International Journal of Plant Production 5 (3), July 2011
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Impacts of different tillage practices on some soil microbiological properties and crop yield under semi-arid Mediterranean conditions

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Received 23 January 2011; Accepted after revision 2 April 2011; Published online 1 June 2011

Abstract

Effects of six tillage practices on some soil microbiological properties and crop yields were evaluated for a clay soil (Typic Haploxererts) under semi-arid Mediterranean conditions in a three year study (2006-2009). The experiment was designed as a completely randomized-block with three replications. Treatments were: conventional tillage with residue incorporated (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow for the first crop + no-tillage for the second crop (RNT), and no tillage (NT). The study was conducted in wheat-corn, wheat-soybean and wheat crop rotations. Dehydrogenase activity, soil respiration, mycorrhizal spore number, total organic carbon (TOC), and total N were determined at three depths (0-10, 10-20 and 20-30 cm). The mycorrhizal spore number responded quite early to tillage practices. Significant tillage effects on TOC and total N were observed only at 0-10 cm depth. The TOC content was increased by NT, RT2, RNT and RT1 practices compared to the initial values at the same depth as 74%, 62%, 56%, and 50%, respectively. Dehydrogenase activity (DHA) and soil respiration were higher on the surface and decreased with depth. Reduced and no-tillage practices significantly increased the mycorrhizal spore number, dehydrogenase activity and soil respiration at all depths ($P<0.05$). Both CT1 and CT2 practices had significant negative effects on all measured soil properties. Tillage practices had no significant effect on crop yields except for the wheat yield in 2008. The results indicated that, as an alternative to conventional tillage, reduced and no-tillage practices provided successful crop production in a clay soil under a semi-arid climate.

Keywords: Dehydrogenase; Microbiological soil properties; Mycorrhizae; Organic carbon; Soil respiration; Tillage practices.

Introduction

Çukurova region, located in the Eastern Mediterranean coastal area of Turkey, is one of the most fertile plains, and comprises 5% of the total arable land of the country. Due to mild climate and sufficient water, two crops can be grown within the same year in the region. Double crop rotational systems, wheat+corn or wheat+soybean are usually preferred and intensive agricultural production is practiced under conventional tillage (CT) methods. Farmers sow wheat in mid-November and harvest it around mid-June as a winter crop. Soil is tilled immediately after wheat harvest for corn, soybean or peanut as the second crop. In order to hasten the planting process of the second crop, farmers generally burn the residues of the first crop (wheat). Very few farmers gather the residues and apply tillage practices without burning the stubble. Residues of the second crop (corn, soybean or peanut) are also burnt to prepare field for the next crop. Following this process the soil is tilled 3 to 5 times with deep and harrowing farm implements after both the first and the second crop harvests.

Although conventional tillage (CT) is the most widespread practice in the Çukurova as well as across Turkey, some rare examples of conservation or reduced tillage (RT) methods are also being applied. However, no-tillage (NT) is not practiced in double crop production. The impact of no-tillage on soil microbiological properties is a topic which hasn't been sufficiently evaluated yet under semi-arid Mediterranean conditions.

Conventional tillage practices have some negative effects on physical, chemical and microbiological properties of the soil, and thus soil ecosystems have been degraded (Carter and Stewart, 1996). Soil quality is dependent on physical and chemical, and also on soil biological properties (Karlen et al., 2001). Soil organic matter plays important key roles in many aspects of soil quality, such as soil structure, soil water relations, soil compaction, water infiltration, and erosion protection together with chemical and biological fertilities (Gregorich et al., 1993).

Conventional tillage leads to the impairment of soil microbiological activity and aggregate stability, and decreases crop yield causing a rapid reduction of soil organic matter (Bayer et al., 2001) and enzyme activities (Acosta-Martinez et al., 2003). However, the potential enzyme activities such as dehydrogenase and phosphatase increased with the use of no-till practices (Doran and Linn, 1994). Miller et al. (1995) and Anken et al. (2004) specified that mycorrhizae spore number could be used as an indicator of soil quality properties. However, tillage practices and agricultural activities have negative effects on mycorrhizae spore numbers (Galvez et al., 2001) and on mycorrhizal hyphae density (Kabir et al., 1998) of soil.

The rates of physical and chemical changes in soil are lower compared to the changes in soil microbiological properties including enzyme activities, the latter are usually measured to monitor the soil quality and degradation (Omidi et al., 2008). Biological and biochemical properties are sensitive indicators, and are rapidly affected by the change in tillage and soil management practices (Izquierdo et al., 2003; Yang et al., 2011). No tillage (NT) caused in increase the organic matter content of surface soils and thus microbiological activity of topsoil is higher in NT than that of CT practices (Mullen et al., 1998). No-tillage system helped sequestration of carbon and nitrogen, build-up of particulate organic carbon at the surface layer (Namr and Mrabet, 2004). β-glucosidase, urease and DHA were increased by NT practices with no residue burning (Angers et al., 1993; Mullen et al., 1998), whereas microbial biomass and enzyme activities decreased with stubble burning (Ajwa et al., 1999). Omidi et al. (2008) compared the effects of no-till, minimum and conventional tillage practices in a two-year study, and reported that the DHA and other microbiological properties were significantly higher in no-till than the tilled soils.

Madejon et al. (2007) reported higher values of organic matter contents and microbiological activities, including DHA, in the surface layer (0-5 and 5-10 cm) after 14 years in NT than that of CT soils. DHA was used as an indicator of microbiological activity in semi-arid soil conditions (Beye et al., 1992). Conservation tillage practices had also positive effects on soil enzyme activities under semi-arid Mediterranean and hot climate conditions (Riffaldi et al., 2002). RT or NT practices produced higher values of DHA compared to CT practices, where the values decreased with depth (Roldan et al., 2005). Inevitably, comparison of these practices might be of great help for the long-term sustainability of agricultural ecosystems under arid and semi-arid climatic conditions.

The effects of different tillage practices on soil microbiological properties in the Çukurova region as well as in Turkey have not been studied. Therefore, this study was undertaken to determine the effects of conventional, reduced and no tillage practices on some microbiological properties and yields of wheat+corn, wheat+soybean and wheat rotation in a clay soil under semi-arid climatic conditions.

