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Effects of Minimum and Conventional Tillage Systems on Soil Properties and Yield of Winter Wheat (*Triticum aestivum* L.) in Clay-Loam in the Çanakkale Region

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Abstract: The experiment was conducted during the 2001-2003 cropping period to evaluate the effects of 3 tillage systems, conventional tillage (CT), and minimum tillage with rototiller (MTR) and disc (MTD), on the soil properties and wheat yield (*Triticum aestivum* L.). Based on 2-year results, soil bulk density at 0-10 cm in the growing period in MTR, CT and MTD was 1.20, 1.34 and 1.24 Mg m^{-3} respectively. Corresponding values at 10-20 and 20-30 cm were 1.26, 1.29 and 1.21 Mg m^{-3} and 1.30, 1.27 and 1.40 Mg m^{-3} respectively. Aggregate size distribution and mean weight diameter throughout the 2 years of the experiment were significantly influenced by the tillage systems. The highest organic carbon was obtained from MTR, followed by MTD and CT. Similarly, total N in the soil was highest in MTR, followed by CT and MTD. Penetration resistance was measured pre-fall tillage, and during the growing period and gave the following values ($P < 0.05$) for CT, MTR and MTD: 1.65, 1.18 and 1.57 MPa, and 1.33, 1.35 and 1.76 MPa at 18-30 cm. Although there were no statistically significant differences between the tillage systems, grain yield was higher in MTR than in CT and MTD. Consequently, we expect MTR to be more sustainable because of increased grain yield and improving soil physical properties over the long term compared with CT and MTD.

Key Words: Minimum tillage, aggregation, penetration resistance, bulk density, wheat yields

Çanakkale Bölgesindeki Killi-Tınlı Topraklarda Minimum ve Klasik Toprak İşleme Sistemlerinin Toprak Özellikleri ve Buğday Verimi Üzerine Etkisi

Özet: Bu araştırma 2001-2003 buğday üretim periyodunda yürütülmüş olup, klasik (CT) ve minimum toprak işleme (rototiller (MTR) ve diskaro (MTD)) ile işleme) sistemlerinin toprak özellikleri ve buğday verimi üzerine olan etkisi incelenmiştir. İki yılın sonuçlarına göre MTR, CT ve MTD'nin yetiştirme periyodu döneminde ve 0-10 cm'deki hacim ağırlığı sırasıyla 1.20, 1.34, ve 1.24 Mg m^{-3} iken; 10-20 ve 20-30 cm'de ise 1.26, 1.29, 1.21 Mg m^{-3}, ve 1.30, 1.27, 1.40 Mg m^{-3} olarak belirlenmiştir. Agregat dağılımı ve ağırlık ortalama çap değerleri tüm toprak işleme yöntemlerinde istatistiksel olarak farklı çıkmıştır. Organik karbon MTR'de daha yüksek iken, bunu MTD ve CT izlemiştir. Benzer şekilde toplam N MTR'de daha yüksek iken, bunu CT ve MTD izlemiştir. Toprak işleme öncesi ve yetiştirme periyodu sırasında 18-30 cm'de ölçülen penetrasyon değerleri ($P < 0.05$) ise; CT, MTR, MTD için sırasıyla 1.65, 1.18, 1.57 MPa ve 1.33, 1.35, 1.76 MPa olarak belirlenmiştir. Toprak işleme uygulamalarının tane verimi bakımından aralarında istatistiki olarak fark olmamasına rağmen, MTR'deki verim sırasıyla CT ve MTD'ye göre daha yüksek çıkmıştır. Dolayısıyla yüksek verimin MTR'de elde edilmesi ve toprağın özelliklerini iyileştirmesi bakımından, CT ve MTD'ye göre buğday üretiminde uzun dönemde uygulanması gereken bir sistem olduğu ifade edilebilir.

Anahtar Sözcükler: Azaltılmış toprak işleme, agregat dağılımı, penetrasiyon direnci, hacim ağırlığı, buğday verimi

Introduction

Seedbed quality is an important factor in maximizing the emergence of seeds and the yields of annual crops (Sing et al., 1994). Some physical soil constraints on seedling emergence and yield are the soil penetration resistance, bulk density, and soil porosity during the growing period (Letey, 1985). Penetration resistance and soil bulk density are 2 of the most common parameters used to determine the presence of compacted soil layers in agricultural soils (Díaz-Zorita, 2000). Soil bulk density is probably the most frequently measured soil quality parameter in tillage experiments. Sometimes, instead of focusing on soil penetration resistance, it may be easier to use bulk density values to determine the presence of root impedance problems (Vepraskas, 1994). High

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penetration resistance results from intensive tillage, and restricted water and mineral supply and leads to poor aeration, which causes reduced root growth.

