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Crop rotation and tillage effects on selected soil physical properties of a Typic Haploxerert in an irrigated semi-arid Mediterranean region

I. Celik[a,*], M.M. Turgut[b], N. Acir[c]

[a]*Cukurova University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition. 01330 Adana, Turkey.*
[b]*Cukurova University, Faculty of Agriculture, Department of Agriculture Machinery, 01330 Adana, Turkey.*
[c]*Gaziosmanpaşa University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition. Tokat, Turkey.*
*Corresponding author. E-mail: icelik@cu.edu.tr

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Abstract

Physical, chemical and biological attributes of soil surface are significantly affected by tillage practices and crop rotation. The objective of this study was to determine the short-term (2006-2009) effects of conventional and conservational tillage practices on selected soil physical properties of a heavy clay soil under two wheat-corn and wheat-legume rotation in a semi-arid Mediterranean Region. Treatments included conventional tillage with residue incorporated in soil (CT_1), conventional tillage with burned residue (CT_2), reduced tillage with heavy tandem disc-harrow (RT_1), reduced tillage with rotary tiller (RT_2), reduced tillage with heavy tandem disc harrow fallowed by no-tillage (RNT) and no tillage (NT). Disturbed and undisturbed soil samples were collected to determine saturated hydraulic conductivity (HC), bulk density (BD), mean weight diameter (MWD), available water content (AWC) and total porosity at 0-10, 10-20 and 20-30 cm depths. The highest HC values of 0-10 cm and 10-20 cm depths were obtained with CT_1 (9.70×10^{-6} m s^{-1}, 8.74×10^{-6} m s^{-1}) and CT_2 (9.39×10^{-6} m s^{-1}, 8.58×10^{-6} m s^{-1}) applications. CT_2 treatment destructed the soil aggregates and resulted in greater bulk density and low total porosity at 0-10 cm depth. The available water content at 0-10 cm depth was significantly reduced with the CT_1 ($P<0.01$) and CT_2 applications ($P<0.05$). Although three years of no-tillage application in clay rich soils caused higher bulk density and low porosity, increase in MWD is an indication of soil and water conservation. Therefore, no till and reduced till applications should be adapted to the farmers' conditions for sustainability in agriculture.

Keywords: Conventional tillage; Hydraulic conductivity; Physical properties; No-tillage; Porosity; Residue burning; Rotation; Tillage Systems.

Introduction

Cukurova Plain covers 5% of arable land in Turkey, and is one of the most fertile regions in which double crops can be grown in a year due to the favorable climate and irrigation conditions. Corn and soybean are the second crops of the region following the harvest of winter wheat. Conventional tillage systems are currently used under intensive agricultural production, and although prohibited by law the crop residues are usually burned to enable soil tillage much faster.

Soil physical properties such as bulk density, pore size distribution, water holding capacity, soil water content, infiltration characteristics and aggregation are quite sensitive to soil disturbance (Spedding et al., 2004; Bhattacharyya et al., 2008). Reduced tillage (RT), zero or no-tillage (NT) being a part of conservation tillage were developed as modern alternatives to conventional tillage (CT) which has highly destructive effects on soil physical properties. The positive economic and environmental influences of RT and NT methods induced the rapid introduction of conservation tillage methods in agriculture all over the world (Birkas et al., 1989; Fowler and Rockstrom, 2001; Liu and Wiatrak, 2011). Reduced machinery, lowered fuel consumption and time are the fundamental advantages of NT and RT systems (Veseth, 1988; Juergens et al., 2004). Organic matter accumulation (Dick et al., 1991; Bhattacharyya et al., 2008), improvement in soil aggregation (Lal et al., 1994; Pagliai et al., 2004; Martinez et al., 2008) and increase in total porosity (Bhattacharyya et al., 2006) and available water holding capacity (McGarry et al., 2000) were reported with the implementation of NT and RT systems. In spite of reported positive effects on soil physical properties under NT and RT, some researchers claimed that NT and RT have some deleterious impacts on soil properties (e.g increased bulk density (Moret and Arrue, 2007), decreased total porosity (Unger and Fulton, 1990) and decreased oxygen diffusion rates (Russell, 1988).

Soil hydraulic properties might be altered by tillage, but the tillage effect on hydraulic conductivity can diminish rapidly by time. Studies of NT management have produced controversial results, but the tendency for NT is to increase macropore connectivity while generating inconsistent responses in total porosity and soil bulk density compared with CT practices (Strudly et al., 2008). Heard et al. (1988) reported that saturated hydraulic conductivity of a silty clay loam soil was higher when subject to 10 years of tillage compared with NT in Indiana. The higher conductivity of tilled soil was attributed to larger or a greater number of voids and cracks caused by the tillage. Therefore, it is not possible to generalize the results from any given study without detailed information on all controlling factors.

The effects of various tillage systems on soil properties may differ (Azooz and Arhad, 1996) under various soil type and climate conditions. Azooz and Arshad (1996) indicated that non stable nature of soil structure after tillage, initial and final soil water contents, site history, time of sampling and potential for soil disturbance may result inconsistencies in soil hydraulic conductivity, porosity and other physical properties. The pore stability and soil moisture conditions modified by tillage practices are the major features to absorb and transmit water at the time of measurement. The lower bulk density in tilled zone of conventionally tilled soils induces to have a greater total porosity (Lipiec et al., 2006) whereas intensive surface vented macropore formation in no-tilled soils resulted in higher hydraulic conductivity and total porosity (Kay and Vandenbygaart, 2002). Schjonning and Rasmussen (2000) studied the effects of tillage systems under different soil texture and reported that under the same site conditions, NT compared to CT resulted in lower volume of macro-pores (> 30 μm) on sandy and silty loam soils, whereas the opposite effect was found on sandy loam soil.

Soil aggregate formation and stabilization are strongly linked to the organic matter content of soils, and are highly affected by agricultural practices (Six et al., 2000). Beare et al. (1994) reported an increase in water stable aggregate fraction and formation of larger size aggregates in NT practices compared with conventionally tilled soils. Tillage intensity is related to organic matter decomposition and aggregate breakdown (Rasmussen et al., 1998), thus long-term application of NT practices allowed continued aggregation whereas conventional tillage disrupted the aggregation process annually (Lichter et al., 2008).