Materials and Methods

Experimental site

A field experiment was carried out in the period from 2006 to 2009 at the Agricultural Experimental Station (37°00′54″ N, 35°21′27″ E; 32 m above sea level) of the Cukurova University, Adana, Southern Turkey. The prevailing climate of study area is Mediterranean with a long-term (30 years) mean annual temperature of 20 °C. The summers are hot and dry and the winters are rainy and mild. The long-term mean annual precipitation is around 670 mm, about 75% of which falls during winter and spring (from November to May), where the long-term mean annual potential evapotranspiration is 1500 mm yr^{-1}. The annual mean temperature during the study period was 19.2 °C, the relative humidity was 70%, and the annual mean precipitation was 563 mm. The experiment was conducted on the Arik clay with a slope of about 1%. The soil had 50% clay (<2 µm), 32% silt (2-50 µm) and 18% sand (50-2000 µm) at the depth 0-30 cm and was classified as Typic Haploxererts (Soil Survey Staff, 1999). The soil (0-30 cm deep) of the experimental field had a pH of 7.82, bulk density of 1.31 Mg m^{-3}, total organic carbon of 8.76 g kg^{-1}, total salt of 0.09 g kg^{-1}, $CaCO_3$ of 244 g kg^{-1}, and electrical conductivity of 0.15 dS m^{-1}.

Experimental design and tillage systems

The field has been used for continuous wheat (*Triticum aestivum* L.) production under conventional tillage for more than 30 years. After harvesting wheat in June 2006, the area was prepared for a field trial. The experiment was a randomized complete block design with three replications, and treatments were conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow for the first crop + no-tillage for the second crop (RNT), and no tillage (NT). The tillage plots were of 12-m width and 40-m length (480 m^2), and 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 are given in Table 1.

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

Tillage Methods	Winter wheat (November 2006, 2007, 2008)	Second crop maize and soybean (June 2007, 2008)
Conventional tillage with residue incorporated in the soil (CT1)	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 (CT2)	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 (RT1)	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 (RT2)	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 + no-tillage (RNT)	Stover chopping of second crop Heavy tandem disc harrow (18-20 cm) Float (2 passes) Drill (4 cm)	Stubble chopping of wheat Herbicide treatment 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 depth of the equipments.

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 corn and soybean was from the second week of June to the first week of October. The crop yield was determined by manually harvesting the crop across 4 m^2 in each plot and weighing.

In the conventional tillage methods (CT1 and CT2), 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 CT2, crop residues were burnt after the wheat, corn, and soybean harvest. In the CTI, RT1 and RT2 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).

Two weeks prior to sowing, the total herbicide (500 g ha^{-1} Glyphosate) was used to control weeds in the NT and RNT treatments. Composed NP-fertilizers were applied in the seedbed at 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 sown 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. 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 were sown at seeding rates of 8.4 and 23.6 plants per m^{-2}, respectively. Corn and soybean were sprinkler-irrigated once in every 13-day and nine times totally during the growing period. 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, soil samples were collected four times throughout the research period, one at the beginning and others immediately after the harvest of the first crop. The first samples were taken in June 2006 following the establishment of the plots. The second, third, and the fourth samples were taken immediately after the harvest of the first crop in the first week of June 2007, 2008 and 2009, respectively. Microbiological characteristics of soil at the beginning of the study (June 2006) are given in Table 2. The soil texture was homogeneous throughout the plots therefore no significant differences were determined at the three depths evaluated.

Table 2. Initial values of soil microbiological properties before different tillage treatments (June 2006).

Tillage Treatments*	Depth (cm)	TOC[a)] (g kg^{-1})	Total N (g kg^{-1})	DHA[b] (µg TPF 10 g dry $soil^{-1}$ $24h^{-1}$)	Soil respiration (mg CO_2 100 g dry $soil^{-1}$ $24h^{-1}$)	Number of mycorrhizal spore (10 g soil)
CT1	0-10	8.81[†]±0.65[a‼]	0.86±0.06[a]	245±10[a]	16.7±2.51[a]	38±6[a]
CT2	0-10	8.65±0.07[a]	0.88±0.05[a]	206±32[a]	13.02±3.68[a]	39±10[a]
RT1	0-10	8.80±0.56[a]	0.90±0.05[a]	273±16[a]	14.98±7.84[a]	35±7[a]
RT2	0-10	8.70±0.14[a]	0.94±0.05[a]	261±17[a]	18.34±2.46[a]	38±11[a]
RNT	0-10	9.28±0.62[a]	0.90±0.08[a]	286±66[a]	16.14±2.87[a]	39±5[a]
NT	0-10	9.46±0.87[a]	0.89±0.12[a]	279±36[a]	16.69±1.34[a]	42±16[a]
CT1	10-20	8.64±0.74[a]	0.86±0.03[a]	202±68[a]	16.33±1.59[a]	34±4[a]
CT2	10-20	8.46±0.14[a]	0.85±0.05[a]	162±57[a]	14.56±1.45[a]	37±15[a]
RT1	10-20	8.80±0.48[a]	0.96±0.08[a]	165±38[a]	13.59±5.37[a]	31±3[a]
RT2	10-20	8.58±0.01[a]	0.91±0.05[a]	162±52[a]	13.52±3.67[a]	34±7[a]
RNT	10-20	9.03±0.46[a]	0.91±0.03[a]	172±19[a]	15.45±1.45[a]	27±1[a]
NT	10-20	9.25±0.83[a]	0.89±0.09[a]	213±49[a]	15.11±1.71[a]	36±9[a]
CT1	20-30	8.50±0.75[a]	0.88±0.03[a]	168±19[a]	17.40±2.15[a]	19±6[a]
CT2	20-30	8.20±0.11[a]	0.88±0.11[a]	156±20[a]	14.90±0.95[a]	29±9[a]
RT1	20-30	8.36±0.30[a]	0.88±0.14[a]	176±24[a]	16.60±3.63[a]	18±2[a]
RT2	20-30	8.32±0.22[a]	0.90±0.05[a]	128±23[a]	20.51±1.87[a]	19±4[a]
RNT	20-30	8.87±0.12[a]	0.85±0.07[a]	166±29[a]	17.36±0.91[a]	20±5[a]
NT	20-30	8.84±0.64[a]	0.90±0.12[a]	204±46[a]	18.40±5.03[a]	20±7[a]

[*] CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, 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).
[a] TOC: Total organic carbon.
[a] DHA: Dehydrogenase activity.

Soil samples were collected at two sites of each individual plot (total of six samples per tillage treatments) at depths of 0-10, 10-20 and 20-30 cm. Field-moist soil samples were divided into two subsamples. One subsample was air-dried at room temperature and sieved to <2 mm for physical and chemical analysis. For microbiological and enzymatic activities, soils were sieved to <2 mm in fresh (field moisture) and stored at 4 $^{\circ}$C until the analyses, which were performed within three weeks of sample collection. Visible pieces of crop residue and roots were removed from soil samples. All analytical results were calculated on the basis of oven-dry weight of soil.

