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Tillage Effects on Some Soil Physical Properties in a Semi-Arid Mediterranean Region of Turkey

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Throughout the world, degradation of soil has become an environmental problem which limits the sustainability of agriculture and decreases soil productivity. The main reason of degradation is either over cultivation or the utilization of improper tillage methods. Therefore, tillage practices play a crucial role in chemical, biological and physical properties of agricultural soils. This role was determined often by using indicators of soil quality such as bulk density, aggregate stability, plant available water, organic carbon content, soil compaction and other properties. The aim of this field study was to examine the effects of different tillage systems on some soil characteristics in the semi-arid Mediterranean coastal plain of Turkey. In the research, the following six different tillage systems were tested: conventional tillage with residue incorporated (CTR), conventional tillage with residue burned (CTB), minimum tillage with heavy tandem disc harrow (MTD), minimum tillage with rotary tiller (MTR), minimum tillage with heavy tandem disc harrow for the first crop + no-tillage for the second crop (MNT), and no tillage (NT). The experiment was initiated with summer soybean, followed by winter wheat and summer corn and ended with winter wheat production. Bulk density, aggregate stability, organic matter content and soil penetration resistance were evaluated as indicators of soil quality in this study. Conservation tillage systems (MT and NT) improved organic carbon content and aggregate stability of the soil. The different tillage systems showed a significant effect with respect to the amount of organic matter and aggregate stability in the soil. Organic matter values were lower (49-60%) under CT practices and residue burning accelerated the loss of organic carbon content. The highest aggregate stability values were found for NT (over 38%). Penetration resistance and bulk density of the tilled soils (CT and MT) were lower than in no-tillage plots (MNT and NT), bulk density was 1.26-1.32 g/cm^3 in CT at all soil depths. The trials showed that, conservation tillage practices (MT and NT) can provide better soil characteristic values than conventional practices in the semi-arid soils of the Mediterranean coastal plain.

1. Introduction

Soil quality indicators can be used to evaluate sustainability of land use and soil management practices in agro-ecosystems. Soil quality indicators can be defined as the soil processes and properties that are sensitive to changes in soil functions. Karlen (2004) also expresses that soil quality assessment is simply a tool focused on dynamic soil properties and processes that are useful for assessing the sustainability of soil management practices. Astier-Calderon et al. (2002) also recommended that indicators such as soil organic matter, infiltration capacity, soil aggregation, pH, bulk density and soil salinity can be used evaluate soil quality. Tillage systems have been compared in terms of soil quality and environment in a great deal of research. Many studies concur that soil organic matter is a good soil quality indicator because of its influence on soil quality and productivity. Penetrometer resistance and bulk density are used as critical indicators of soil compaction. Plant roots are affected negatively by soil layers with high mechanic resistance. An increment in soil mechanic resistance decreases the rate of root elongation and penetration of the roots into the soil. Besides, higher penetrometer resistance values also reflect a higher compaction level, which can produce adverse effects like a decrease in crop growth (Hall and Raper, 2005). Soil bulk density is usually included in minimum data sets used to evaluate tillage effects on soil quality (Karlen, 2004). High bulk density values are a sign of a higher compaction level. Roscoe and Burman (2003) detected that conventional tillage systems caused significant

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increases in bulk density and soil compaction compared to no-tillage systems. Birkas et al., (2004) researched impacts of tillage on soil quality. Research results showed that regular deep tillage, carried out with the plough and disc tools, caused compress layers. The compaction was close to surface in the first 3 years, but occurred into bottom layers after 5 years.

In semi-arid southern Turkey, organic matter content of soil is low due to the burning or removal of stubble and intensive soil tillage practices. Although most research has been carried out on the effects of tillage systems in semi-arid conditions, there is currently no information on the effects of tillage systems on soil properties throughout the whole year. On the other hand, it is not a proper approach to investigate the effects of tillage systems, used for different productions throughout a year, separately, since previous tillage applications affect the results of subsequent tillage practices. Therefore, the objective of this study was to examine the effects of conventional and conservation tillage systems on bulk density, aggregate stability, organic matter and soil penetration resistance for winter wheat and summer corn production.