Annual ploughing to the same depth (normally 20-25 cm) results in plough pan on clay soils. On the other hand, the mouldboard plough embeds the residues, weeds, minerals and organic fertilizers, and improves the soil's physical condition. However, a disc harrow is used as a complete replacement of the mouldboard plough in minimum tillage systems to cut and mix the soil (Silva and Soares, 2000). In contrast to mouldboard ploughing tillage previous crop residues in minimum tillage are left on or near the soil surface as mulch. This improves the soil's physical properties and water storage, increases infiltration rates (Hao et al., 2000), and reduces erosion (Bradford and Huang, 1994). Furthermore, due to reduced soil erosion and surface runoff, the organic carbon content is usually greater in soils managed with minimum tillage than in those managed with conventional tillage (Dalal, 1989). However, soil penetration resistance was high in minimum or no tillage because of reduced/lack of tillage during the seedbed preparation (Carter, 1991). On the other hand, Cassel et al. (1995) pointed out that penetration resistance was not affected by the tillage.

Appropriate tillage and sowing techniques can reduce soil factor that impede seedling emergence. They also reduce energy and labor costs, and provide weed control. However, tillage system success depends on the soil, climate, and management practices. Although little difference in soil structural characteristics has been reported among tillage systems (Bauer and Black, 1981), low rainfall and high temperature in arid and semiarid regions result in a lower potential of soil organic carbon accumulation (Campbell and Souster, 1982). On the other hand, several studies have reported that the minimum tillage system in arid regions has an adverse effect on wheat yield (e.g., Hemmat and Khashoei, 1997).

The aim of the present study was to evaluate the effects of conventional and 2 minimum tillages with a rototiller and disc on the soil's physical properties, total N, and soil organic carbon, and wheat yields in the Çanakkale region.

Materials and Methods

Experimental site

A field experiment was conducted during the growing periods of 2001-2002 and 2002-2003 at the Dardanos Agricultural Research Station of Onsekiz Mart University in Çanakkale, which is a leading city in Turkey's agriculture in terms of the production of fruit and vegetables. Selected soil properties before the experiment started are given in Table 1. The soil was a Typic Haploxererts (Soil Taxonomy) and Eutric Vertisols (FAO/UNESCO) (Özcan et al., 2003). Çanakkale has a Mediterranean climate (semiarid, with rainy cold winters and dry hot summers) with an annual mean rainfall of 616 mm (80% occurring from October to June), mean temperature of 14.8 ^{o}C, and evaporation of 1500 mm.

Tillage experiment

The treatments consisted of 3 levels of tillage (mouldboard ploughing, CT; rototiller (MTR) and disc (MTD)). The MTR (or minimum tillage) consisted of a rototiller followed by 1 discing and planking (levelling with a 3 m long wooden bar) of the field. Similarly, CT (conventional tillage) consisted of mouldboard ploughing followed by 2 discings and plankings. The MTD (or minimum tillage) was double disced with 1 levelling. The treatments were arranged in a strip plot design with tillage and 3 replications. The previous crop was wheat *(Triticum aestivum* L.*)* in the first year, while it was vetch (*Vicia sativa* L.) in the second year. The size of the tillage plots was 75 x 15 m. Field management operations conducted during this 2-year experimental period are listed in Table 2. The test crop was a local winter wheat

Table 1. Soil properties at 0-20 cm of experimental area at the start of study (2001).

Parameter	Experimental area
Sand (g kg^{-1})	399
Silt (g kg^{-1})	298
Clay (g kg^{-1})	304
PH (H_2O)	7.69
EC (dS m^{-1})	177
Bulk density (Mg m^{-3})	1.31
CEC (me 100 g^{-1})	22.3
Organic C (g kg^{-1})	7.3
Slope (%)	1-2

Table 2. Field management operations throughout the study periods (conventional tillage with mouldboard plough (CT); minimum tillage with rototiller (MTR) and disc (MTD)).