Particle size distribution was determined with a Bouyoucos hydrometer (Bouyoucos, 1962). Total organic carbon (OC), total nitrogen (TN), calcium carbonate, pH, electrical conductivity and total salts were measured according to methods described by Page et al. (1982). Soil respiration was measured as CO_2 evolution after 24 h of incubation period at 25 $^{\circ}$C, in darkness, with moisture content adjusted at 50% of water holding capacity, according to Isermeyer (1952). Data were expressed as mg CO_2 100 g^{-1} dry soil. Dehydrogenase enzyme activity (DHA) was determined according to Thalmann (1968) after soil incubation with 2,3,5 triphenyl-tetrazolium chloride (TTC) and measuring the triphenyl formazan (TPF) absorbance at 546 nm. Data were expressed as µg TPF 10 g^{-1} dry soil. Mycorrhizal spores were collected from soil and counted according to the wet sieving method (Gerdemann and Nicolsson, 1963).

Statistical analysis

One-way (tillage levels) analysis of variance (ANOVA) was applied to determine the significance of differences in microbiological properties (organic C, total N, dehydrogenase activity, soil respiration and mycorrhizal spore) for 0-10, 10-20, and 20-30 cm depths separately. Following the ANOVA test, the Tukey test was performed to compare differences in means of the parameters at significance level of 0.05. The statistical analyses were performed using SPSS software (version 9.0).

Results

Total organic carbon (TOC)

Tillage treatments generally did not statistically affect TOC, although significant differences were found at the depth of 0-10 cm in 2008 and 2009 (Table 3) for NT and RT practices. The highest TOC values at 0-10 cm were 13. 47 and 16.47 g kg^{-1} under NT, and the lowest values were 9.56 and 10.09 g kg^{-1} under CT2 for 2008 and 2009, respectively. TOC values were lower under both CT practices and residue burning that accelerated the loss of organic carbon content. When CT1 and CT2 results were compared, the organic carbon content was low in the CT2 treatment due to burning the stubbles.

Table 3. Effect of tillage practices on soil total organic carbon content for each year and depth.

Tillage Treatments*	Organic C (g kg^{-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
CT1	$9.69^{\dagger}\pm0.95^{a\ddagger}$	9.63 ± 1.08^{a}	9.26 ± 0.73^{a}	10.23 ± 0.62^{bc}	10.10 ± 0.12^{a}	9.63 ± 0.80^{a}	10.67 ± 0.41^{cd}	10.36 ± 0.71^{a}	9.13 ± 0.57^{a}
CT2	9.83 ± 0.28^{a}	8.89 ± 0.61^{a}	9.15 ± 0.69^{a}	9.56 ± 0.79^{c}	9.54 ± 0.69^{a}	9.13 ± 0.95^{a}	10.09 ± 0.11^{d}	9.86 ± 0.26^{a}	8.36 ± 0.29^{a}
RT1	10.56 ± 1.0^{a}	9.38 ± 0.82^{a}	9.73 ± 0.60^{a}	11.55 ± 0.35^{ab}	9.35 ± 1.31^{a}	8.98 ± 0.79^{a}	13.22 ± 0.67^{bc}	9.88 ± 0.52^{a}	7.98 ± 0.97^{a}
RT2	10.90 ± 0.69^{a}	9.12 ± 0.87^{a}	8.74 ± 0.54^{a}	11.22 ± 0.37^{bc}	9.70 ± 0.73^{a}	8.81 ± 0.21^{a}	14.14 ± 0.64^{ab}	8.96 ± 0.16^{a}	8.00 ± 0.36^{a}
RNT	10.57 ± 1.29^{a}	9.35 ± 0.88^{a}	8.93 ± 1.06^{a}	12.03 ± 0.98^{ab}	10.97 ± 0.18^{a}	9.26 ± 1.48^{a}	14.44 ± 0.63^{ab}	10.05 ± 0.29^{a}	8.92 ± 0.58^{a}
NT	10.79 ± 1.61^{a}	9.46 ± 1.44^{a}	9.18 ± 1.16^{a}	13.47 ± 0.87^{a}	10.52 ± 0.58^{a}	9.46 ± 0.31^{a}	16.47 ± 2.31^{a}	9.87 ± 1.12^{a}	8.20 ± 1.38^{a}
F values#	0.675	0.212	0.496	11.364^{***}	1.567	0.372	15.487^{***}	1.778	1.127

* CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, NT: No tillage.

† The numbers following ± indicate standard deviation.

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

Significance level of F values: ***, $P<0.001$.

The results obtained at the third year of the study indicated an organic carbon increase at 0-10 soil depth under NT, RNT, RT2 and RT1 practices. The rates of increase in organic carbon were 74%, 62%, 56% and 50% as compared to those obtained in 2006, respectively. On the other hand, conventional methods (CT1 and CT2) increased the organic carbon 21% and 16%, respectively, within the same period. At the end of the experiment, TOC values under NT application were 54% and 63% higher than those under CT1 and CT2, respectively (Table 3).

Total N

The effects of tillage practices on the total N content were significantly different only at 0-10 cm depth in 2008 and 2009 (Table 4). The highest total N at 0-10 cm was obtained under NT (1.06 g kg^{-1}) and RNT (1.37 g kg^{-1}) in 2008 and 2009, respectively. However, the lowest total N was recorded under CT2 (0.86 and 0.97 g kg^{-1}). RT1, RT2 and RNT had similar effects on total N at 0-10 cm depth. Tillage treatments had no different effect on total N at 10-20 cm and 20-30 cm depths for each of three years.

When the initial and final values were considered, statistically significant differences occurred between tillage treatments. The results (2009) indicated a total N increase at 0-10 cm under RNT, NT, RT1 and RT2 practices. The total N contents were 52%, 43%, 41% and 27% higher compared to those found in 2006, respectively. However, the total N content was increased 10% with the application of CT2, within the same period. The higher TOC content caused high total N content in reduced and no-tillage plots compared to conventional tillage.

Dehydrogenase activity

Tillage practices had significant and different effects on dehydrogenase activity in 2008 and 2009, but no differences were found in 2007 (Table 5). Dehydrogenase activity increased at all depths compared to the initial measurements in 2006. The highest dehydrogenase activity values were obtained under NT and RNT at all depths in 2008 and 2009. On the other hand, the lowest values were in the conventional tillage practices. Effects of the practices on the dehydrogenase activity in 2009 were obtained as the orders of NT>RNT≥RT1>RT2>CT1>CT2 at 0-10 cm; NT>RNT>RT1≥RT2>CT1>CT2 at 10-20 cm and NT>RNT>RT2≥CT1≥RT1≥CT2 at 20-30 cm depths, respectively. In all soil samplings, dehydrogenase activity values were higher in the surface layer and diminished with depth (Table 5).

