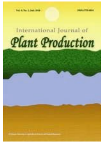

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Long-term tillage and residue management effect on soil compaction and nitrate leaching in a Typic Haploxerert soil

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Abstract

A field experiment was conducted to compare the effects of long-term tillage and crop residue management on some physical properties and nitrate leaching of a Typic Haploxerert soil under winter wheat (*Triticum vulgare* L.)-soybean (*Glycine max* L.) double-cropping system. The tillage systems consisted of conventional tillage with stubble (CT1), conventional tillage with stubbles burned (CT2), heavy disc harrow reduced tillage (RT1), rototiller reduced tillage (RT2), reduced tillage with heavy tandem disc harrow fallowed by no-tillage (RNT) and no-till (NT). Each tillage method applied at 480 m^2 plot and replicated three times in randomly distributed plots. In the experiment, organic matter content (OM), aggregate stability (AS), penetration resistance (PR), porosity, bulk density (BD) in 0-15 cm and 15-30 cm depth and nitrate concentrations at 90 cm depth were determined. Tillage practices significantly affected the measured properties at both soil depths. The BD and PR within the conservational managed plots were higher than under conventional managed plot. Whereas, OM content and AS were significantly greater under conservational managed plots, indicating improved soil quality. Soybean yield was not affected by tillage practices. The concentrations of NO_3-N leached had strong variation within sampling dates and significantly different among treatments after the first and the third irrigation ($P<0.01$). The highest average NO_3-N (1440.8b±74.9 mg L^{-1}) in leachate was measured in the CT2 plot while the lowest value (774.8a±56.5 mg L^{-1}) was obtained in the RT1 plot. The results of this study revealed that reduced tillage and no-till treatments could significantly improve soil physical quality and reduce NO_3-N leaching of Typic Haploxerert soil in the Çukurova Region.

Keywords: Mediterranean; Conventional; Conservative; No-till; Compaction; Nitrate leaching.

Introduction

Soil tillage has always attracted the attentions of scientists due to assisting in preparation of the seed bed by loosening the soil, helping to reduce the weed population, causing the disturbance of aggregates by stimulating the mineralization of organic matter and leading to wind and water erosion, compacting subsurface soil and resulting in severe decline in crop yield and so on. Although farmers in many of the developed countries have been extensively practicing reduced and in some cases no-till practices due to the effective agricultural extension services, farmers in Turkey are still using conventional tillage in the production of field crops (Günal et al., 2015). Studies on conservation tillage proved that soil physical quality is significantly improved compared to conventional tillage (CT) by decreasing the disturbance of soil, leaving crop residue at the soil surface and supporting the activities of soil organisms (Alvarez and Steinbach, 2009; Yang et al., 2011).

Inadequate inputs of organic matter, overuse of agricultural lands without sustainable planning and climate that favors mineralization resulted in low organic matter levels of soils in Mediterranean region (Imaz et al., 2010). Practices such as removing crop residue outside the field or burning the residue within the field are also responsible for low soil organic matter content of soils in Mediterranean region (Moreno et al., 2006; Abdullah, 2014; Günal et al., 2015). Reducing tillage (RT) and retaining crop residues at soil surface led to increase soil organic matter content in time. Retaining residues in fields has a vital role to promote physical, chemical and biological soil health of agricultural ecosystems (Turmel et al., 2015). However, farmers in Eastern Mediterranean Region of Turkey continue to use intensive soil tillage practices along with burning the crop residue. Difficulties in accepting conservative land management practices led to serious decline in organic matter content of soils in southern Mediterranean highland of Turkey (Celik, 2005).

Soil physical properties such as bulk density and penetration resistance of the surface layers were lower under conventional tillage than reduced and no-till systems. Infiltration rate and stability of aggregates were also lower in soils under conventional tillage compared to the soils subjected to reduced and no-till systems (Alvarez and Steinbach, 2009). Soil compaction has always been a problem to the agricultural productivity, mainly in clayey soils under the no-tillage (NT).

Nitrate applied with fertilizers or resulted from microbial decomposition of organic matter in the root zone is prone to leach down during periods of excessive precipitation (Hansen and Djurhuus, 1997). Nitrate losses from root zone predominantly take place in fall, winter and early spring months when evaporation is lower and precipitation is higher (Stenberg et al., 1999). Stenberg et al. (1999) also indicated that tillage practices which incorporate crop residues with high C/N ratios instead of removal may have a positively significant effect to reduce transformation of nitrogen and leaching. Available nitrogen in soil is biologically immobilized by the incorporations of crop residues with C/N ratios higher than 20:1 (Green and Blackmer, 1995). Thus, reduced tillage has been considered an alternative way to lower the nitrogen leaching risk in soils. The majority of rainfall (75% of 670 mm) in Cukurova Region of Turkey occurs during winter and spring months. The occurrence of three-fold more rainfall in winter and spring months than the rest of the year increases the risk of nitrate leaching particularly under conventionally tilled agricultural fields.