Conventional tillage method is widely applied in Cukurova region as well as in over all of the Turkey. In general, farmers of region use one equipment throughout the production season, NT system has rarely been applied in some of the large farms in mid-Anatolia region of Turkey. On the other hand, reduced tillage systems have just started being applied in the main crop management where ecological conditions are not suitable for the second crop production. The discussions on application and necessity of NT and RT methods have considerably increased due to the increased fuel prices, erosion and land degradation issues. However, studies on applicability of NT on heavy clay soils of Turkey are quite limited.

Therefore, the objective of this study was to determine the short-term (3-year) effects of conventional and conservational tillage practices, such as NT and RT, on selected soil physical properties of a heavy clay (mean 50% clay) soil under two crop sequences, wheat-corn and wheat-legume rotation in a semi-arid irrigated Mediterranean Region.

Materials and Methods

Experimental site

A field experiment was carried out between 2006 and 2009 at the Agricultural Experimental Station (37° 00′ 54″ N, 35° 21′ 27″ E; 32 m above sea level) of the Cukurova University, Adana, Turkey. The prevailing climate of study area is Mediterranean with a long-term (30 years) mean annual temperature of 19.1 °C. The summer is hot and dry, and the winter is rainy and mild. The long-term mean annual precipitation is 670 mm, about 75% of which falls during the winter and spring (from November to May) and the long-term mean annual potential evapotranspration is 1500 mm. The annual mean temperature during the study period was 19.2 °C, the relative humidity was 70%, and the mean precipitation was 563 mm.

The experiment was carried out on the Arik clay soil series with a slope about 1%, and soils were classified as fine, smectitic, active, mesic Typic Haploxererts (Soil Survey Staff, 1999). Experimental soil had a pH of 7.82, $CaCO_3$ of 244 g kg^{-1}, and electrical conductivity of 0.15 dS $m^{-1}$with 50% clay, 32% silt and 18% sand at the depth 0-30 cm (Celik et al., 2011).

Experimental design and tillage systems

The land has been used for continuous wheat (*Triticum aestivum* L.) production under conventional tillage by the farmers' in the region for more than 30 years. After harvesting wheat in June 2006, the area was prepared for field trials. The experiment was conducted on a randomized complete block design with three replications of conventional tillage with residue incorporated in the soil (CT_1), conventional tillage with residue burned (CT_2), reduced tillage with heavy tandem disc-harrow (RT_1), reduced tillage with rotary tiller (RT_2), reduced tillage with heavy tandem disc harrow fallowed by no-tillage (RNT), and no tillage (NT). The tillage plots were of 12 m width and 40 m length (480 m^2). A 4 m buffer zone was left around the plots to avoid interactions among the tillage treatments and to facilitate the maneuver of soil tilling machines. Details for tillage practices, order of the treatments within each practice and sowing methods were given in Table 1.

Table 1. Tillage methods, depth of tillage, and type of the equipment used in the study.

Treatments	Winter wheat (November 2006, 2007, 2008)	Second crop maize and soybean (June 2007, 2008)
Conventional tillage with residue incorporated in the soil (CT_1)	Stover chopping of second crop Mouldboard plough (30-33 cm)a Disc harrow (2 passes, 13-15 cm) Float (2 passes) Drill (4 cm)	Stubble chopping of wheat Heavy tandem disc harrow (18-20 cm) Disc harrow (2 passes, 13-15 cm) Float (2 passes) Planter (8 cm)
Conventional tillage with residue burned (CT_2)	Stover burning of second crop Mouldboard plough (30-33 cm) Disc harrow (2 passes, 13-15 cm) Float (2 passes) Drill (4 cm)	Stubble burning of wheat Chisel plow (35-38 cm) Disc harrow (2 passes, 13-15 cm) Float (2 passes) Planter (8 cm)
Reduced tillage with heavy tandem disc harrow (RT_1)	Stover chopping of second crop Heavy tandem disc harrow (2 passes, 18-20 cm) Float (2 passes) Drill (4 cm)	Stubble chopping of wheat Rotary tiller (13-15 cm) Float (2 passes) Planter (8 cm)
Reduced tillage with rotary tiller (RT_2)	Stover chopping of second crop Rotary tiller (13-15 cm) Float (2 passes) Drill (4 cm)	Stubble chopping of wheat Rotary tiller (13-15 cm) Float (2 passes) Planter (8 cm)
Reduced tillage with heavy tandem disc harrow fallowed by no-tillage (RNT) for the second crop	Stover chopping of second crop Heavy tandem disc harrow (18-20 cm) Float (2 passes) Drill (4 cm)	Stubble chopping of wheat Herbicide application No-till planter (8 cm)
No tillage (NT)	Stover chopping of second crop Herbicide treatment No-till drill (4 cm)	Stubble chopping of wheat Herbicide treatment No-till planter (8 cm)

[a] Figures in parenthesis are average working depths of the equipment.

The rotations of winter wheat (*Triticum aestivum* L.)-corn (*Zea Mays* L.), wheat-soybean (*Glycine max.* L.) and wheat were applied in all treatments from 2006 to 2009. The crop rotation was wheat-corn in the 2006-2007, wheat-soybean in the 2007-2008 and wheat in the 2008-2009 growing seasons, respectively. In each growing season, the first crop was winter wheat and the second crop was corn and soybean in turn. The growing period of winter wheat was from November to the first week of June, and for second crop was from the second week of June to the first week of October.

In the conventional tillage methods (CT_1 and CT_2), following wheat harvest, farmers burn the residues, and plough the soil to save time for the second crop corn or soybean. Similar practices were applied following the second crop to sow winter wheat as early as possible. Some farmers till the soil immediately after harvesting the second crop while others leave residues on the soil surface for a while and then plough the soil with a moldboard. In CT_2, crop residues were burnt after the wheat, corn, and soybean harvest. In the CTI, RT_1 and RT_2 practices, the soil was tilled after the first and second crop residues shredded on the plots. The residues of first and second crops were shredded and left on the soil surface in NT system. Whereas, the stover of the second crop were shredded, and soil was tilled in RNT where the stubble of the first crop were only chopped (Table 1). RT_1, RT_2, RNT and NT methods are thought to be possible alternatives to the conventional methods used in the region for a long time.