Soil respiration

The tillage treatments had significant effect on soil respiration at all depths in 2008 and 2009, whereas no differences were determined in 2007 (Table 6). The highest soil respiration values were obtained in NT at all soil depths in 2008 and 2009 although the lowest values were reported in CT2.

Table 4. Effect of tillage practices on total nitrogen content for each year and depth.

Tillage Treatments*	Nitrogen (g kg^{-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
CT1	0.88[†]±0.04[a‡‡]	0.89±0.05[a]	0.89±0.05[a]	0.88±0.07[b]	0.88±0.04[a]	0.81±0.06[a]	1.13±0.14[ab]	1.03±0.16[a]	0.93±0.16[a]
CT2	0.94±0.07[a]	0.92±0.09[a]	0.86±0.05[a]	0.86±0.02[b]	0.84±0.10[a]	0.97±0.01[a]	0.97±0.20[b]	1.11±0.15[a]	1.03±0.16[a]
RT1	0.97±0.08[a]	0.90±0.01[a]	0.90±0.07[a]	0.95±0.02[ab]	0.87±0.08[a]	0.78±0.08[a]	1.27±0.08[ab]	1.12±0.09[a]	1.00±0.02[a]
RT2	0.94±0.03[a]	0.87±0.02[a]	0.85±0.06[a]	0.96±0.05[ab]	0.82±0.04[a]	0.82±0.06[a]	1.19±0.10[ab]	1.03±0.16[a]	0.95±0.16[a]
RNT	0.99±0.04[a]	0.96±0.14[a]	0.91±0.02[a]	0.98±0.09[ab]	0.94±0.08[a]	0.85±0.02[a]	1.37±0.11[a]	1.07±0.08[a]	1.00±0.29[a]
NT	0.98±0.09[a]	0.87±0.08[a]	0.89±0.14[a]	1.06±0.06[a]	0.94±0.11[a]	0.85±0.14[a]	1.27±0.09[ab]	1.02±0.22[a]	0.96±0.17[a]
F values[#]	1.114	0.581	0.297	4.969*	1.218	0.488	3.464*	0.252	0.151

* CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, NT: No tillage.

[†] The numbers following ± indicate standard deviation.

[‡‡] Values in a column followed by the same latter are not significantly different (Tukey, $P \leq 0.05$).

[#] Significance level of F values: *, $P<0.05$.

Table 5. Effect of tillage practices on dehydrogenase activity for each year and depth.

Tillage Treatments*	Dehydrogenase (µg TPF 10 g dry soil^{-1} 24h^{-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
CT1	$352^{\dagger}\pm68^{a\ddagger}$	301 ± 40^{a}	229 ± 52^{a}	292 ± 21^{cd}	258 ± 3^{b}	219 ± 4^{bc}	311 ± 8^{d}	271 ± 4^{c}	221 ± 2^{c}
CT2	363 ± 22^{a}	257 ± 29^{a}	214 ± 90^{a}	241 ± 7^{d}	245 ± 9^{b}	215 ± 41^{bc}	236 ± 6^{e}	232 ± 8^{d}	210 ± 4^{c}
RT1	365 ± 146^{a}	236 ± 72^{a}	230 ± 81^{a}	408 ± 44^{ab}	302 ± 59^{ab}	208 ± 36^{bc}	423 ± 12^{b}	332 ± 10^{b}	218 ± 6^{c}
RT2	455 ± 96^{a}	240 ± 51^{a}	171 ± 55^{a}	364 ± 42^{bc}	289 ± 48^{ab}	200 ± 29^{c}	366 ± 11^{c}	317 ± 7^{b}	221 ± 7^{c}
RNT	432 ± 68^{a}	228 ± 11^{a}	208 ± 10^{a}	440 ± 26^{ab}	329 ± 30^{ab}	268 ± 6^{a}	446 ± 16^{b}	336 ± 14^{ab}	256 ± 11^{b}
NT	477 ± 106^{a}	281 ± 63^{a}	207 ± 41^{a}	491 ± 26^{a}	359 ± 35^{a}	253 ± 11^{ab}	487 ± 13^{a}	363 ± 15^{a}	278 ± 12^{a}
F values#	1.019	1.028	0.377	28.266^{***}	4.153^{*}	3.287^{*}	198.853^{***}	60.326^{***}	32.355^{***}

* CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, 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).

\# Significance level of F values: *, P<0.05; ***, P<0.001.

Table 6. Effect of tillage practices on soil respiration for each year and depth.

Tillage Treatments[*]	Soil respiration (mg CO_2 100 g dry $soil^{-1}$ $24h^{-1}$)								
	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
CT1	10.84[†]±0.60[a‼]	10.18±2.84[a]	9.85±1.83[a]	12.35±0.54[bc]	11.93±0.36[bc]	10.67±1.12[bc]	11.68±0.19[d]	11.07±0.26[c]	10.70±0.49[cd]
CT2	14.30±2.62[a]	10.92±2.10[a]	11.81±1.43[a]	10.74±0.77[c]	10.16±0.45[c]	9.53±0.15[c]	9.92±0.08[d]	9.52±0.12[c]	8.64±0.21[d]
RT1	15.64±1.93[a]	11.85±0.93[a]	15.94±8.39[a]	15.06±0.97[b]	13.29±0.44[b]	11.94±0.82[ab]	17.46±0.54[b]	15.76±0.62[ab]	12.63±0.15[bc]
RT2	16.55±5.47[a]	9.50±2.28[a]	9.42±1.60[a]	13.71±1.74[bc]	12.99±1.01[b]	10.91±0.66[bc]	15.11±1.42[c]	14.06±1.78[b]	12.79±1.74[bc]
RNT	15.05±3.45[a]	8.57±2.53[a]	9.09±1.19[a]	18.33±1.78[a]	16.18±0.54[a]	13.54±0.75[a]	18.82±0.44[b]	15.55±0.60[ab]	14.12±0.75[ab]
NT	15.87±2.04[a]	12.08±3.66[a]	10.43±4.18[a]	19.36±0.09[a]	16.96±0.98[a]	13.65±1.05[a]	21.12±0.48[a]	17.90±0.87[a]	15.96±0.76[a]
F values[#]	1.321	0.874	1.216	25.468[***]	42.460[***]	12.106[***]	118.454[***]	36.889[***]	26.408[***]

[*] CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, NT: No tillage.

[†] The numbers following ± indicate standard deviation.

[‼] Values in a column followed by the same latter are not significantly different (Tukey, $P \leq 0.05$).

[#] Significance level of F values: ***, $P<0.001$.