2. Materials and methods

A field study was carried out at the Çukurova Agricultural Research Station in the semi-arid Mediterranean coastal plain of Turkey between 2009 and 2012 years. The site is located near Adana (37^o latitude N, 35^o longitude E, 30 m above sea level). The Mediterranean region has hot and arid summers, mild and rainy winters. From 1979 to 2008, annual rainfall average was 768 mm. Annual temperature average is 19.3^{o}C, though monthly averages range from 29,6^{o}C in August to 9.9^{o}C in January according to the long-term average. The experiment was carried out on an Arik clay soil. The soil consisted of 50% clay, 33% silt and 17% sand. The tillage and sowing implements were operated using a standard 70 kW power class tractor. Table 1 shows the basic specifications of the tillage and sowing equipment used for seedbed preparation.

Table 1: The characteristics of the tillage and sowing equipment used in the experiment

Equipment	Type	Equipment width (m)	Equipment depth (m)	Average working speed[a] ($km^{-1}h$)
Plough	Three furrows	0.90	0.30	6.73
Chisel	7 shanks	2.05	0.35	6.45
Heavy disc harrow	20 discs	2.00	0.18	9.61
Disc harrow	28 discs	2.75	0.15	10.49
Rotary tiller	16 knifes	2.10	0.15	3.42
Float	1 unit	3.50	-	9.17
Universal drill	19 rows	2.50	0.03	8.53
Direct universal drill	15 rows	2.10	0.03	7.92
Single seed planter	4 rows	2.80	0.08	3.19
Direct single seed planter	4 rows	2.80	0.08	2.66

[a] Average working seed of the equipment used in the experiment

As plant materials, winter wheat (*Triticum aestivum L*), Balatilla domestic cultivar, and summer corn (*Zea mays L.*) or soybean (*Glycine max*) hybrid seed, were used. The study carried out on trial plots (12 m wide and 40 m long), was planned utilizing a completely randomized block design with three replications. In the study, six different tillage and sowing methods were used for winter wheat/summer corn or soybean production (Table 2). The production season started in June 2010 for summer soybean, followed by December 2010- June 2011 for winter wheat, June 2011- December 2011 for summer corn and ended with December 2011- June 2012 for winter wheat. Stubble on conventional-1 plot (CTB) was burnt, while that on other plots remained non-burnt. Herbicide was applied at a dose of 5000 $ml^{-1}ha$ to the no-tillage plots before sowing. The fertilizer was spread at 260 kg ha^{-1} for wheat (20% N, 20% P) and at 300 kg ha^{-1} for soybean and corn (15% N, 15% P, 15% K) with a spinning disc distributor. The winter wheat was sown into dry soil whereas the corn and soybean was sown into irrigated soil. The sowing machines were adjusted to a seeding rate of 230 kg ha^{-1} for wheat and 17 cm for corn and 5 cm for soybean along the row and 70 cm between rows for both. After seeding, cultivation practices such as chemical weed control, plant protection treatments, and irrigation were homogeneously applied over the whole area at the same time and dose.

Penetrometer measurements and soil samples were collected to reveal the effect on soil of the tillage systems before each sowing (June and December). Soil samples were taken from depths of 0-10cm, 10-20cm and 20-30cm for each plot. The samples were tested in the laboratory for bulk density, aggregate stability and organic matter content. Bulk density was determined from undisturbed soil samples. Undisturbed soil samples were taken by using a steel cylinder of 100 cm^3 volume (5 cm in diameter, and 5 cm in height). Particle size distribution and soil organic matter content were determined using disturbed soil samples (2 mm sieved) by the Bouyoucos hydrometer method (Bouyoucos, 1962) and the modified Walkley-Black wet oxidation procedure, respectively (Nelson and Sommers, 1982). Dry bulk density was measured by the core method (Blake and Hartge, 1986). A wet sieving method was used to determine the percentage of aggregate stability (WSA %) as indices of soil aggregation. The wet sieving method of Kemper and Rosenau (1986) was used with a set of sieves, which have openings of 4, 2, 1, and 0.5 mm diameters. The penetration resistance was determined to a depth of 45 cm by a hand pushed electronic cone penetrometer (Eijkelkamp Penetrologger) following ASAE standard procedures using a cone with 1 cm^2 base area, 60º included angle and 80 cm driving shaft; readings were recorded at 10 mm intervals. The measurements were performed at 6 points (3 readings for each point) in each plot.