Two weeks prior to sowing, the total herbicide (500 g ha^{-1} Glyphosate) was used to control weeds in the NT and RNT treatments. Compound NP-fertilizers were applied in the seedbed at the rates of 172 kg N ha^{-1} and 55 kg P_2O_5 ha^{-1} for wheat, 250 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} for corn, and 120 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} for soybean. Winter wheat was seeded in the first week of November 2006, 2007 and 2008 at seeding rate of 240 kg ha^{-1}, and harvested in the first week of June 2007, 2008 and 2009. The second crops (corn and soybean) were sown in the third week of June, and harvested in the second week of October 2007 and 2008. Corn and soybean seeding rates were 8.4 and 23.6 plants per m^{-2}, respectively. Soybean and corn were nine times irrigated by sprinklers in 13 day intervals. The amount of water applied for each irrigation was identical for all treatments and no irrigation water was applied to the wheat.

Soil sampling and analysis

In order to determine the effects of tillage practices on soil properties, disturbed and undisturbed samples were collected four times throughout the research period from 0-10, 10-20 and 20-30 cm depths. The first samples were taken in June 2006 following the establishment of the plots. The second, third, and the fourth samples were taken in the first weeks of June 2007, 2008 and 2009, immediately after the harvest of the first crop. The physical characteristics of soils at the beginning of the study were determined (Table 2). Since the texture of the research area was homogeneous and the same agricultural practices have long been applied to all plots before the experiment, soil properties were not different at the three depths evaluated. The only difference was in bulk density of 10-20 cm depth which was slightly higher in CT_2 plot prior to the experiment.

Table 2. Soil physical properties prior to different tillage treatments (June 2006).

Treatments*	Depth (cm)	HC[b] (10^{-6} m s^{-1})	BD[c] (Mg m^{-3})	AWC[d] (%)	MWD[e] (mm)	TP[f] (cm^3 cm^{-3})
CT_1	0-10	8.04†±2.53[a&]	1.23±0.07[a]	11.68±0.44[a]	0.16±0.02[a]	0.539±0.023[a]
CT_2	0-10	7.94±2.38[a]	1.22±0.01[a]	10.26±1.39[a]	0.23±0.07[a]	0.542±0.023[a]
RT_1	0-10	8.14±2.68[a]	1.20±0.09[a]	12.81±1.01[a]	0.24±0.11[a]	0.547±0.044[a]
RT_2	0-10	7.96±3.01[a]	1.25±0.04[a]	10.53±0.11[a]	0.19±0.02[a]	0.537±0.020[a]
RNT	0-10	8.08±1.93[a]	1.23±0.05[a]	11.40±0.69[a]	0.17±0.02[a]	0.554±0.017[a]
NT	0-10	8.01±2.97[a]	1.24±0.03[a]	12.91±3.78[a]	0.18±0.03[a]	0.534±0.015[a]
CT_1	10-20	8.18±1.96[a]	1.30±0.06[ab]	9.84±1.90[a]	0.21±0.05[a]	0.525±0.024[a]
CT_2	10-20	8.70±2.55[a]	1.41±0.01[a]	9.42±0.33[a]	0.29±0.07[a]	0.493±0.016[a]
RT_1	10-20	8.50±3.26[a]	1.28±0.01[b]	10.37±0.74[a]	0.28±0.08[a]	0.529±0.014[a]
RT_2	10-20	8.54±2.71[a]	1.30±0.05[ab]	9.02±1.73[a]	0.22±0.03[a]	0.509±0.015[a]
RNT	10-20	8.48±3.17[a]	1.31±0.05[ab]	9.95±1.55[a]	0.23±0.04[a]	0.510±0.009[a]
NT	10-20	9.05±2.80[a]	1.37±0.07[ab]	10.84±3.52[a]	0.23±0.05[a]	0.509±0.016[a]
CT_1	20-30	7.36±2.81[a]	1.32±0.01[a]	9.44±1.35[a]	0.25±0.07[a]	0.534±0.048[a]
CT_2	20-30	7.66±2.53[a]	1.44±0.07[a]	9.83±0.88[a]	0.31±0.08[a]	0.492±0.013[a]
RT_1	20-30	7.45±3.61[a]	1.35±0.02[a]	10.04±1.59[a]	0.28±0.08[a]	0.512±0.023[a]
RT_2	20-30	7.70±2.73[a]	1.40±0.03[a]	10.39±2.24[a]	0.26±0.07[a]	0.507±0.021[a]
RNT	20-30	7.59±2.43[a]	1.36±0.05[a]	10.00±1.97[a]	0.21±0.03[a]	0.503±0.021[a]
NT	20-30	7.33±2.61[a]	1.40±0.04[a]	12.46±5.01[a]	0.29±0.05[a]	0.513±0.015[a]

[a] CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage; [b] HC, hydraulic conductivity; [c] BD, bulk density; [d] AWC, available water content; [e] MWD, mean weight diameter; [f] TP, total porosity.

† The numbers following ± indicate standard deviation.

& Values in a column for same soil depth followed by the same latter are not significantly different (Tukey, P≤0.05).

The total of six disturbed and twenty four undisturbed samples per tillage treatments were collected. In order to sample RNT and NT parcels, the residue on the soil surface was cleaned. Undisturbed soil samples were taken using a steel cylinder of 100 cm^3 volume (5 cm in diameter, and 5.1

cm in height). Bulk density, total porosity, saturated hydraulic conductivity and field capacity were determined from undisturbed soil samples.

For aggregate analysis, approximately 3 kg disturbed soil samples were taken from 0-10, 10-20 and 20-30 cm depths. Samples were then air-dried and sieved through 8 mm sieves. The bulk density was measured by the core method (Blake and Hartge, 1986), porosity was determined according to Danielson and Sutherland (1986), saturated hydraulic conductivity was determined by the falling-head method (Klute and Dirksen, 1986). Water retention capacity at -33 kPa (field capacity) was measured in the undisturbed soil samples and at -1500 kPa (permanent wilting point) in disturbed samples. Available water content (AWC) was then calculated taking the difference between water retained at -33 and -1500 kPa (Klute, 1986). Total porosity was determined in undisturbed water-saturated samples of 100 cm^3 assuming no air trapped in the pores and its validity checked using dry bulk density and average particle density (2.65 g cm^{-3}) values.