Winter wheat production under rainfed conditions within any of the rotation schema in Mediterranean region is very common. Indeed, wheat is the major crop for the agricultural production of Turkey and grown mostly under rainfed conditions. High frequency of winter wheat on rotations possesses a risk of declining crop yield and functioning capacity of soils in the long-term (Bonciarelli et al., 2016). Long-term experiments are useful to provide reliable information on quantifying the risks of reduction in yield, soil quality (Valboa et al., 2015) and environmental impacts e.g nitrate leaching imposed by the management decisions. Despite the importance of long-term studies, no long term study (more than 10 years at least) is continuing to address the qualitative changes of soil quality parameters in response to tillage, especially under Mediterranean climate. A long-term experiment (started in 2006) was established in east Mediterranean region (Cukurova) of Turkey to monitor the changes of soil quality indicators and crop yields under several soil tillage practices and residue management strategies. Turkish Government is encouraging the farmers to adopt reduced and also no-till in their farming practices. Recently, a special incentive was announced by the Ministry of Agriculture to support farmers in adopting the conservative tillage practices.

Cukurova region is suitable to produce two crops in the same year due to the climate and soil characteristics. Despite the government's incentives to expand the use of conservative practices, farmers continue to use moldboard plough as the main tillage equipment and burn the crop residues. This study was conducted to assess the changes in soil compaction parameters (penetration resistance, bulk density and porosity) and aggregate stability with application of six different soil tillage systems. Conventional tillage systems are widely practiced in Cukurova Region. In addition, the nitrate leaching potential of soils under tested tillage practices were determined.

Materials and Methods

Experimental site

The experimental site was established in 2006 at the Agricultural Experimental Station (37° 00′ 54″ N, 35° 21′ 27″ E; elevation 32 m) of the Cukurova University, Adana, Turkey. The same agricultural practices have been practiced on the assigned plots from that time until present. The experiment had been established on the Arik soil series and soils were classified as fine, smectitic, active, mesic Typic Haploxererts (Soil Survey Staff, 1999). The slope of the site is about 1%. The pH of 0 to 30 cm soil depth was 7.82, $CaCO_3$ was 244 g kg^{-1}. Electrical conductivity of soils was 0.15 dS m^{-1} with 50% clay, 32% silt and 18% sand (Celik et al., 2011).

The Mediterranean climate is prevailing in the study area with a long-term (30 years) mean annual temperature of 19.1 °C. The climate is characterized with warm to hot, dry summers and the rainy and mild winters. The average long-term annual rainfall is 670 mm, about 75% of precipitation falls during the winter and spring. The average long-term annual potential evapotranspiration is 1500 mm. The annual mean temperature during the study period was 19.8 °C, the relative humidity was 66.9% and total annual precipitation was 593.6 mm.

Experimental layout and tillage systems

The field experiment was initiated in 2006 and experimental site has been used for agricultural production for more than 35 years prior to the experiment. After harvesting wheat in June 2006, the area had been prepared for field trials.

The experiment was conducted in a randomized complete block design where similar experimental units are grouped into blocks or replicates. The treatments with three replications 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 fallowed by no-tillage (RNT) for the second crop and no tillage (NT). The size of tillage plots were 12 m width and 40 m length (480 m^2). A buffer of 4 m zone was reserved around each plot for better operation of tractor, tillage machinery and all other equipment. The detailed information on treatments within each practice and sowing methods were presented in Table 1.

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

Treatment	Soil Tillage for Winter Wheat	Soil Tillage for Second Crop Soybean
Conventional tillage with residue incorporated (CT1)	• Stover chopping of second crop • Mouldboard plough (30-33 cm)* • 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 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, Direct Planting (NT)	• Stover chopping of second crop • Herbicide treatment • No-till planter (4 cm)	• Stubble chopping of wheat • Herbicide treatment • No-till planter (8 cm)

* Numbers in parenthesis are the average working depths of the tillage equipment.

The rotations of winter wheat (*Triticum aestivum* L.)-corn (*Zea Mays* L.) and wheat-soybean (*Glycine max.* L.) were applied in all treatments from 2006 to 2014. 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.