Year	Month	Field operations
2001	June	Harvesting of wheat
2001	October	Beginning of study (soil sampling)*
2001	October	Tillage: CT-treatments ploughed to a average depth of 22 cm. Rototiller and disc applied. Seedbed preparation: CT, MTR, and MTD treatments with disc, sowing of winter wheat was done on 25 December 2001.
2002	June	Harvest of winter wheat was done on 25 June 2002. Stubble removed from treatments and then left until tillage operation.
2002	October	Tillage: CT-treatments ploughed to an average depth of 22 cm. Rototiller and disc applied. Seedbed preparation: CT, MTR, and MTD treatments with disc, sowing was done on 27 October 2002.
2003	June	Winter wheat harvested on 19 June 2003. End of study.

* In the first year of the experiment, weather was drier than normal in October and November, whereas in early December it was rainy; most of the precipitation fell at the beginning of that month (239.2 mm) and subsequently sowing was done at the end of December.

(*Triticum aestivum* L.) cultivar, 'Gönen', which has a maturity period of about 7 months and is the most extensively grown wheat in the area. It was sown at a rate of 210 kg ha^{-1} using a grain drill with a row spacing of 15 cm. Fertilizer was applied at rates according to the regional soil test recommendation guidelines with an NP rate (150/50 kg ha^{-1}).

Soil properties

Soil moisture content was determined gravimetrically. Soil bulk density (BD) was measured by the core method from a soil depth of 0-10, 10-20 and 20-30 cm in each treatment. The total number of samples was 54 each time for both distributed and undistributed soil. Saturated hydraulic conductivity (K_s) was determined by the constant-head method on undisturbed soil cores with cylinders (Klute, 1986) at 3 times: pre-tillage, during the growing period, and at the harvest in each year. The cores were then dried at 105 ºC and BD was calculated from net dry weight, and then total porosity (TP) was calculated according to Kezdi (1974). The soil organic carbon (OC) and total N were also determined from distributed soils. OC and total N in soil (SOTN) and in straw (STTN) were determined by the Walkley-Black and Kjeldahl methods, respectively. For aggregate characteristic determination, soil samples were obtained from 0-20 cm soil depth immediately after sowing in the seedbed. Soil samples were air dried and sieved to <4 mm and large particles of organic matter were removed, and were then passed through a set of sieves (2.0, 1.0, 0.5 and 0.25 mm) to determine the aggregate size distribution (ASD). The sieve set was gently vibrated for approximately 3 min. The cumulative weight of soil passing through each sieve was recorded (Terence, 1975). For calculating the mean weight diameter of aggregates (MWD) the following equation was used (Van Bavel, 1949):

$$MWD = \sum_{i=l}^{n} X_i W_i$$

where X is the average diameter of the openings of 2 consecutive sieves, and W the weight ratio of aggregates remaining on the i^{th} sieve.

Penetration resistance (PR) of soil was measured on 9 September 2002 in pre-tillage and on 4 April 2003 during the growing period in the second year of the study, using a digital penetrologger (Eijkelkamp Equipment, Model 06.15 Eijkelkamp, Giesbeck, The Netherlands). Ten PR were taken from each treatment, and the parallel values at each depth were expressed as an average at 1-cm increments from the soil surface to 40-cm soil depth. The penetrologger had a 30° cone and a base area of 2 cm^2.

Crop yield measurements

Winter wheat was harvested in late June using a hand tool for the determination of yield. Yield was obtained from a 3-m^2 equivalent area within each treatment after air drying of the samples (approximately 0.102 kg kg^{-1} grain moisture content). Data were analyzed using analysis of variance (ANOVA) for each year. Means separation among the treatments was determined by LSD test at 5% significance.