Soil respiration values of RNT and NT practices were higher compared to the other tillage treatments at all depths in 2008 and 2009. The lowest soil respiration values were under CT1 and CT2 practices for 0-10 and 10-20 cm depths, but at 20-30 cm depth this reduction was much greater under the CT2 practice in which crop residues were burnt (Table 6). In all samplings, soil respiration values were higher in the surface and diminished with depth.

Mycorrhizal spore numbers

There were significant effects of tillage system on mycorrhizal spore numbers within all soil layers for each of three years (Table 7). The highest mycorrhizal spore numbers were obtained in NT and RNT plots with 52 and 48 spores in 2007, 76 and 68 spores in 2008, and 58 and 46 spores in 2009 at 0-10 cm, respectively. Obviously, the conservation tillage positively affected and improved mycorrhizal spore numbers while the conventional practices (CT1 and CT2) significantly decreased them. For all depths and years, the lowest spore numbers were obtained for CT2, in which stubble was completely burnt and the values were between 7 to 14 spores in 2007, 10 to 16 spores in 2008 and 9 to 12 spores in 2009 for all depths (Table 7).

Table 7. Effect of tillage practices on mycorrhizal spore for each year and depth.

Tillage Treatments*	Number of mycorrhizal spore (10 g soil)								
	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
CT1	24[†]±4[bc‼]	28±5[ab]	25±9[bc]	33±4[d]	31±9[c]	29±4[c]	20±3[d]	29±3[d]	27±2[d]
CT2	7±2[c]	14±2[b]	17±3[c]	10±3[e]	16±2[c]	17±1[c]	9±1[e]	12±1[e]	17±3[d]
RT1	35±3[ab]	49±15[a]	41±12[ab]	56±8[bc]	57±8[b]	62±10[b]	35±6[c]	40±3[cd]	42±3[c]
RT2	24±4[bc]	28±6[ab]	20±9[c]	44±3[cd]	47±3[b]	49±5[b]	34±3[c]	39±4[c]	45±0[bc]
RNT	48±11[a]	47±10[ab]	47±21[a]	68±2[ab]	77±2[a]	79±1[a]	46±2[b]	53±2[b]	55±2[b]
NT	52±10[a]	53±11[a]	45±4[ab]	76±6[a]	90±5[a]	88±3[a]	58±3[a]	70±6[a]	70±8[a]
F values[#]	18.640***	4.779*	4.186*	77.679***	73.181***	97.628***	78.862***	85.202***	65.890***

* CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, 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).

Significance level of F values: *, P<0.05; ***, P<0.001.

Crop Yield

Effects of different tillage practices on wheat, corn and soybean yields were presented in Table 8. Except the wheat in 2008, no differences were obtained among different tillage practices on crop yield. In the 2007-2008 growing season, the highest wheat crop yield was obtained under RNT (7.73 t ha^{-1}), and the lowest yields were obtained under CT2 (6.22 t ha^{-1}) and NT (6.30 t ha^{-1}) practices (Table 8). However, the differences in the crop yield under different practices might have resulted from irregular rainfall conditions and relatively dry growing season as well.

Table 8. Effects of different tillage practices on crop yield.

Tillage Treatments*	Winter wheat June-2007 (t ha^{-1})	Corn November-2007 (t ha^{-1})	Winter wheat June-2008 (t ha^{-1})	Soybean November-2008 (t ha^{-1})	Winter wheat June-2009 (t ha^{-1})
CT1	4.50†±0.60^{a}‼	11.71±0.60^{a}	7.21±0.42^{ab}	4.32±0.32^{a}	6.84±0.87^{a}
CT2	4.93±0.75^{a}	12.05±0.50^{a}	6.22±0.66^{b}	4.21±0.24^{a}	6.40±0.43^{a}
RT1	4.84±0.38^{a}	11.99±0.85^{a}	6.90±0.47^{ab}	4.56±0.47^{a}	6.48±0.79^{a}
RT2	4.49±0.84^{a}	12.24±0.88^{a}	6.78±0.17^{ab}	4.54±0.26^{a}	5.98±0.50^{a}
RNT	5.22±0.77^{a}	11.26±0.18^{a}	7.73±0.59^{a}	4.30±0.23^{a}	7.22±0.71^{a}
NT	5.16±0.98^{a}	12.16±0.94^{a}	6.30±0.30^{b}	4.17±0.19^{a}	6.38±0.32^{a}

* CT1: Conventional tillage with residue incorporated in the soil, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow for the fist crop+no-tillage for the second crop, 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).

Discussion

Total organic carbon

The results indicated that the tillage practices had statistically important ($P<0.05$) effects on all soil microbiological parameters in 2008 and 2009. However, no significant differences were observed in soil properties in 2007, except mycorrhizal spore numbers (Tables 3, 4, 5, 6 and 7).

There were no significant effects of tillage systems on TOC within all soil layers in 2007. However, significant differences were found at the 0 to 10 cm depth in 2008 and 2009 (Table 3). We observed a significant increase in organic carbon content in 0-10 cm soil depth, immediately after one year of the reduced and no-tillage treatments. This increase is particularly important in the Çukurova region where organic matter contents are low (normally around 10-15 g kg^{-1}) (Acosta-Martinez et al., 2003). Increases in organic carbon with reduced and no-tillage treatments have previously been reported by others, although the results depended particularly on soil type, cropping system, kind of management, and climate (Holland, 2004). The studies conducted to compare CT and NT (Bhattacharyya et al., 2008) for four years and CT, RT and NT practices (Tebrügge and During, 1999) for eighteen years indicated a higher organic carbon content under RT and NT practices compared to CT practice. Melero et al. (2008) indicated that tillage treatments had no different effect on TOC at 10-20 cm and 20-30 cm depths due to the high clay content of the soil.

Our findings were in agreement with the results reported by Resck et al. (1999) and Amezketa (1999). Another factor causing the loss of organic carbon under conventional methods (CT1 and CT2) might be the breakdown of soil structure and of macro aggregates by relatively frequent and deep plowing of the soil (Resck et al., 1999). Tillage temporarily increases the O_2 level in the soil which increases the mineralization rate of organic matter thus enhancing the release of CO_2 into the atmosphere (Alvarez et al., 1995). There is a corresponding oxidation of nutrients contained in the organic matter, the most abundant being nitrogen. These released nutrients, which become available for plant uptake, provide a short term economic advantage for tillage. Since plant nutrients have a known value and C doesn't, SOC is sacrificed to temporarily increase nutrient availability to plants (Shah et al., 2009). This is a short term benefit to the producer but a long-term detriment to the quality of our soil, water and air. The increases in organic carbon content with RT and NT practices under intensive crop production within a three year period are significant for the sustainability of agricultural production in semi-arid conditions. Since many of the soil quality parameters are generally related to soil organic matter content and its quality (Gregorich et al., 1994), it is of prime importance to increase or preserve the soil organic matter content for the physical, chemical and biological qualities of the soil (Bradford and Peterson, 2000).