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 at seeding rate of 240 kg ha^{-1} and harvested in the first week of June. Corn and soybean were sown in the third week of June and harvested in the second week of October. 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 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. Current study was conducted in 2014 under soybean.

Irrigation events and water sampling

Sprinkler systems were installed to irrigate the soybean. The plants have been irrigated fallowing the emerging once in a 13/14 days. Total of 561 mm water was applied with 5 irrigation and 2 rainfall events. These rainfalls were 53 mm and 42 mm, respectively.

Two soil water samplers (Soil moisture®, the model 1900 type, 4.8 cm outside diameter and 4.5 cm inner diameter with a porous ceramic cup, PVC tube) were installed in each plot at soil depths of 90 cm fallowing the soybean planting (Figure 1). A total of 36 soil water samplers were installed in the experimental field.

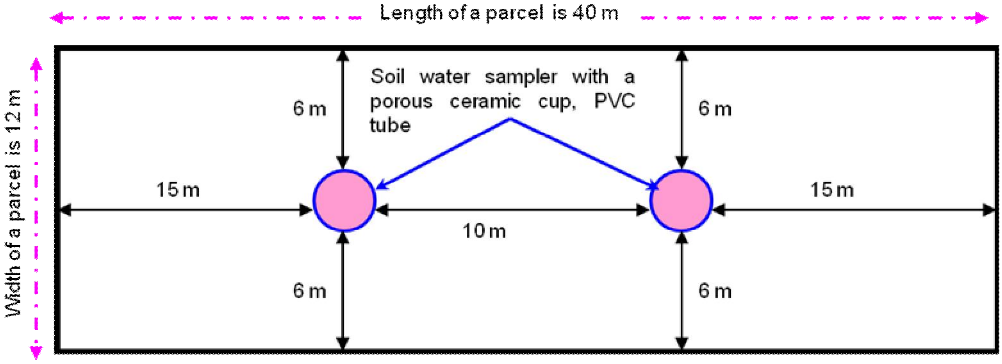

Figure 1. Placement plan of the soil water sampler (with a porous ceramic cup) in the research parcels.

Special care was taken in placing the water samplers and the surroundings of the tips were filled with sieved soil to provide better contact with soil profile. The soil solution was sampled through water samplers at almost 2-week intervals by applying sufficient vacuum using a vacuum pump (0.65-0.70 b) just before irrigating soybean (Figure 2). Samplers were carefully closed by the stopper assemblies after applying the vacuum (Figure 2). Three days after the irrigation or rain, samplers were opened and water in samplers was collected by a vacuum pump. Water samples were stored at 4 °C in the laboratory till the analyses.

Figure 2. Placing a soil water sampler on a research plot. Water was collected after each of the irrigation and rain event.

Laboratory analysis

Water samples collected were filtered through filter papers and 50 ml of subsamples were taken for nitrate analyses. The nitrate concentration was determined as described by Clesceri et al. (1998).

Disturbed and undisturbed soil samples from 4 sites of each individual plot (total of twelve samples per tillage treatments) were collected at depths of 0-15 and 15-30 cm right after the harvest of the soybean. In order to determine the effects of tillage practices on soil compaction and nitrate leaching, bulk density (Blake and Hartge, 1986), organic matter (Nelson and Sommers, 1996), macro, micro and total porosity (Danielson and Sutherland, 1986) and aggregate stability were determined.

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. Microporosity (consisting of pores with equivalent radius <4.5 µm) was determined from the volumetric water content, using a pressure membrane apparatus at field capacity (−33 kPa). Macroporosity (consisting of pores with equivalent radius >4.5 µm) was calculated as the difference between total porosity and microporosity.

A set of sieves (4, 2, 1 and 0.5 mm diameters) was used in the wet sieving method as described by Kemper and Rosenau (1986). The soil samples were passed through an 8 mm sieve, 50 g of the soil was placed on the 4 mm sieve and gently moistened. 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 water-stable aggregates (AS) was calculated as follows:

$$AS = \frac{(M_{(a+s)} - M_s)}{(M_t - M_s)} \times 100$$

where $M_{(a+s)}$ is the mass of the resistant aggregates plus sand (g); M_s the mass of the sand fraction alone (g) and M_t the total mass of the sieved soil (g).

The penetration resistance indication of soil compaction was determined to a depth of 50 cm by a hand-pushing electronic cone penetrometer *(Eijkelkamp Penetrologger 06.15.SA)* following ASAE standard procedures (ASAE, 1994), using a cone with 1 cm^2 base area, 60° included angle and 80 cm driving shaft; readings were recorded at 10 mm intervals. The measurements were performed at 8 points in each plot.