Results and Discussion

Bulk density

In first year of the study, the pre-tillage soil BD at 0-10, 10-20 and 20-30 cm soil depth was 1.24, 1.38 and 1.31 Mg m^{-3}, respectively. During the growing period, MTR at 0-10, 10-20, and 20-30 cm provided 1.24, 1.32 and 1.42 Mg m^{-3}, respectively; corresponding values in CT and MTD were 1.43, 1.41 and 1.49 Mg m^{-3}, and 1.37, 1.36 and 1.35 Mg m^{-3}, respectively. At end of the first year of the study, BD values were slightly higher in MTR than in CT and MTD at all soil depths. Considering all the sampling times, there was a statistically significant difference between sampling times in the 3 tillage systems (Figures 1a, b, c). In general, BD of the growing period in MTR and MTD at 10-20 cm was slightly lower than pre-tillage values, while CT provides similar BD values to pre-tillage. On the other hand, BD was slightly increased in all tillage systems at 0-10 cm compared to pre-tillage probably due to equipment trafficable for cultural practices or soil moisture content during this period. Similar to the first year, in the second year, BD was significantly different with regard to the sampling times in all tillage systems (Figures 1d, e, f). Pre-tillage values were higher than those of the other 2 sampling times in all tillage systems at all soil depths. In view of the growing period sampling time, MTR was slightly higher at 10-20 cm and 20-30 cm, although MTD and MTR were identical regarding BD values, while CT had the lowest BD at 20-30 cm. During this period, MTR and MTD over CT at 0-20 cm provided lower BD probably due to loosening of the surface soil by the rototiller and disc during the seedbed preparation. In contrast to the first year, second year BD values were slightly decreased at 0-10 cm in all tillage systems compared to pre-tillage.

After 2 years of cropping, BD values at 20-30 cm soil depth were lower in CT with 1.04 Mg^{-3} than in MTD with 1.15 Mg^{-3} and MTR with 1.11 Mg^{-3}. The low BD value of the CT at this soil depth was probably related to the mouldboard ploughing of wheat each fall. However, BD at 10-20 cm was similar in CT and MTD with 1.13 Mg^{-3}, and slightly higher than in MTR with 1.11 Mg^{-3}. Arvidsson et al. (2000) also pointed out that BD was significantly higher in minimum tillage than in conventional tillage.

Penetration resistance

Soil PR as a function of depth and tillage treatments is shown in Figure 2. PR for all treatments showed an increasing trend with depth. However, the effects of tillage according to soil depth were statistically significant ($P < 0.05$). Before fall tillage, there was a small and statistically significant difference in PR between treatments in the topsoil layer (0-18 cm). PR values in all treatments at 0-18 cm were below the 2-3 MPa critical level, above which root growth is generally considered slow (Taylor and Ratliff, 1969; Bengough and Mullins, 1990; Vepraskas, 1994) both pre-tillage and during the growing period. In contrast to the topsoil layer, these were statistically significant difference betweens treatments in the sublayer (18-30 cm). The highest PR was obtained in CT (1.80 MPa), fallowed by MTD (1.68 MPa) and MTR (1.17 MPa) at 30 cm soil depth. The general trend was an increase in PR with depth, with a greater increase in CT than in MTD and MTR particularly at 25 cm; higher PR in CT was probably due to repeated tillage practices. The soil PR values, however, at 18-30 cm for the 3 treatments were generally near 2 MPa seen mostly in the CT treatment. Considering all the tillage treatments, the PR was higher in pre-tillage than in the growing period, probably due to wetter soil during the growing period or tillage equipment effect.

Similar to pre-tillage, during the growing period in all treatments, there were small statistically significant differences in PR at 0-18 cm. Differences in PR within each treatment were identical, while a gradual increase with depth until 10 cm was observed in all treatments. The highest PR was obtained in MTD (1.50 MPa), the lowest in CT (0.89 MPa), and intermediate in MTR (1.11 MPa), especially at 4-10 cm soil depth. On the other hand, it was nearly constant at 10-20 cm, and then increased again with soil depth from 20 cm in all treatments. The PR was higher in MTD as 1.76 MPa under the depth of 18 cm than in CT (1.33 MPa) and MTR (1.35 MPa).