A wet sieving method was used to determine the mean weight diameter (MWD) as an index of soil aggregation. The wet sieving method of Kemper and Rosenau (1986) was used with a set of sieves of 4, 2, 1 and 0.5 mm diameters. After the soil samples were passed through an 8 mm sieve, approximately 50 g of the soil was put on the first sieve and gently moistened to avoid a sudden rupture of aggregates. Once the soil had been moistened, the set was sieved in distilled water at 30 oscillations per minute. With 10 minutes of oscillation, the soil remaining on each sieve was dried, and then sand and aggregates were separated (Gee and Bauder, 1986). The mean weight diameter was calculated as follows:

$$MWD = \sum_{i=1}^{n} X_i W_i$$

Where, MWD is the mean weight diameter of water stable aggregates, X_i is the mean diameter of each size fraction (mm) and W_i is the proportion of the total sample mass in the corresponding size fraction after the mass of stones deducted (upon dispersion and passing through the same sieve).

Statistical analysis

One-way analysis of variance (ANOVA) was applied to compare the effects of tillage treatments on soil properties determined for the three soil depths of 0-10, 10-20 and 20-30 cm separately. Following the ANOVA test (the Tukey test) was applied to establish differences in the treatments. In order to evaluate the effects of tillage practices on soil properties, paired t-test was used to compare initial and final values. Significance levels of 0.05 and 0.01 were applied in all the statistical analysis. The statistical analyses were carried out using SPSS software (version 13.0).

Results and Discussion

Saturated Hydraulic Conductivity (HC)

Saturated hydraulic conductivity (HC) of 0-10 cm soil depth was greater compared to that of 10-20 and 20-30 cm depths, however the tillage applications did not yield significant differences on HC in the first year of the experiment (Table 3). The increase in bulk density with depth (Table 4) induced a decrease ($P<0.05$) in HC of subsurface soils. The effects of tillage systems on HC in 2008 was significantly different ($P<0.05$) at all depths. The highest HC values of 0-10 and 10-20 cm depths were obtained with conventional tillage with residue incorporated in soil (CT1) (9.79×10^{-6} m s^{-1}, 8.80×10^{-6} m s^{-1}) and conventional tillage with residue burned (CT_2) (9.47×10^{-6} m s^{-1}, 8.64×10^{-6} m s^{-1}) applications. NT and RNT tillage systems yielded the lowest HC values (Table 3).

Saturated hydraulic conductivity was increased with increasing the intensity, number and depth of the first and the second tillage operations to prepare the seed bed (Table 3). Therefore, the effect of tillage systems on HC after the fifth application (2006-2007 wheat; 2007 second crop corn; 2007-2008 wheat; 2008 second crop soybean and 2008-2009 wheat) was prominent. Hydraulic conductivities in CT_1 and CT_2 parcels were greater compared with the other tillage systems. The HC in 0-10 cm was ended up as $CT_1=CT_2>RT_2=RT_1=RNT>NT$, and HC in 10-20 cm was $CT_1>CT_2>RT_2>RT_1>RNT=NT$ (Table 3).

Tillage applications yielded similar HC values at 20-30 cm depth, and the differences between tillage systems were not statistically significant. The highest HC values were obtained at CT_1 and RT_1 systems, respectively (Table 3). Although HC was found to be greater for tilled soils (as in CT_1 and CT_2) at the beginning of growing season due to the increased porosity caused by tillage (Suwardji and Eberbach, 1998), Messing and Jarvis (1993) found lower HC values in tilled soils during the growing season due to the structural breakdown and surface sealing and root growth that progressively blocks the pores. Heard et al. (1988) attributed the greater hydraulic conductivity in conventionally tilled soils to greater number of voids and cracks caused by tillage.

Table 3. Effects of different tillage practices on saturated hydraulic conductivity after the wheat harvest for each year and depth.

Treatments*	Hydraulic conductivity (10^{-6} m s^{-1})								
	First year (June 2007)			Second year (June 2008)			Third year (June 2009)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
CT_1	8.84[†]±2.24[a&]	8.48±2.93[a]	6.21±0.90[a]	9.79±0.03[a]	8.80±0.04[a]	7.28±0.07[a]	9.70±0.70[a]	8.74±0.11[a]	7.31±0.39[a]
CT_2	7.03±2.26[a]	6.29±1.57[a]	4.23±0.60[a]	9.47±0.05[a]	8.64±0.06[a]	6.00±0.04[b]	9.39±0.14[a]	8.58±0.53[ab]	6.18±0.48[b]
RT_1	7.22±1.61[a]	8.27±2.04[a]	4.07±0.50[a]	7.95±0.10[bc]	6.80±0.04[bc]	6.34±0.06[ab]	8.13±0.15[ab]	6.87±0.51[bc]	6.30±0.63[ab]
RT_2	10.60±2.00[a]	9.60±1.92[a]	7.58±1.54[a]	8.53±0.03[ab]	7.99±0.09[ab]	5.93±0.03[b]	8.47±0.09[ab]	7.83±0.16[abc]	6.07±0.36[b]
RNT	8.22±2.19[a]	6.25±1.52[a]	4.68±1.18[a]	7.23±0.03[bc]	6.22±0.08[c]	5.86±0.02[b]	7.30±0.15[ab]	6.34±0.67[c]	5.90±0.33[b]
NT	5.31±1.27[a]	5.98±0.64[a]	4.38±2.00[a]	6.66±0.02[c]	6.15±0.02[c]	5.72±0.03[b]	6.50±0.34[b]	6.31±0.28[c]	5.80±0.16[b]

*CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage.

† The numbers following ± indicate standard deviation.

& Values in a column followed by the same latter are not significantly different (Tukey, P≤0.05).

Hydraulic conductivity in agricultural soils is affected by the porosity and pore-size distribution, bulk density, soil compaction and aggregation (Kutilex, 2004; Lipiec et al., 2006). High bulk density values obtained under no-tillage and reduced tillage systems are the indications of soil compaction (Abu-Hamdeh, 2003), and might explain the low hydraulic conductivity obtained in no-tillage and reduced tillage systems (Table 3). Effective porosity of a soil is dependent on macropores, and has been related to saturated hydraulic conductivity (Ahuja et al., 1989; Zhang et al., 2006). Low total porosity values obtained under NT and RNT systems were responsible from low hydraulic conductivity of soils (Logsdon et al., 1999; Bhattacharyya et al., 2006).