Statistical analysis

One-way analysis of variance (ANOVA) was applied to compare the effects of tillage treatments on nitrate leaching, penetration resistance, aggregate stability, organic matter, porosity and bulk density determined for the 0-15 and 15-30 depths separately. Following the ANOVA, DUNCAN homogeneity test was used to group the soil tillage practices 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 21.0).

Results and Discussion

Organic matter, aggregate stability and penetration resistance

Tillage practices had significant impact on organic matter (OM) contents in surface soils ($P<0.01$). The differences in OM content were more pronounced at depth 0–15 cm than 15-30 cm depth ($P<0.05$). The highest OM content (2.56%) was found under NT and the lowest OM contents were in CT2 (1.48%) and CT1 (1.51%), at 0-15 cm respectively. The order of OM content in 0-15 cm depth among soil tillage systems was; NT>RT2>RNT>RT1>CT1=CT2 (Table 2). The first and second crop residue burning treatment (CT2) had the lowest OM content. The NT system provided 70% and 73% higher OM content in 0-15 cm depth as compared to CT1 and CT2 after 9 years of applications (from 2006 to 2014). The OM content under reduced tillage practices (RT2 and RT1) in 0-15 cm depth was also 53% and 42% higher than CT1, respectively. The OM content under RNT in 0-15 cm depth was also 50% and 53% higher than CT1 and CT2, respectively. The increase in OM under the NT and RT systems can be attributed to the residues of crops in rotation left on the soil surface (Reeves, 1997; Alvaro-Fuentes et al., 2008; Kabiri et al., 2015) and a combination of less disturbance and low residue decomposition due to low soil/residue interaction (Dolan et al., 2006; Zhou et al., 2007; Du et al., 2010). The OM content reduced with increase in depth regardless of the tillage applied and this trend is in accordance with other studies (Dong et al., 2009; Mishra et al., 2010; Dikgwatlhe et al., 2014). Similar to the surface soil, NT and RT treatments yielded significantly higher OM content in 15-30 cm depth. The OM content in this depth under RNT treatment was slightly higher than that of NT probably due to the mixing of surface residue into the subsurface soils with heavy tandem disc harrow working at 18-20 cm depth.

The order of OM content in 15-30 cm depth among soil tillage systems was; RNT>NT=CT1=RT1=RT2=CT2 (Table 2). The results clearly indicated that OM content of soils severely decreased with the number and intensity of tillage practices applied meaning of carbon emission to atmosphere as affecting climate change. Experimental site is located in the East Mediterranean Region of Turkey and the climate allows for the cultivation of two crops a year. Conservative practices (RT1, RT2, RNT and NT) in crop production will yield a significant amount of OM to the soils that helps in increasing carbon sequestration. Many of the soil functions have been related to the OM content of soils (Cambardella and Elliot, 1992; Gregorich et al., 1994). The increase in OM will improve to store and transmit water and air, to increase the plant nutrient holding capacity, prevent from further compaction, stabilize soil and reduce water and wind erosion (Laudicina et al., 2015). This increase in OM is crucial to improve the functioning capacity of Mediterranean soils, where the OM levels in agricultural soils are usually reported less than 10 g kg^{-1} (Martinez et al., 2003). Intensive tillage is reported to degrade soil structure by destructing soil aggregates (Balesdent et al., 2000; Six et al., 2004) and increase the penetration of oxygen into soil. Better aeration of soils increases the mineralization of organic matter stored in soils (Tisdall and Oades, 1982; Salinas-Garcia et al., 2002; Kay and Vandenbygaart, 2002). Plenty of researches published support the findings of this study (Presley et al., 2012; Jemai et al., 2013). Several studies have been reported higher OM content under NT and RT treatments compared to conventional treatments for different soil types and climates (Bhattacharyya et al., 2008; Daraghmeh et al., 2009; Chen et al., 2009; Montemurro and Maiorana, 2014).

Long-term tillage practices adopted in this study have significant impacts on aggregate stability (AS) of soils. The difference on tillage practices were also significantly differed from each other. The presence of plant residue on soil surface under NT may have stabilized aggregates by protecting OM from microbial degradation. The reduced rate of OM mineralization led to improve soil structure. Thus, more stable aggregates in the surface soil were associated with NT treatment compared to CT and RT treatments. Alvaro-Fuentes et al. (2008) reported similar results when comparing CT, RT and NT treatments for dry and wet aggregate stability of soils under barley-fallow and continues barley production. In a similar study from Gottingen, Germany, Jacobs et al. (2009) showed that RT tillage practices compared to CT practices increased both soil organic matter content and consequently the AS of soils. The tillage practices affected AS in surface and subsurface soils in the order; NT>RT2>RT1>RNT>CT1>CT2 (Table 2).