Hydraulic conductivity and porosity

Saturated hydraulic conductivity (K_s) measurements of 2-year averages differed significantly ($P < 0.05$)

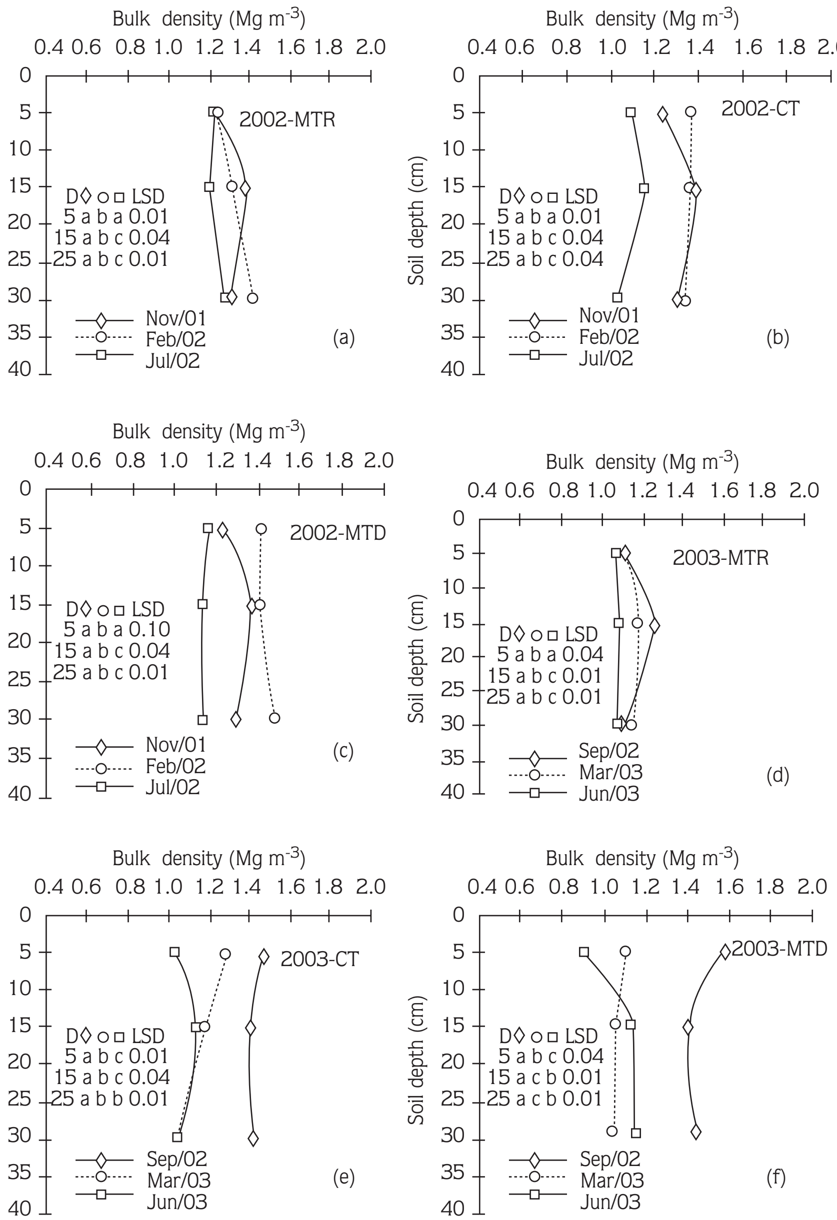

Figure 1. Bulk density profiles of soils tilled with a rototiller, mouldboard plough, and disc for the first and second year; (a), (b), (c); (d), (e) and (f) at 3 dates pre-tillage, during the growing period, and at harvesting. CT: conventional tillage with mouldboard plough, MTR: minimum tillage with rototiller, MDR: minimum tillage with disc. D: Soil depth (cm).

between the treatments during the growing period and at harvest in all treatments at all soil depths (Table 3), while K_s at the beginning of the experiment was 4.17, 3.24 and 1.90 cm h^{-1} at 0-10, 10-20 and 20-30 cm, respectively. During the growing period, K_s was significantly lower in CT than in MTD and MTR at 0-10 cm depth. However, at 10-20 cm the highest K_s was observed in CT (2.93 cm h^{-1}), while MTR and MTD were similar, with 1.84 and 1.89 cm h^{-1}, respectively. At 20-30 cm soil depth, K_s measured in MTD, CT and MTR were 3.87, 0.81 and 0.51 cm h^{-1}, respectively. At harvesting time, K_s was significantly higher in CT than in MTR and MTD at all soil