Total N

The effect of the tillage treatments on total N content of 0-10 cm varied with years, and it was statistically significant in 2008 and 2009 and insignificant in 2007 (Table 4). The total N increased after the second year under the reduced and no-tillage with respect to the conventional tillage treatments (CT1 and CT2) at the surface soil.

The higher TOC content caused high total N content in reduced and no-tillage plots compared to conventional tillage at the surface soil (Tables 2 and 4). Our results are in agreement with those of Heenan et al. (2004), who reported that NT and RT practices increased the total N content of the soil when compared to CT. Dalal (1992) also found greater amount of total N under NT than CT in a Vertisol. The effects of tillage practices on TOC and total N in the surface layer was probably resulted lowering the TOC and total N contents (Monreal et al., 1997; Gren et al., 2007; Madejon et al., 2007).

There was no significant effect of the different tillage methods on the total N at 10-20 cm and 20-30 cm that could be related to the high clay content. The literature shows only small or no difference in total N concentrations between tillage methods in the first year of treatment (McCarty et al., 1998), and generally relative differences did not become significant until three years (Aon et al., 2001).

Dehydrogenase activity

The effect of the tillage practices was statistically significant ($P<0.05$) on the dehydrogenase activity at all depths in 2008 and 2009 (Table 5). Conservation tillage practices improved the dehydrogenase activity. But, the conventional tillage caused decreases not only in the dehydrogenase activity but also in TOC and total N (Tables 3, 4 and 5). Roldan et al. (2005) reported similar results under no-tillage or reduced tillage.

Decreasing of dehydrogenase activity with depth may be due to the higher TOC of the surface layer (Tables 3 and 5). A significant positive correlation between TOC and dehydrogenase activity was reported in many other studies (Bastida et al., 2006; Melero et al., 2008; Truu et al., 2008). Many of the microbiological properties including the dehydrogenase activity were reported high in surface and considerably decreased with depth (Roldan et al., 2005; Madejon et al., 2007; Gren et al., 2007; Melero et al., 2008).

Soil respiration

Soil respiration was affected by the tillage treatments as well as the dehydrogenase activity. The conservation tillage treatments increased soil respiration values compared to those of the conventional tillage. The soil respirations of NT and RNT practices were higher than those of the other treatments (RT1 and RT2) at all depths in 2008. The lowest soil respiration value was obtained under the CT2 practice, in which crop residues were burnt (Table 6). Ajwa et al. (1999) also indicated that residue burning significantly reduced the soil microbial biomass and enzyme activities. A significant and positive correlation between TOC and soil respiration (Garcia et al., 1997; Truu et al., 2008) probably resulted higher soil respiration values in the surface layer.

In many long and short term studies conducted in arid and semi-arid climate conditions, greater dehydrogenase activity, soil respiration and organic carbon values have also been obtained under the conservation practices (RT and NT) compared to the conventional practices (Angerst et al., 1993; Mullen et al., 1998; Roldan et al., 2005; Madejon et al., 2007).

Mycorrhizal spore numbers

The effect of the tillage practices was significant on the mycorrhizal spore numbers in all depths of the first year (Table 7). These early findings clearly indicated that the conservation tillage practices had a positive effect on the mycorrhizal spore numbers. On the other hand, the conventional practices (CT1 and CT2) had a negative effect on the spore numbers. The negative effect was prevalent at 0-10 cm depth under the CT2 practice. Stubble burning in CT2 caused a decrease in the spore numbers of the surface soil. The results obtained were in agreement with those of Anken et al. (2004); Borie et al. (2006), who reported higher mycorrhizal spore numbers under RT and NT compared to CT practices.

The results indicated that the mycorrhizae were deteriorated and the spore numbers decreased with depth and increasing frequency of the tillage practices. The higher mycorrhizal spore numbers were obtained under RT and NT practices compared to CT by Galvez et al. (2001), Borie et al. (2006) and Li et al. (2007). Tillage reduces the inoculation potential of the soil and the efficiency of mycorrhizae by disrupting the extra radical hyphae network (McGonigle and Miller, 1999). The hyphae network is rendered non-infective by breaking apart the soil macrostructure (Miller et al., 1995; McGonigle and Miller, 1999).

The high TOC values under the RT and NT practices might have also resulted from relatively high mycorrhizal spore numbers (Tables 3 and 7). Guo and Han (2008) also reported a positive correlation between organic matter contents and mycorrhizal spore density. The disruption of macro aggregates and soil structure due to tillage practices at 10-20 and 20-30 cm depths resulted in changes of the dehydrogenase activity, soil respiration and mycorrhizal spore numbers without a statistical change in TOC values during 2007 to 2009 (Tables 5, 6 and 7). This may be resulted from tillage practices destroying macro aggregates, which provide a vital and adequate environment for microbiological activities in the soil (Hu et al., 2007).

Yield

The tillage practices had no significant effect on crop yield. The only significant difference was observed on wheat yield in 2008, where the RNT yield was higher than the other treatments (Table 8). The cause of the higher wheat yield of 2008 in RNT remain unknown, being probably due to the effect of tillage treatments on soil physical, chemical, and biological properties as well as the relatively dry growing season conditions and their complex interactions. Studies earlier conducted, to evaluate the effects of tillage methods on crop yield, have shown similar variations in yield. Some have indicated that tillage practices affected yield (Madejon et al., 2007), whereas others have reported no effect (Pala et al., 2000; Glab and Kulig, 2008; Bhattacharyya et al., 2008). Wicks et al. (1994) have stressed that crop yield highly depends on climate conditions, soil type and its properties, crop selection, management methods and the duration of the research conducted.

Conclusions

The reduced and no-tillage practices were more effective than those of the conventional tillage for increasing the total organic carbon and N at 0-10 cm, and especially for improving biological soil properties under the semi-arid conditions. The earliest affected soil microbiological parameter was the mycorrhizal spore numbers. After the first application of different tillage practices, a decrease in mycorrhizal spore numbers at 0-10 and 10-20 cm depth was observed under CT2. Effects of the tillage practices on soil properties became more evident with time over the application.

The highest difference on TOC and total N contents between tillage practices was observed at the depth of 0-10 cm. Stubble burning was responsible for the negative effect on the soil microbiological parameters in the CT2 treatment, when compared to the other conventional tillage (CT1). NT had the most significant positive effect on all soil microbiological parameters throughout the study. When compared to each other, although all reduced tillage practices (RT1, RT2 and RNT) had positive effects depending on sampling periods and soil depth, the most significant improvement in soil parameters was observed under RNT.