The effect of soil tillage on saturated hydraulic conductivity is not uniform. In contrast to our findings, Voorhees and Lindstrom (1984), Bhattacharyya et al. (2006) and others indicated that conventionally tilled soils under continuous cultivation tend to become less porous with time in the plow layer. Conversely, some soils under no-tillage management tend to become more porous with time. Azooz and Arshad (1996) attributed this inconsistency to transitory nature of soil structure after tillage, initial and final soil water content, site story, time of sampling and potential for soil disturbance. Decline in total porosity induced to lower HC of soils in RNT and NT applications and increase in CT_1, CT_2, RT_1 and RT_2 of 0-10 cm; however the variations in HC were not significant (Table 3).

Initial and final values of HC measured in the current experiment were compared using paired t-tests. Although HC values of three depths were either declined or increased with the applications of different soil tillage practices, the changes in HC were not significant as compared to the initial values (Table 4).

Bulk density (BD)

There were significant differences among years within the treatment at 0-10, 10-20 and 20-30 cm depths (Table 5). The bulk densities of three layers were the highest under NT, and the lowest in CT_1 (Table 5). The order of tillage effects on bulk density in the third year at 0-10 cm depth was $NT>RNT>CT_2>RT_1=RT_2=CT_1$, at 10-20 cm depth was $NT>RNT>RT_1=CT_2=RT_2>CT_1$, and 20-30 cm depth was $NT=RNT>RT_2=RT_1>CT_2>CT_1$.

Greater bulk density values under conventional tillage systems were usually reported when compared to no tillage (Horn et al., 1995; Dao, 1996; Roscoe and Buurman, 2003). However, our results indicated that soil bulk density was increased in RNT and NT systems, and decreased in CT_1 and CT_2 systems. In other words, decreasing the number, intensity and depth of tillage induced to obtain higher bulk density values. Tebrügge and Düring (1999) and Lipiec et al. (2006) also indicated that decreasing tillage intensity from the conventional tillage to NT generally resulted in an increase in bulk density of the upper soil layers. However, due to the crucial role of dynamic properties such as soil aeration and water transmission in plant growth with respect to bulk density (Cavalieri et al., 2009), higher bulk densities obtained are tolerable in NT.

Table 4. Mean difference and paired t-test results for initial (June 2006) and final (June 2009) data of study area.

Treatments[a]	Depth (cm)	BD[b] (Mg m^{-3})	AWC[c] (%)	MWD[d] (mm)	TP[e] (cm^3 cm^{-3})	HC[f] (10^{-6} m s^{-1})
	0-10	-0.05^{ns}	2.20**	-0.13**	-0.08**	-1.640^{ns}
CT_1	10-20	0.01^{ns}	0.96^{ns}	-0.08**	-0.08**	-0.574^{ns}
	20-30	0.02^{ns}	0.35^{ns}	-0.05*	-0.06*	0.039^{ns}
	0-10	-0.10**	2.02*	0.02^{ns}	-0.07**	-1.460^{ns}
CT_2	10-20	0.08**	1.70^{ns}	0.05^{ns}	-0.11**	0.157^{ns}
	20-30	0.11**	1.41^{ns}	0.01^{ns}	-0.11**	1.480^{ns}
	0-10	-0.12**	0.64^{ns}	-0.12**	-0.05*	-0.000^{ns}
RT_1	10-20	-0.06*	-0.95^{ns}	-0.11*	-0.05**	1.630^{ns}
	20-30	0.00^{ns}	-1.23^{ns}	-0.15**	-0.05**	1.150^{ns}
	0-10	-0.06*	-0.27^{ns}	-0.12**	-0.05**	-0.503^{ns}
RT_2	10-20	-0.03^{ns}	-1.41^{ns}	-0.15**	-0.05*	0.709^{ns}
	20-30	0.04*	0.43^{ns}	-0.17**	-0.05**	1.640^{ns}
	0-10	-0.15**	-0.13^{ns}	-0.20**	0.03**	0.776^{ns}
RNT	10-20	-0.10**	-1.80*	-0.17**	0.02^{ns}	2.130^{ns}
	20-30	-0.06*	-1.45^{ns}	-0.23**	0.00^{ns}	1.690^{ns}
	0-10	-0.17**	0.58^{ns}	-0.23**	0.02*	1.500^{ns}
NT	10-20	-0.06^{ns}	-1.10^{ns}	-0.21**	0.02*	2.74^{ns}
	20-30	-0.03^{ns}	0.52^{ns}	-0.18**	0.03**	1.52^{ns}

Significant at **P<0.01, *P<0.05, ns: non significant, respectively.

[a] CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage. [b] BD, bulk density; [c] AWC, available water content; [d] MWD, mean weight diameter; [e] TP, total porosity; [f] HC, hydraulic conductivity.

Table 5. Effects of different tillage practices on dry bulk density after the wheat harvest for each year and depth.

Treatments*	Bulk density (Mg m^{-3})								
	First year (June 2007)			Second year (June 2008)			Third year (June 2009)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
CT_1	$1.12^{\dagger}\pm0.08^{a\&}$	1.21 ± 0.07^{a}	1.14 ± 0.06^{a}	1.27 ± 0.03^{c}	1.27 ± 0.05^{c}	1.30 ± 0.02^{b}	1.27 ± 0.03^{c}	1.28 ± 0.02^{c}	1.30 ± 0.02^{c}
CT_2	1.26 ± 0.03^{a}	1.17 ± 0.02^{a}	1.21 ± 0.03^{a}	1.33 ± 0.05^{abc}	1.30 ± 0.05^{bc}	1.33 ± 0.02^{b}	1.32 ± 0.02^{bc}	1.33 ± 0.02^{b}	1.33 ± 0.01^{bc}
RT_1	1.30 ± 0.02^{a}	1.27 ± 0.09^{a}	1.19 ± 0.10^{a}	1.32 ± 0.02^{abc}	1.34 ± 0.04^{abc}	1.36 ± 0.03^{ab}	1.32 ± 0.01^{c}	1.34 ± 0.01^{b}	1.34 ± 0.01^{b}
RT_2	1.26 ± 0.07^{a}	1.23 ± 0.03^{a}	1.12 ± 0.04^{a}	1.29 ± 0.04^{bc}	1.31 ± 0.04^{abc}	1.35 ± 0.05^{ab}	1.32 ± 0.02^{c}	1.33 ± 0.02^{b}	1.35 ± 0.02^{b}
RNT	1.23 ± 0.09^{a}	1.24 ± 0.09^{a}	1.11 ± 0.06^{a}	1.37 ± 0.01^{ab}	1.39 ± 0.01^{ab}	1.41 ± 0.02^{a}	1.38 ± 0.02^{ab}	1.40 ± 0.01^{a}	1.42 ± 0.02^{a}
NT	1.18 ± 0.07^{a}	1.22 ± 0.03^{a}	1.21 ± 0.07^{a}	1.40 ± 0.01^{a}	1.41 ± 0.01^{a}	1.41 ± 0.02^{a}	1.40 ± 0.01^{a}	1.43 ± 0.01^{a}	1.43 ± 0.02^{a}

* CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage.