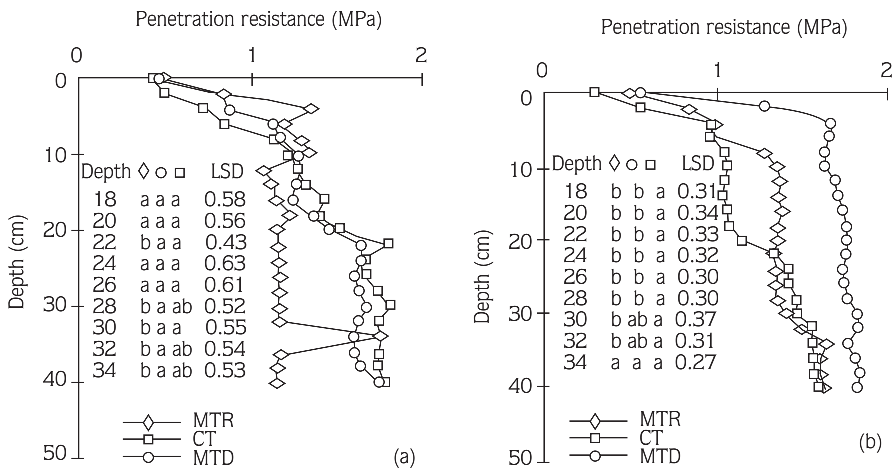

Figure 2. Penetration resistance at pre-tillage (a) and during the growing period (b) in winter wheat (measured at moisture contents of 16% and 19%, respectively). CT: conventional tillage with mouldboard plough, MTR: minimum tillage with rototiller, MDR: minimum tillage with disc. D: Soil depth (cm).

Table 3. Effect of tillage treatments on hydraulic conductivity and total porosity in growing period and at harvest in 0-10, 10-20 and 20-30 cm (2-year average).

	Tillage[a]	K_s (cm h^{-1})			TP (% v/v)		
		0-10	10-20	20-30	0-10	10-20	20-30
In growing period	MTR	2.23[a*]	1.84[b]	0.51[c]	55[a]	53[a]	50
	CT	0.42[b]	2.93[a]	0.81[b]	48[b]	45[c]	50
	MTD	2.11[a]	1.89[b]	3.87[a]	49[b]	49[b]	49
	LSD[b]	0.26	0.12	0.20	3.21	0.76	ns
At harvesting	MTR	0.22[b]	0.77[b]	0.29[b]	44[a]	43	38[c]
	CT	1.43[a]	1.38[a]	1.08[a]	46[ab]	42	46[a]
	MTD	0.55[b]	0.22[c]	0.22[b]	50[a]	42	42[b]
	LSD	0.40	0.08	0.13	4.14	ns	3.02

* Means in the same columns followed by the same letter are not significantly different at P < 0.05 level.

[a] Tillage systems: MTR, minimum tillage with rototiller;

CT, conventional tillage with mouldboard plough;

MTD, minimum tillage with disc.

K_s: hydraulic conductivity, TP: total porosity.

[b] LSD between the treatments within a column (P < 0.05).

depths: 1.43, 1.38 and 1.08 cm h^{-1}, respectively. MTR and MRD were statistically in the same group at 0-10 and 20-30 cm depth wheres MTD had lowest value at 10-20 cm with 0.22 cm h^{-1}. These results are similar to the findings of McQueen and Shepherd (2002) in that K_s showed different behaviors in tillage treatments investigated in respect of different soil levels and different sampling times. On the other hand, Arvidsson et al. (2000) reported that there were no significant differences between mouldboard ploughing and ploughless tillage in terms of K_s. However, some authors (e.g., Whitbread et al., 2000) stated that wheat stubble increased K_s by more than 65% when it was left on the soil surface rather than when it was removed.

TP was significantly different between treatments at 0-10 cm and 10-20 cm soil depth in the growing period, except for 20-30 cm depth (Table 3), while TP at the beginning of the experiment was 38%, 33% and 36% at 0-10, 10-20 and 20-30 cm depth, respectively. At harvesting, TP was only significantly different at 0-10 cm and 20-30 cm in all treatments, while it was not statistically significant at 10-20 cm. However, looking at sampling times, TP during the growing season was slightly higher than before establishing the experiment and at harvesting.

Mean weight diameter

The overall results of the experiment revealed a weak influence of tillage on aggregate size distribution and mean weight diameter in the average of 2 years, at the 0-20 cm soil depth (Table 4). The quantity of fine aggregates (<0.25 mm) was much higher than that of coarse aggregates (>0.25 mm) in MTR compared to CT and MTD. Tisdall and Oades (1982) also reported that the stability of macro-aggregates (>0.25 mm) was controlled by soil management (tillage, rotations, etc.), but the stability of micro-aggregates (<0.25 mm) depended on the amount and stability of organic cementing agents and seemed to be independent of soil management.