Table 2: The characteristics of the tillage and sowing equipment used in the research

Methods	Winter wheat	Summer corn/soybean
Conventional tillage 1 (CTS)	Stubble chopping Mouldboard plough Disc harrow (2 passes) Float (2 passes) Universal drill	Stubble chopping Heavy disc harrow Disc harrow (2 passes) Float (2 passes) Pneumatic planter
Conventional tillage 2 (CTB)	Stubble burning Heavy disc harrow Disc harrow (2 passes) Float (2 passes) Universal drill	Stubble burning Heavy disc harrow Disc harrow (2 passes) Float (2 passes) Pneumatic planter
Minimum tillage 1 (MTD)	Stubble burning Heavy disc harrow (2 passes) Float (2 passes) Universal drill	Stubble burning Heavy disc harrow (2 passes) Float (2 passes) Pneumatic planter
Minimum tillage 2 (MTR)	Stubble chopping Rotary tiller Float (2 passes) Universal drill	Stubble chopping Rotary tiller Float (2 passes) Pneumatic planter
Minimum+No-tillage (MNT)	Stubble chopping Heavy disc harrow (2 passes) Float (2 passes) - Universal drill	Stubble chopping Herbicide application Direct pneumatic planter
No-tillage (NT)	Stubble chopping Herbicide application Direct universal drill	Stubble chopping Herbicide application Direct pneumatic planter

One-way (tillage levels) analysis of variance (ANOVA) was applied to determine the significance of differences in organic matter, bulk density and aggregate stability of soil at depths of 0-10, 10-20, and 20-30 cm separately. Following 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.

3. Results and discussion

3.1 Soil organic matter

The effect of different tillage systems is significant on amount of organic matter in the soil as shown in Table 3. But, no significant tillage effect was found for 10-20 cm and 20-30 cm in 2011. Organic matter contents were lower at 0-10, 10-20 and 20-30 cm depth of all plots in 2011 compared to 2010. The amount of rainfall between January and May of 2011 was lower than in 2010, therefore wheat residue was lower in 2011. This situation was reflected in the soil organic matter in 2011. The differences between tillage systems were significant at levels of 0.05 at 0-10 cm depth of the plots. Organic matter values were lower under CT practices and residue burning accelerated the loss of organic carbon content. When CTS and CTB results were compared to MT and NT results, the main difference between CT and other plots was the burning or burying of stubble in CT plots, while the residues were shredded and incorporated into soil in MT and NT plots. The residue burning and burying activities caused the lowest organic matter levels under CT. In 2010 and 2011, organic matter contents were higher in MT and NT plots at all soil depths relative to CT plots. The highest organic matter content was measured for NT (3.63%) for the 0-10 cm depth soil layer. The lowest was 0.84% for CTS at the 20-30 cm layer. Organic matter accumulation was close to the soil surface in all plots. Thomas et al. (2007) found similar results where soils under no-till generally contain greater organic carbon than those under conventional till, especially those closer to the soil surface. In a long-term experiment (13 years) on fine-textured soil and similar climatic conditions, soil organic matter under conventional tillage was only slightly lower than under no-tillage (Dalal, 1989).

Table 3: The organic matter content of soil (%) at 0-10, 10-20 and 20-30 cm depths under tillage systems for 2010 and 2011; CTB, conventional tillage with stubble; CTB, conventional tillage with stubble burning; MTD, minimum tillage with disc; MTD, minimum tillage with rotary tiller; MNT, minimum tillage with disc + no-tillage and NT, no-tillage

Tillage	2010			2011		
Methods	0-10	10-20	20-30	0-10	10-20	20-30
CTS	1.86 e	1.50 c	1.37 b	1.04 c	1.16 a	0.84 a
CTB	1.57 f	1.42 d	1.12 e	0.98 c	1.28 a	0.95 a
MTD	2.51 d	1.71 a	1.19 d	1.68 b	1.39 a	1.09 a
MTR	2.75 c	1.59 b	1.24 c	1.76 b	1.21 a	0.96 a
MNT	2.95 b	1.48 c	1.26 c	2.29 a	1.42 a	1.10 a
NT	3.63 a	1.72 a	1.67 a	2.46 a	1.30 a	1.09 a

* Means with the same letter in column are not significantly different at the 5% level of Tukey test.

3.2 Soil bulk density

Tillage systems affected bulk density statistically in 2010 and 2011 (Table 4). NT and MT practices considerably increased soil bulk density at all depths. But, no difference in bulk density among tillage treatments was reported in long-term experiments (Dalal, 1989)], indicating that an increase in bulk density appears to be only temporary, with the initial compaction compensated later by the development of soil pores originating from soil biological activity, including earthworms.