† The numbers following ± indicate standard deviation.

& Values in a column followed by the same latter are not significantly different (Tukey, $P\leq0.05$).

The decline in organic matter (data not shown) due to stubble burning under CT_2 system caused to weakened aggregate stability (Figure 1), and increase the bulk density in CT_2 compared with the CT_1. Stubble burning is a convenient practice often employed although prohibited by law, in cropping systems to reduce loads on soil surface. The differences in crops, soil properties and climate of study areas might result to obtain contradictory results in bulk density when compared different soil tillage systems (Rasmussen, 1999).

Soil bulk density and porosity are also fundamental to soil compaction and related agricultural management issues. Soil bulk density alters with the disturbance of natural arrangement of soil particles, soil pore geometry and total porosity. The paired t-test results revealed that the bulk density was not significantly changed with application of CT_1; however CT_2 where stubbles were burned had significant impact ($P<0.01$) on bulk density. Burning the crop residue in CT_2 caused to obtain significantly different BD values at three depths investigated. Burning crop residue in CT_2 method probably resulted in destruction of soil aggregates which lowered the ratio of voids, and increased the bulk density at upper 10 cm of soil surface (Table 4). In contrast to soil surface, final bulk densities of 10-20 and 20-30 cm depths at CT_2 system were lower than the initial values (Table 4). The use of chisel that tills about 35 to 38 cm in the second crops probably lowered the bulk density.

Double use of heavy tandem disk harrowing prior to planting the winter wheat (RT_1) induced significant increase in bulk density at 0-10 and 10-20 cm depths ($P<0.01$ and $P<0.05$). The bulk density at 0-10 cm was significantly increased ($P<0.05$) with the application of RT2 method (Table 4). The RNT method caused a significant increase in bulk density at three depths evaluated ($P<0.01$). The increase in NT system was significant ($P<0.01$) only at 0-10 cm depth of soil profile (Table 4).

Available water content (AWC)

Available water contents (AWC) in the first year were ranged from 9.19% (RNT) to 11.66% (RT_2) at 0-10 cm depth, from 8.35% (CT_2) to 10.03% (RT_1) at 10-20 cm depth, and from 7.17% (RNT) to 8.74% (RT_1) at 20-30 cm depth respectively (Table 6). The effects of tillage systems on AWC at three depths were not statistically different from each other. The difference in AWC of soils among tillage systems was significant ($P<0.05$) at the second and the third year of the experiment. The highest AWC was obtained from NT and RT applications, and the lowest AWC was obtained from CT_2 application (Table 6).

Table 6. Effects of different tillage practices on available water content after the wheat harvest for each year and depth.

Treatments*	Available water (%)								
	First year (June 2007)			Second year (June 2008)			Third year (June 2009)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
CT_1	$10.06^{\dagger}\pm1.46^{a\&}$	9.77 ± 0.64^{a}	8.15 ± 1.15^{a}	9.58 ± 0.33^{bc}	9.32 ± 1.04^{bc}	9.16 ± 0.56^{c}	9.47 ± 1.76^{ab}	8.87 ± 1.97^{a}	9.08 ± 1.06^{a}
CT_2	11.26 ± 0.96^{a}	8.35 ± 1.86^{a}	8.16 ± 2.13^{a}	7.67 ± 0.63^{c}	8.50 ± 0.62^{c}	8.43 ± 0.89^{c}	8.24 ± 1.23^{b}	7.72 ± 0.96^{a}	8.42 ± 1.66^{a}
RT_1	11.16 ± 2.34^{a}	10.03 ± 1.04^{a}	8.74 ± 0.49^{a}	11.19 ± 0.47^{ab}	10.48 ± 1.41^{bc}	9.69 ± 0.26^{bc}	12.17 ± 1.10^{a}	11.31 ± 1.45^{a}	11.27 ± 1.68^{a}
RT_2	11.66 ± 0.76^{a}	8.96 ± 1.13^{a}	7.43 ± 1.13^{a}	10.72 ± 1.96^{ab}	10.40 ± 0.58^{bc}	9.74 ± 0.71^{bc}	10.79 ± 1.15^{ab}	10.43 ± 2.70^{a}	9.96 ± 1.79^{a}
RNT	9.19 ± 1.27^{a}	8.56 ± 1.03^{a}	7.17 ± 1.17^{a}	12.05 ± 0.36^{ab}	11.66 ± 1.06^{ab}	11.21 ± 1.02^{ab}	11.53 ± 0.70^{a}	11.75 ± 3.31^{a}	11.45 ± 2.25^{a}
NT	10.56 ± 1.18^{a}	9.16 ± 0.46^{a}	8.24 ± 0.99^{a}	13.35 ± 1.56^{a}	13.52 ± 0.87^{a}	12.68 ± 0.15^{a}	12.33 ± 0.63^{a}	11.94 ± 0.70^{a}	11.94 ± 0.67^{a}

[*] CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage.

[†] The numbers following ± indicate standard deviation.

[&] Values in a column followed by the same latter are not significantly different (Tukey, $P\leq0.05$).

Available water content in the third year of the experiment significantly differed only at 0-10 cm, and the order of AWC content was $NT=RT_1=RNT>RT_2=CT_1>CT_2$ (Table 6). The improved water intake capacity, combined with a minimized soil surface evaporation, are the major factors that explain the possibility of increasing available water in no-till and reduced tillage systems.