From the point of view of the average percentage of ASD of tillage systems, about 30% of the aggregates were larger than 2 mm, 25% were between 1 and 2 mm, about 11% were between 1 and 0.5 mm, about 9% were in the range of 0.5-0.25 mm, and almost 26% were smaller than 0.25 mm. In comparison, in the arid and semiarid regions about 5% of the aggregates are larger than 2 mm, indicating a low structural stability in these soils (Unger, 1997a; Hajabbasi and Hemmat, 2000). However, aggregates of 1-2 mm were most effective in reducing evaporation, particularly in drylands (Heinonen, 1985). Hajabbasi and Hemmat (2000) also pointed out that tillage practices showed a similar effect on ASD and MWD. However, the percentage of small aggregates was larger in the untilled than in the plough tillage treatment (Unger, 1997b).

ASD was significantly ($P < 0.05$) influenced by tillage treatments at the 0-20 cm layer. In view of the average of the 2 years, only 78% of the aggregates in CT were greater than 0.25 mm compared with 87% of the aggregates in MTD. Similarly, Arshad et al. (1999) pointed out that aggregates >0.25 mm were 60% greater in no-till than in CT at a depth of 0-5 cm, but were not different at a depth of 12.5-20 cm. Aggregates

Table 4. Effects of tillage systems on aggregate size classes as a percentage, mean weight diameter, organic carbon and total N at the 0-20 cm layer.

Tillage[a]	Aggregate size classes (mm)					MWD (mm)	OC ($g\ kg^{-1}$)	SOTN ($g\ kg^{-1}$)	STTN ($g\ kg^{-1}$)
	>2	2-1	1-0.5	0.5-0.25	<0.25				
MTR	26[b*]	14[c]	7[c]	10[a]	43[a]	0.290[c]	11.5a	0.11[a]	5.48[a]
CT	33[a]	27[b]	10[b]	8[b]	22[b]	0.572[b]	8.8b	0.08[b]	2.00[c]
MTD	30[ab]	35[a]	15[a]	7[b]	13[c]	0.645[a]	9.5b	0.06[c]	4.79[b]
LSD[b]	5.63	3.70	1.51	1.51	7.14	0.02	0.82	0.001	0.22

* Means in the same columns followed by the same letter are not significantly different at a=0.05 level.

[a] Tillage systems: MTR, minimum tillage with rototiller; CT, conventional tillage with mouldboard plough;
MTD, minimum tillage with disc. MWD: mean weight diameter. OC: organic carbon. SOTN: soil total N, STTN: straw total N.

[b] LSD between the treatments within a column ($P < 0.05$).

>2 mm in CT were significantly higher than those in MTR and MTD. The percentage of aggregates with sizes of 1-2 mm, which was the most effective size for reducing evaporation (Heinonen, 1985), was similarly influenced ($P < 0.05$) by tillage practices: the highest rate was with MTD (35%), followed by CT (27%) and MTR (14%). MTD also had the highest amount of 0.5-1 mm aggregates (15%) and CT was higher (10%), while MTR contained the lowest amount of this size of aggregates (7%). MTR had the highest amount of 0.25-0.5 and <0.25 mm aggregates (10% and 43%, respectively), while CT and MTD were identical for 0.25-0.5 mm aggregate size and CT was significantly higher (22%) than MTD (13%) for <0.25 mm.

Mean weight diameter of the aggregates in MTD was significantly ($P < 0.05$) higher than that in CT and MTR. Similarly, the highest MWD value was determined under the no-till and the lowest under the mouldboard tillage (Sing et al., 1994). In contrast, Hajabbasi and Hemmat (2000) reported that the MWD was greater in the mouldboard tillage compared to the minimum tillage at 0-15 cm depth. Unger (1997a) also reported that MWD was smaller in no-till than in other tillage systems.