The values of bulk density were detected to increase in all plots as depth increases. This increment in bulk density was greater in CT plots compared with other plots in 2011. Bulk density was lower in CT (1.26-1.32 g cm^{-3}) in all soil depths in 2010 and 2011. Dam et al. (2005) found that bulk density was 10% higher in NT (1.37 gcm^{-3}) than in CT (1.23 gcm^{-3}), particularly at the 0–10 cm depth. Tebrügge (2001) reported bulk density of 1.2–1.35 gcm^{-3} under inversion tillage and 1.4–1.5 gcm^{-3} under no-tillage. The change in bulk density values, despite an increase in organic matter amount, means that this organic carbon increase in the short term is not reflected to soil bulk density and has not impacted soil structure development. These increases were based on a compaction resulting from high clay content and weak structure of soil in the research area. However, some researches showed that bulk density values declined in soils where organic carbon increases have occurred.

Table 4: The bulk density of soil (g cm^{-3}) at 0-10, 10-20 and 20-30 cm depths under tillage systems adopted for 2010 and 2011; CTB, conventional tillage with stubble; CTB, conventional tillage with stubble burning; MTD, minimum tillage with disc; MTR, minimum tillage with rotary tiller; MNT, minimum tillage with disc + no-tillage and NT, no-tillage

Tillage	2010			2011		
Method	0-10	10-20	20-30	0-10	10-20	20-30
CTS	1.26 d	1.29 b	1.29 b	1.27 d	1.29 c	1.32 b
CTB	1.30 cd	1.31 b	1.32 b	1.28 cd	1.32 bc	1.32 b
MTD	1.31 bc	1.32 b	1.33 b	1.32 c	1.33 bc	1.35 b
MTR	1.32 bc	1.32 b	1.33 b	1.33 bc	1.35 b	1.36 b
MNT	1.36 ab	1.38 a	1.39 a	1.39 ab	1.42 a	1.42 a
NT	1.40 a	1.41 a	1.40 a	1.42 a	1.44 a	1.44 a

* Means with the same letter in column are not significantly different at the 5% level of Tukey test.

3.3 Aggregate stability

The effect of tillage systems was significant on aggregate stability in 2010 and 2011 at soil depths (Table 5). Soil aggregate stability increased 9-43% in all plots as the depth increased. There were differences between aggregate stability means of tillage systems in all layers. The soil structure was weak (<50%) which is due to low organic content. The highest aggregate stability values were found for NT (over 38%), in 2010-2011. However, the lowest aggregate stability was reported for CTB (under 31%). These results were supported by Arshad et al. (1999), where no-tillage improved aggregate stability in surface soil compared to CT. Intensive tillage systems can cause the disruption of soil aggregates and loss of organic content.

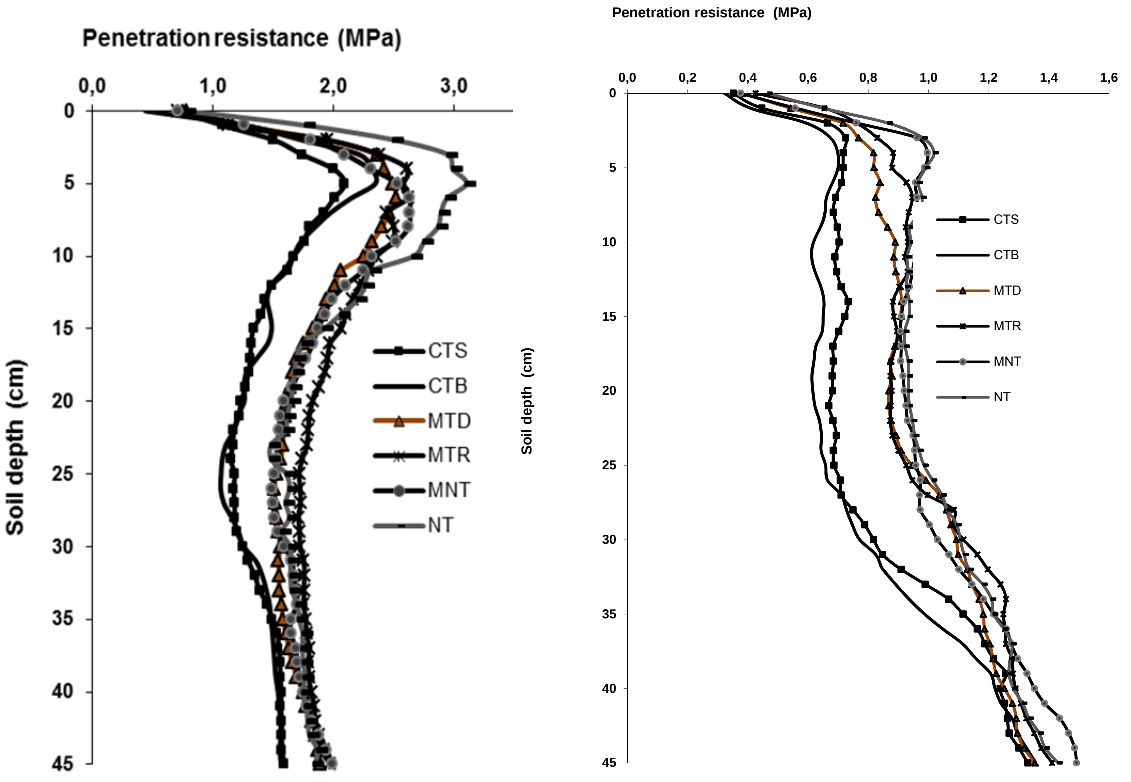
Table 5: The aggregate stability of soil (%) at 0-10, 10-20 and 20-30 cm depths under tillage systems for 2010 and 2011; CTB, conventional tillage with stubble; CTB, conventional tillage with stubble burning; MTD, minimum tillage with disc; MTR, minimum tillage with rotary tiller; MNT, minimum tillage with disc + no-tillage and NT, no-tillage