It is accepted that no-tillage system is very effective to increase organic matter content and improve soil aggregation to reduce evaporation from soil surface and also to increase available water content. Therefore NT and RT applications induced to increase available water content compared with conventional tillage methods. Higher AWC under NT and RT methods might be attributed to a more stable structure and continues earthworm channels connected to the soil surface in the no-tilled soils (Azooz and Arshad, 1996). Although both CT_1 and CT_2 applications are considered as conventional methods, AWC content under CT_1 system was higher than that of CT_2 system. Burning the crop residue in CT_2 resulted in a decline of organic matter content and MWD value (Figure 1) which explains low AWC content in CT_2 application. Bhattacharyya et al. (2008) and Lichter et al. (2008) also reported high AWC values in soils with high organic matter content and greater aggregate stability with reduced tillage systems. However, Duiker and Lal (1999) stated that tillage systems have no significant effect on soil water holding characteristics.

The paired t-test results revealed that available water content at 0-10 cm depth was significantly reduced with CT_1 and CT_2 methods ($P<0.01$ and $P<0.05$), except 10-20 cm of soils in RNT application. RT_1, RT_2, RNT and NT methods had no significant impact on AWC at three depths (Table 4).

Soil aggregation

Mean weight diameter (MWD) of soils is an important indication of soil aggregation. The MWDs at 0-10 cm of plots prior to experiment for NT, RNT, RT_1, RT_2, CT_1 and CT_2 systems were 0.18, 0.17, 0.24, 0.19, 0.16 and 0.23 mm, respectively (Table 2). The effects of tillage on MWD among tillage systems were not significantly different in the first year. The results showed significant increases ($P<0.01$) in MWD values occurred starting at the second year of the experiment. Final MWD values of 0-10 cm depth for NT, RNT, RT_1, RT_2, CT_1 and CT_2 were 0.41, 0.37, 0.36, 0.32, 0.28 and 0.20 mm, respectively (Figure 1). The highest MWD values were obtained with NT, and the CT_2 system yielded the lowest MWD values both at 0-10 cm and 10-20 cm depths.

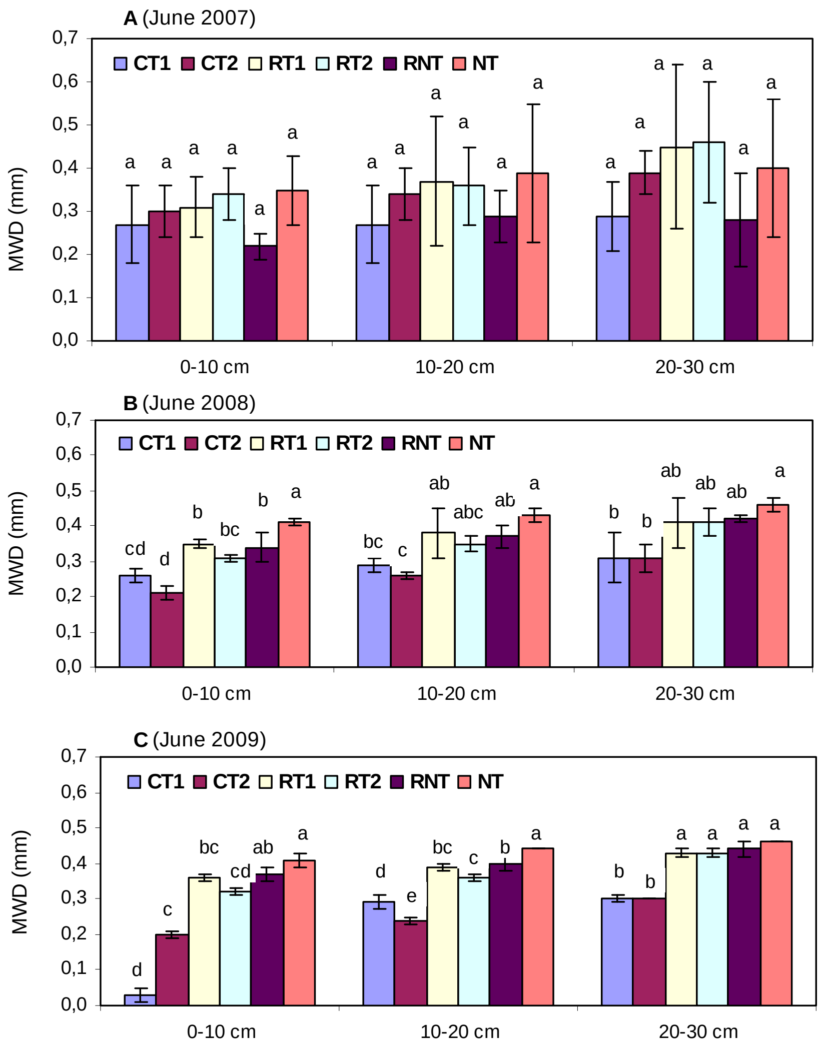

Figure 1. Effects of different tillage practices on soil aggregation as measured by mean weight diameter (MWD) after the wheat harvest for each year and depth. Bars in for the same soil depth with the same latter are not significantly different (P<0.05).

Initial effects of tillage practices on MWD were similar, though aggregation was clearly increased under NT system followed by the second and the third year rotations. Conventional tillage methods (CT_1 and CT_2) caused destruction of aggregates and yielded lower MWD values (Figure 1). Reduced and NT tillage systems considerably increased (P<0.05) the MWD values at three depths (0-10, 10-20 and 20-30 cm) compared with the CT_1 and CT_2 applications. Degradation of soil aggregates and lower MWD values due to the soil tillage under different soil and climate conditions have also been reported by Pagliai et al. (2004), Gren et al. (2007), Alvaro-Fuentes et al. (2008).

Burning the residue along with conventional tillage reduced organic matter that induced degradation of soil aggregates lowering the MWD values (Figure 1). Positive correlation between aggregate stability of soils and organic matter content have been reported by Elliot (1986) and Smith and Elliot (1990). The increase in intensity, number and depth of soils tillage practices resulted in lowered MWD values particularly at 0-10 and 10-20 cm depths (Figure 1). Resck et al. (1999) also reported that conventional tillage practices are the major threats on degradation of soil aggregates. Tillage equipments used in the experiment were disturbing the upper 20 cm of soil profile, therefore the influence on soil properties were more prominent on upper 20 cm depth. The difference between RT_1 and RT_2 was probably due to the use of rotary tiller which shreds the soil aggregates into smaller pieces. Rotary tiller under RT_2 system was used twice each year one for winter wheat and the second one for either corn or soybean. Whereas in RT_1 system, rotary tiller was only used for preparation of seed bed in the second crop.