The dehydrogenase activity and soil respiration were determined to be higher on the surface layer and decreased with depth. The reduced and no-tillage practices not only provided the accumulation of TOC but also caused the improvement of soil microbiological parameters. The reduced and no-tillage practices increased all measured microbiological properties at the 0-30 cm depth by increasing TOC and total N contents especially at 0-10 cm depth due to the accumulation of crop residues on the soil surface. These tillage systems were of great contribution in the long-term sustainability of agricultural ecosystems under semi-arid climate conditions. Moreover, in a soil with 50% clay content, three times wheat as the first crop, once corn and once soybean as the second crop were successfully cultivated under the reduced and no-tillage practices. Except for the wheat yield in 2008, the tillage treatments didn’t have any significant effect on crop yields. The findings indicate that no-tillage and reduced tillage may be more desirable than conventional tillage in terms of soil microbiological properties in a high clay content soil under a semi-arid climate. We hope results achieved with the practice of these tillage methods will provide local farmers with important and profitable advantages due to improvement of soil quality and reduced operational cost. However, to achieve the desired results, long-term practices of the reduced and no-till methods under different soil and climate conditions are required.

Acknowledgement

We thank the TUBITAK (The Scientific and Technological Research Council of Turkey) for financial support for the project (Grant No: 106O023), which allowed this work to be carried out. We also would like to thank three anonymous reviewers for their valuable comments on the previous version of the manuscript.

References

Acosta-Martinez, V., Klose, S., Zobeck, T.M., 2003. Enzyme activities in semiarid soils under conservation reserve program, native rangeland, and cropland. J. Plant Nutr. Soil Soc. 166, 699-707.

Ajwa, H., Dell, C., Rice, C., 1999. Changes in enzyme activities and microbial biomass of tallgrass prairie soil as related to burning and nitrogen fertilization. Soil Biol. Biochem. 31, 769-777.

Alvarez, R., Díaz, R.A., Barbero, N., Santanatoglia, O.J., Blotta, L., 1995. Soil organic carbon, microbial biomass and CO_2-C production from three tillage systems. Soil Till. Res. 33, 17-28.

Amezketa, E., 1999. Soil aggregate stability: a review. J. Sustain. Agric. 14, 83-151.

Angers, D., Bissonette, N., Legera, A., Samson, N., 1993. Microbial and biochemical changes induced by rotation and tillage in a soil under barley production. Can. J. Soil Sci. 73, 39-50.

Anken, T., Weisskopf, P., Zihlmann, U., Forrer, H., Jansa, J., Perhacova, K., 2004. Long-term tillage system effects under moist cool conditions in Switzerland. Soil Till. Res. 78, 171-183.

Aon, M.A., Sarena, D.E., Burgos, J.L., Cortassa, S., 2001. (Micro)biological, chemical and physical properties of soils subjected to conventional or no-till management: an assessment of their quality status. Soil Till. Res. 60, 173-186.

Bastida, F., Moreno, J.L., Hernandez, T., Garcia, C., 2006. Microbial degradation index of soils in a semiarid climate. Soil Biol. Biochem. 38, 3463-3473.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pillon, C.N., Sangoi, L., 2001. Changes in soil organic matter fractions under subtropical no-till cropping system. Soil Sci. Soc. Am. J. 65, 1473-1478.

Beye, L., Wachendorf, C., Balzen, F.M., Balzer-Graf, U.R., 1992. The effect of soil texture and soil management on microbial biomass and soil enzyme activities in arable soils of northwest Gemany. Agrobiology Research, 45, 276-283.

Bhattacharyya, R., Kundu, S., Pandey, S.C., Singh, K.P., Gupta, H.S., 2008. Tillage and irrigation effects on crop yields and soil properties under the rice-wheat system in the Indian Himalayas. Agric. Water Manage. 95, 993-1002.

Borie, F., Rubio, R., Rouanet, J.L., Morales, A., Borie, G., Rojas, C., 2006. Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol. Soil Till. Res. 88, 253-261.

Bouyoucos, G.J., 1962. Hydrometer method improved for making particle size analyses of soils. Agron. J. 54, 464-465.

Bradford, J.M., Peterson, G.A., 2000. Conservation Tillage. In: Sumner, M.E. (Ed.), Handbook of Soil Science. CRC Press, Boca Raton, USA, pp. 247-270.

Carter, M.R., Stewart, B.A., 1996. Structure and organic matter storage in agricultural soils. Advences in Soil Science. CRC Press, Boca Raton, FL. pp. 182-245.

Dalal, R.C., 1992. Long-term trends in total nitrogen of a Vertisol subjected in zero tillage, nitrogen application and stubble retention. Aust. J. Soil Res. 30, 223-231.

Doran, J.W., Linn, D.M., 1994. Microbial ecology of conservation management systems. In: Hatfield, J.L., Stewart, B.A. (Eds.), Soil Biology: Effects on Soil Quality. Lewis Publishers, Boca Raton, FL, pp. 1-27.

Galvez, L., Douds, D.D., Drinkwater, L.E., Wagoner, P., 2001. Effect of tillage and farming system upon VAM fungus populations and mycorrhizas and nutrient uptake of maize. Plant Soil, 228, 299-308.

Garcia, C., Roldan, A., Hernandez, T., 1997. Changes in microbial activity alter abandonment of cultivation in a semiarid Mediterranean environment. J. Environ. Qual. 26, 285-291.

Gerdemann, J.W., Nicolson, T.H., 1963. Spores of mycorrhizal endogone species extracted from soil by wet sieving and decanting. T. Brit. Mycol. Soc. 46, 235-244.

Glab, T., Kulig, B., 2008. Effect of mulch and tillage system on soil porosity under wheat (*Triticum aestivum).* Soil Till. Res. 99, 169-178.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., Ellert, H.H., 1994. Towards a minimum data set to assess soil organic matter guality in agricultural soils. Can. J. Soil Sci. 74, 367-385.

Gregorich, E.G., Monreal, C.M., Ellert, B.H., Angers, D.A., Carter, M.R., 1993. Evaluating changes in soil organic matter. In: Acton, D.F. (Ed.), A Program to Assess and Monitor Soil Quality in Canada. Center Land and Biol. Res. Contr. Agric. Res. Branch, Agriculture Canada, Ottawa, pp. 93-149.

Gren, V.S., Stott, D.E., Cruz, J.C., Curi, N., 2007. Tillage impact on soil biological activity and aggregation in a Brazilian Cerrada Oxisol. Soil Till. Res. 92, 114-121.

