as compared to the conventional (MD) and non-inversion (CD, CR, 2CD and KD) tillage systems (Table 6). In summary, in all the treatments, the upper most layer of soil revealed the most suitable soil physical characteristics, thus the largest magnitudes of root mass, length and consequently root surface area, were obtained in this layer, while in the deepest layer the lowest values were observed. Application of chisel plowing + rotary tilling (CR), with lower soil disturbance (compared to the conventional moldboard plow) resulted in the highest amount of root surface area and consequently could result in a higher water and nutrient uptake. Thus, CR as a conservational soil management practice can be rec-

Table 6. Root surface area density (km^2 m^{-3}) in soil cores taken in different tillage systems at four depths, averaged across three years.

	Depth (m)				
Treatments	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	Mean
MD[a]	0.114 ab	0.074 a	0.056 ab	0.033 bc	0.069 a
CD	0.116 ab	0.074 a	0.057 a	0.042 ab	0.072 a
CR	0.132 a	0.058 ab	0.053 ab	0.032 bc	0.069 a
2CD	0.116 ab	0.063 ab	0.042 b	0.045 a	0.066 ab
KD	0.119 ab	0.061 ab	0.045 ab	0.029 c	0.063 ab
TP	0.112 ab	0.059 ab	0.045 ab	0.030 b	0.061 b
NT	0.107 b	0.054 b	0.048 ab	0.038 ab	0.062 b
Mean [b]	0.117 a	0.061 b	0.049 b	0.035 c	

[a] Moldboard + disk, CD= chisel + disk, CR=chisel + rotary, 2CD=chisel (twice) + disk, KD= khish-chi, TP= till planting with cultivator combined drill, NT=no-tillage. Means in each column followed by the same letter are not significantly different (P< 0.10). [b] Means in this row followed by the same letter are not significantly different (P<0.05).

ommended in this region when preparing land for wheat production.

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تاثیر عملیات خاک ورزی بر تراکم خاک و مرفولوژی ریشه گندم

چکیده

عملیات خاک‌ورزی خصوصیات فیزیکی، شیمیایی و بیولوژیکی خاک را تغییر می‌دهد و به تبع آن خصوصیات مرفولوژیکی ریشه نیز تغییر می کند. مطالعه حاضر به مدت سه سال (۷٦-۱۳۷٤) تاثیر هفت نوع مختلف خاک‌ورزی بر جرم مخصوص ظاهری، مواد آلی و تراکم خاک و وزن، طول، و قطر ریشه گندم (قدس) را بررسی نموده است. تیمارهای خاک ورزی عبارت بودند از گاوآهن برگرداندار+ دیسک (MD) گاوآهن قلمی + دیسک (CD)، گاوآهن قلمی + روتیواتور (CR)، دوبار دیسک عمود برهم(2CD)، خیش چی (KD)، ورزکاشت (TP) و بدون خاک ورزی (NT). طرح به صورت بلوکهای کامل تصادفی در ٤تکرار در مزرعه تحقیقاتی سازمان تحقیقات کشاورزی اصفهان در کبوترآباد اجرا گردید. پس از سه سال آزمایش اگرچه وزن مخصوص کمتر ولی شاخص مخروطی (تراکم) در تیمار بدون خاک‌ورزی بیشتر از بقیه تیمارها بوده است. عمق بالایی (۰-۱۰ cm) تقریبا″٤٦٪ از وزن مرطوب ریشه ها را به خود اختصاص داد، در صورتی که این مقدار در اعماق ۲۰-۱۰، ۳۰-۲۰ و ٤۰-۳۰ سانتیمتری به ترتیب برابر با ۲۳ ، ۱۸/۵ و ۱۲/۵ درصد بوده است مقادیر تراکم ریشه در تیمارهای MD , CD , CR و2CD به ترتیب برابر با ۲٤/۹ km-m^{-3} ، ۲۵/۱ ، ۲٤/۱ و ۲۳/۸ می‌باشد که از لحاظ آماری (۱۰ درصد احتمالات) بیشتر از KD , TP وNT بوده که به ترتیب ۲۲/۳ km m^{-3} ، ۲۱/۸ و ۲۱/٦ را به خود اختصاص داده اند. نتیجه کلی این آزمایش نشان داد که برای خاکهای مناطق خشک مرکزی ایران که خاک تقریبا″ بدون ساختمان است و مقدار مواد آلی آن کم می باشد با افزایش عملیات خاک ورزی ریشه رشد بهتری خواهد داشت.