The paired test results revealed that MWD values at the end of the study was significantly increased ($P<0.01$) with the application of RT_1, RT_2, RNT and NT methods at 0-30 cm depth (Table 4). Although the final MWD values obtained in CT_2 applications were lower than the initial MWD values, burning crop residue along with conventional tillage method (CT_2) did not significantly affect the MWD. However, conserving plant residue in conventionally tilled soils (CT_1) significantly increased the MWD at 0-10 and 10-20 cm depths (Table 4) ($P<0.01$).

Soil porosity

Roseberg and McCoy (1992) reported that tillage can alter total porosity and pore-size distribution in soils. The effects of tillage practices were not significant on total porosity in the first year of the experiment probably due to inadequate organic matter addition and mineralization with the first year of treatments. The difference in porosity among tillage systems became significant in the second and third year ($P<0.05$). The lowest total porosity values were obtained with NT and RNT systems at the end of the experiment (Table 7).

Table 7. Effects of different tillage practices on porosity after the wheat harvest for each year and depth.

Treatments*	Total porosity (cm^3 cm^{-3})								
	First year (June 2007)			Second year (June 2008)			Third year (June 2009)		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
CT_1	$0.579^{\dagger}\pm0.022^{a\&}$	0.548 ± 0.023^{a}	0.583 ± 0.023^{a}	0.630 ± 0.010^{a}	0.614 ± 0.010^{a}	0.607 ± 0.016^{a}	0.624 ± 0.014^{a}	0.608 ± 0.008^{a}	0.594 ± 0.014^{ab}
CT_2	0.533 ± 0.031^{a}	0.556 ± 0.008^{a}	0.550 ± 0.003^{a}	0.610 ± 0.032^{a}	0.606 ± 0.018^{a}	0.603 ± 0.021^{a}	0.608 ± 0.015^{a}	0.604 ± 0.020^{a}	0.598 ± 0.013^{a}
RT_1	0.525 ± 0.008^{a}	0.543 ± 0.037^{a}	0.589 ± 0.054^{a}	0.590 ± 0.022^{a}	0.574 ± 0.021^{ab}	0.561 ± 0.017^{ab}	0.596 ± 0.010^{a}	0.576 ± 0.015^{a}	0.561 ± 0.012^{bc}
RT_2	0.523 ± 0.029^{a}	0.540 ± 0.015^{a}	0.586 ± 0.014^{a}	0.574 ± 0.014^{ab}	0.557 ± 0.017^{abc}	0.550 ± 0.015^{ab}	0.589 ± 0.016^{a}	0.562 ± 0.031^{a}	0.557 ± 0.011^{c}
RNT	0.535 ± 0.031^{a}	0.531 ± 0.024^{a}	0.602 ± 0.009^{a}	0.518 ± 0.025^{bc}	0.493 ± 0.036^{bc}	0.488 ± 0.055^{bc}	0.529 ± 0.030^{b}	0.491 ± 0.011^{b}	0.498 ± 0.012^{d}
NT	0.559 ± 0.020^{a}	0.543 ± 0.007^{a}	0.554 ± 0.045^{a}	0.495 ± 0.038^{c}	0.478 ± 0.055^{c}	0.458 ± 0.010^{c}	0.512 ± 0.013^{b}	0.485 ± 0.027^{b}	0.480 ± 0.012^{d}

* CT_1, conventional tillage with residue incorporated in the soil; CT_2, conventional tillage with residues burned; RT_1, reduced tillage with heavy tandem disc harrow; RT_2, reduced tillage with rotary tiller; RNT, reduced tillage with heavy tandem disc harrow fallowed by no-tillage; NT, no tillage.

† The numbers following ± indicate standard deviation.

& Values in a column followed by the same latter are not significantly different (Tukey, P≤0.05).

The order of total porosity values in the third year (June 2009) at 0-10 and 10-20 cm was $CT_1=CT_2=RT_1=RT_2>RNT=NT$. The effects of tillage practices on total porosity was distinctive at 20-30 cm depth, and the order was $CT_2>CT_1>RT_1>RT_2>RNT=NT$. Due to the differences in physical effects of tillage equipments and tillage depths (Table 1), total porosity at 20-30 cm depth differed between conventional and reduced tillage applications (Table 7). Higher bulk densities in NT and RT applications (Table 5) indicated probable compactions which might be resulted in lower porosity values (Alegre et al., 1991; Martinez et al., 2008). Salinas-Garcia et al. (1997) and Lipiec et al. (2006) also indicated that the conventionally tilled soils generally tend to have a greater total porosity in tilled zone due to lower bulk density achieved by tillage.

Total porosity of soils was significantly ($P<0.01$ and $P<0.05$) increased with the application of CT_1, CT_2, RT_1 and RT_2 methods as compared to those of initial values (Table 4). However, total porosity of soils was significantly reduced ($P<0.01$) with RNT method at 0-10 cm and all three depths with NT method (Table 4).

Conclusions

The study was conducted to determine the short-term (2006-2009) effects of conventional and conservational tillage practices on soil physical properties of a heavy clayey Typic Haploxerert under two wheat-corn and wheat-legume rotation in a semi-arid irrigated Mediterranean Region.

Tillage applications had no significant effects on physical properties of soils at the end of the first year of experiment; however the differences were significant among tillage methods at the second and third year. Conventional tillage methods (CT_1 and CT_2) induced to increase hydraulic conductivity (HC) of soils though available water content (AWC) and aggregation were reduced as compared to reduced (RT) and no-tillage (NT) systems. Burning the crop residue along with conventional tillage (CT_2) probably weakened the bindings between soil particles that resulted in occurrence of the lowest mean weight diameter (MWD) and AWC values.

Bulk density of soils was reduced with conventional tillage systems as compared to reduced and no-tillage systems. The increase in bulk density and reduction in hydraulic conductivity and total porosity under NT and RNT conditions of heavy clayey soils need to be monitored preventing erosion and runoff in sloping areas and avoiding negative impacts of water logging in level areas for plant production. Therefore, no-tillage system particularly at sloppy fields with heavy clay conditions should cautiously be applied.

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