Organic carbon and total N

OC content in the 0-20 cm soil layer increased significantly ($P < 0.05$) in MTR compared to that of CT and MTD; there was no statistically significant difference between these 2 treatments (Table 4). The increase in OC in MTR and MTD compared to that of CT was probably caused by less oxidation of the organic matter in the soil (roots, etc.) due to the reduced of tillage, and less soil disturbance and slower crop residue decomposition (Reicosky et al., 1995). Tisdall and Oades (1982) pointed out that cultivation can cause the disruption of soil aggregates and loss of OC. Dalal (1989) also reported that due to reduced soil erosion and surface runoff the OC content is usually greater in soils managed with minimum tillage than with conventional tillage. As noted by Arshad et al. (1999) the C level is usually greater in no-tillage and conservation tillage than in CT tillage; the difference between tillage systems was observed mainly in the 8 cm, and no difference was observed below 15 cm.

Comparing the amount of C obtained at the start of the study (Table 1), soil OC increased in MTR, CT and MTD by 58%, 21% and 30%, respectively, at the end of the study in the 0-20 cm soil depth. The results of many studies also confirm that plough tillage reduces OC contents relative to no-till in the topsoil (e.g., Unger 1997b; Hajabbasi and Hemmat, 2000).

Regarding total N, there was a significant difference ($P < 0.05$) between tillage treatments, being greater in MTR (0.11 g kg^{-1}) than in CT and MTD (Table 4), although there was little difference between CT (0.08 g kg^{-1}) and MTD (0.06 g kg^{-1}). In straw, total N was higher in minimum tillage treatments than in CT. The highest value was obtained in MTR as 5.48 g kg^{-1}, followed by MTD as 4.79 g kg^{-1} and CT as 2.00 g kg^{-1}. In contrast, Ghuman and Sur (2000) reported that N uptake was higher in CT than in minimum tillage under removed residues.

Tillage effects on wheat production

There was no statistically significant difference between tillage treatments in the 2 years (Table 5). However, wheat yield for all treatments increased discernibly in the second year compared with the first year, in which sowing was delayed for nearly 5 weeks due to wet weather. Delayed sowing in the first year decreased yield probably partly due to cold weather at the wheat seeding time or early vegetative stage and thus the growing period was shorter than optimum. However, it was not possible to estimate how much yield was lost due to the delayed sowing or whether the 3 treatments were equally affected. On the other hand, it is well known that the rainfall timing and amount are important factors affecting in the wheat growing in the region.

Table 5. Wheat yield per treatment and year.

Tillage[a]	Grain yield (kg ha^{-1}) Years 2002	2003	Two-year mean
MTR	4055	5167	4611
CT	3540	5209	4375
MTD	3188	5138	4163
LSD[b]	ns	ns	ns

[a]Tillage systems: MTR, minimum tillage with rototiller; CT, conventional tillage with mouldboard plough; MTD, minimum tillage with disc.
[b] LSD between the treatments within a column ($P < 0.05$).

In the first year, MTR had the highest wheat yield (4055 kg ha^{-1}), while MTD had the lowest (3188 kg ha^{-1}). In contrast to the first year, in the second year although CT had the highest yield (5209 kg ha^{-1}) differences among treatments were not statistically significant. This was probably due to better rooting induced by reduced soil strength in the 10-18 cm layer (Figure 2). MTD had the lowest yield (5138 kg ha^{-1}), just as in the first year. MTD treatment continued to show lower yield than CT and MTR treatments throughout the study period. Other authors (e.g., Gajri et al., 1999; Hajabbasi and Hemmat, 2000) found similar results, namely that wheat yields were greater in conventional tillage than in non-inversion tillage and no-till. Moreover, when the farmers' results in the region are taken into consideration, the yield obtained from annually continuous wheat or wheat-sunflower rotations are lower than that obtained from wheat-vetch (legume) rotation. It has been reported that the incorporation of legumes in the crop rotation improved wheat yield and quality (Galantini et al., 2000) but, under low rainfall, such a practice may be detrimental to grain production. It is evident from these results that MTR is an alternative and sustainable practice of soil management for wheat production and it also improves soil properties.

Conclusions

Compared to conventional tillage, rototiller tillage proved to be a promising alternative soil management practice to improve and sustain higher yields of wheat in this region. This practice also improved soil quality by increasing organic matter, probably due to high amounts of crop residue when wheat followed vetch, as well as decreasing bulk density and penetration resistance as much as CT throughout the 0-30 cm soil profile.

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