Tillage	2010			2011		
Method	0-10	10-20	20-30	0-10	10-20	20-30
CTS	28.09 b	28.65 d	31.09 b	30.16 c	32.34 d	33.98 c
CTB	20.59 c	24.09 e	28.65 b	24.10 d	26.21 e	30.81 d
MTD	35.04 a	36.60 bc	43.14 a	30.31 c	38.60 b	42.30 a
MTR	29.36 b	33.23 c	41.97 a	31.20 c	35.35 c	39.11 b
MNT	35.73 a	39.39 ab	40.00 a	36.79 b	39.45 ab	41.09 ab
NT	38.52 a	42.88 a	42.85 a	39.35 a	42.12 a	43.08 a

* Means with the same letter in column are not significantly different at the 5% level of Tukey test.

3.4 Soil compaction

There were differences between means of tillage systems on soil compaction (Figure 1). Soil compaction values were under 2 MPa up to 45 cm depth for CTS in 2010. The lowest soil resistance values were obtained from CT and MT plots, respectively. The highest soil resistance value was in NT between the 3-15 cm soil layer and values were over 2 MPa.



a) b)

Figure 1: Penetration resistance values for 2010 (a) and 2011 (b); CTS, conventional tillage with stubble; CTB, conventional tillage with stubble burning; MTD, minimum tillage with disc; MTR, minimum tillage with rotary tiller; MNT, minimum tillage with disc + no-tillage and NT, no-tillage

Penetration resistance showed a decreasing trend between 10 and 30 cm soil depth in all tillage systems (Figure 1a). Soil compaction values were under 2 MPa up to 45 cm depth for all tillage systems (Figure 1b).

Penetration resistance values were lower in cultivated plots (CT) compared to MT and NT plots in 2011 as mostly seen in 2010. Generally, soil compaction values of plots cultivated (CT and MT) were found to be lower than that of non-cultivated areas (NT), which agrees with the results reported by Bueno et al. (2006).

4. Conclusions

This research performed in semi-arid Mediterranean coastal plains of Turkey demonstrated that the effects of tillage systems on some soil quality indicators were significant. Soil bulk density was higher in MNT and NT compared to plots cultivated (CT and MT) at all depths in 2010 and 2011. The lowest soil resistance values were obtained with CT with the highest soil resistance values in NT. But, this increase in NT was under 1.5 MPa in 2011. The conservation tillage systems (MT and NT) with residue increased organic matter content in all soil layers. But, organic matter content decreased at the 20-30 cm soil depth with all tillage practices. Generally, organic carbon content was very low in this study, indicating that accumulation requires a longer period. There was a small increase in soil aggregate stability in all plots except for CT plots. The highest aggregate stability values were found in NT (over 38%). However, the soil structure was weak (<50%) due to very low organic carbon content. This research shows that conservation tillage practices such as no-tillage and reduced tillage may be more desirable than conventional tillage in terms of improving some soil quality properties in a high clay soil found in semi-arid climatic regions. These practices are essential especially in terms of protection of natural resources. However, to achieve the desired results, long-term use of the reduced and the no-till practices, under different soil and climate conditions, are required.

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