Guo, Y.J., Han, J.G., 2008. Soil biochemical properties and arbuscular mycorrhizal fungi as affected by afforestation of rangelands in northern China. J. Arid Environ. 72, 1690-1697.

Heenan, D.P., Chan, K.Y., Knight, P.G., 2004. Long-term impact of rotation, tillage and stubble management on the loss of soil organic carbon and nitrogen from a Chromic Luvisol. Soil Till. Res. 76, 59-68.

Holland, J.M., 2004. The environmental consequences of adopting conservation tillage in Europe¨reviewing the evidence. Agr. Ecosyst. Environ. 103, 1-25.

Hu, Z., Yi-zhong, L., Zhi-chen, Y., Bao-guo, L., 2007. Influence of Conservation Tillage on Soil Aggregates Features in North China Plain. Agric. Sci. China. 6, 1099-1106.

Isermeyer, H., 1952. Eine Einfache Methode Zur Bestimmung der Bodenatmung und der Carbonate im Boden. Z. Pflanzenernaehr. Bodenk, 56, 26-38.

Izquierdo, I., Caravaca, F., Alguacil, M.M., Roldan, A., 2003. Changes in physical and biological soil quality indicators in a tropical crop system (Havana, Cuba) in response to different agroecological management practices. Environ. Manag. 32, 639-645.

Kabir, Z., O'Halloran, I.P., Widden, P., Hamel, C., 1998. Vertical distribution of arbuscular mycorrhizal fungi under corn (*Zea mays* L.) in no-till and conventional tillage systems. Mycorrhiza 8, 53-55.

Karlen, D.L., Andrews S.S., Doran, J.W., 2001. Soil quality: current concepts and applications. Adv. Agron. 74, 1-40.

Li, L.F., Li, T., Zhao, Z.W., 2007. Differences of arbuscular mycorrhizal fungal diversity and community between a cultivated land, an old field, and a never-cultivated field in a hot and arid ecosystem of southwest China. Mycorrhiza, 17, 655-665.

Madejon, E., Moreno, F., Murillo, J.M., Pelegrin, F., 2007. Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. Soil Till. Res. 94, 346-352.

McCarty, G.W., Lyssenko, N.N., Starr, J.L., 1998. Short-term changes in soil carbon and nitrogen pools during tillage management transition. Soil Sci. Soc. Am. J. 62, 1564-1571.

McGonigle, T.P., Miller, M.H., 1999. Winter survival of extraradical hyphae and spores of arbuscular mycorrhizal fungi in the field. Appl. Soil Ecol. 12, 41-50.

Melero, S., Vanderlinden, K., Ruiz, J.C., Madejon, E., 2008. Long-term effect on soil biochemical status of a Vertisol under conservation tillage system in semi-arid Mediterranean conditions. Eur. J. Soil Biol. 44, 437-442.

Miller, M.H., McGonigle, T.P., Addy, H.D., 1995. Functional Ecology of vesicular arbuscular Mycorrhizas influenced by phosphate fertilization and tillage in an agricultural ecosystem. Crit. Rev. Biotechnol. 15, 241-255.

Monreal, C.M., Zentner, R.P., Robertson, J.A., 1997. An analysis of soil organic matter dynamics in relation to management, erosion and yield of wheat in long-term crop rotation plots. Can. J. Soil Sci. 77, 553-563.

Mullen, M., Melhorn, C., Tyler, C., Duck, D., 1998. Biological and biochemical soil properties in no-till corn with different cover crops. J. Soil Water Conserv. 5, 219-224.

Namr, K.I., Mrabet, R., 2004. Influence of agricultural management on chemical quality of a clay soil of semi-arid Morocco. J. Afr. Earth Sci. 39, 485-489.

Omidi, H., Tahmasebi, Z., Torobi, H., Miransari, M., 2008. Soil enzymatic activities and available P and Zn as affected by tillage practices, canola (*Brassica napus* L.) cultivars and planting dates. Eur. J. Soil Biol. 44, 443-450.

Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), 1982. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd Edition, Agronomy Monograph No. 9, ASA and SSSA Publishers, Madison, USA.

Pala, M., Haris, H.C., Ryan, J., Makboul, R., Dozom, S., 2000. Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Exp. Agric. 36, 223-242.

Resck, D.V.S., Vasconcellos, C.A., Vilela, L., Macedo, M.C.M., 1999. Impact of conversion of Brazilian Cerrados to cropland and pasture land on soil carbon pool and dynamics. In: Lal, R., Kimble, J.M., Stewart, B.A. (Eds.), Global Climate Change and Tropical Ecosystems. Adv. Soil Sci. CRC Press, Boca Raton, FL, pp. 169-196.

Riffaldi, R., Saviozzi, A., Levi-Minzi, R., Cardelli, R., 2002. Biochemical properties of a Mediterranean soil as affected by long-term crop management systems. Soil Till. Res. 67, 109-114.

Roldan, A., Salina-Garcia, J.R., Alguacil, M.M., Caravaca, F., 2005. Changes in soil enzyme activities, fertility, aggregation and C sequestration mediated by conservation tillage practices and water regime in a maize field. Appl. Soil Ecol. 30, 11-20.

Shah, S.A., Shah, S.M., Mohammad, W., Shafi, M., Nawaz, H., 2009. N uptake and yield of wheat as influenced by integrated use of organic and mineral nitrogen. Int. J. Plant Prod. 3, 45-56.

Soil Survey Staff, 1999. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys, 2nd edition. Agriculture Handbook, vol. 435. USDA, NRCS., US Government Printing Office, Washington DC.

Tebrügge, F., Düring, R.A., 1999. Reducing tillage intensity- a review of rusults from a long-term study in Germany. Soil Till. Res. 53, 15-28.

Thalmann, A., 1968. Zur Methodik der Bestimmung der Dehydrogenaseaktivitat im Boden mittels Triphenyltetrazoliumchlorid (TTC), Landwirtschaftliche Forschung, 21, 249-258.

Truu, M., Truu, J., Ivask, M., 2008. Soil microbiological and biochemical properties for assessing the effect of agricultural management practices in Estonian cultivated soils. Eur. J. Soil Biol. 44, 231-237.

Wicks, G.A., Crutchfield, D.A., Burnside, O.C., 1994. Influence of wheat (*Triticum aestivum)* straw mulch and metolachlor on corn *(Zea mays)* growth and yield. Weed Sci. 42, 141-147.

Yang, X., Chen, C., Luo, Q., Li, L., Yu, Q., 2011. Climate change effects on wheat yield and water use in oasis cropland. Int. J. Plant Prod. 5, 83-94.