Our results showed that the increase in OM content in soil is responsible from the increased AS of soils. The AS in surface soil ranged from 32.2% (CT2) to 59.8% (NT) and in subsurface soil from 36.3% (CT2) to 52.9% (NT) (Table 2). This trend is very similar in OM content of soils. The highest content of OM in surface was occurred under NT with 2.56% and the lowest OM was under CT2 with 1.48%. The decline in OM content under CT treatments had adverse effect on AS of surface and subsurface soils. Although Barzegar et al. (2003) found that plowing with a chisel has less destructive effects on aggregates when compared to plowing with a mouldboard, stubble burning along with the use of mouldboard and chisel severely degraded the aggregates in CT2. The increased AS values under RT treatments compared to CT treatments might also be associated to the significant increase in OM content of soils. Because, OM of soil plays an important role in cementing mineral particles to form stable aggregates (Six et al., 2004). Pagliai et al. (2004) also reported greater AS values under RT treatments when compared to CT treatments.

Table 2. Mean values of organic matter, aggregate stability and penetration resistance for soil tillage systems and one way ANOVA.

Tillage Treatments*	Organic matter (%)	Aggregate stability (%)	Penetration resistance (MPa)
		0-15 cm	
CT1	$1.51^{\#\ d\&} \pm 0.07$	$38.5^{d} \pm 6.20$	$1.11^{b} \pm 0.179$
CT2	$1.48^{d} \pm 0.08$	$32.2^{e} \pm 4.14$	$0.97^{c} \pm 0.148$
RT1	$2.15^{c} \pm 0.13$	$45.8^{c} \pm 7.41$	$1.15^{b} \pm 0.107$
RT2	$2.31^{b} \pm 0.17$	$53.5^{b} \pm 7.91$	$1.39^{a} \pm 0.203$
RNT	$2.26^{bc} \pm 0.13$	$44.1^{cd} \pm 4.60$	$1.20^{b} \pm 0.171$
NT	$2.56^{a} \pm 0.32$	$59.8^{a} \pm 5.54$	$1.35^{a} \pm 0.198$
ANOVA	**	**	**
		15-30 cm	
CT1	$1.44^{b} \pm 0.11$	$45.3^{c} \pm 5.53$	$1.13^{c} \pm 0.128$
CT2	$1.41^{b} \pm 0.08$	$36.3^{d} \pm 5.68$	$0.99^{d} \pm 0.143$
RT1	$1.42^{b} \pm 0.14$	$50.8^{abc} \pm 3.87$	$1.47^{a} \pm 0.116$
RT2	$1.42^{b} \pm 0.08$	$52.0^{ab} \pm 6.88$	$1.40^{a} \pm 0.182$
RNT	$1.54^{a} \pm 0.12$	$46.5^{bc} \pm 5.84$	$1.39^{ab} \pm 0.100$
NT	$1.45^{b} \pm 0.14$	$52.9^{a} \pm 5.35$	$1.31^{b} \pm 0.133$
ANOVA	*	**	**

* CT1: Conventional tillage with residue incorporated, 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 fallowed by no tillage for the second crop, NT: No tillage, direct planting.

$^{\#}$ The numbers following ± indicate the standard deviation.

$^{\&}$ Mean values in a column followed by the same latter are not significantly different (Duncan, $P \leq 0.05$).

* Difference is significant at $P \leq 0.05$ level, ** Difference is significant at $P \leq 0.01$ level.

Determining and monitoring penetration resistance (PR) of soils is a useful method to evaluating the outcomes of management decisions on quality of soils. The results showed significant differences in PR among the different tillage practices. The mean PR value under CT2 was the lowest in surface and subsurface soils (Table 2 and Figure 3). Low PR values in CT2 treatment (0.97 Mpa in 0-15 cm and 0.99 in 15-30 cm) were probably related to the use of a chisel plow working at 35-38 cm depth in seedbed preparation of second crops (soybean and maize). The highest PR value (1.39 MPa) in surface soil was obtained in RT2 treatment where a rotary tiller acting at 13-15 cm depth was used. The PR value under NT treatment was not significantly different but slightly lower than that of RT2. The order of PR values in surface soils under different tillage systems was; RT2=NT>RNT=RT1=CT1>CT2. Higher PR values under NT treatment compared to CT treatments have been previously reported by others (Taser and Metinoglu, 2005; Alvarez and Steinbach, 2009; Afzalinia and Zabihi, 2014; Salem et al., 2015).

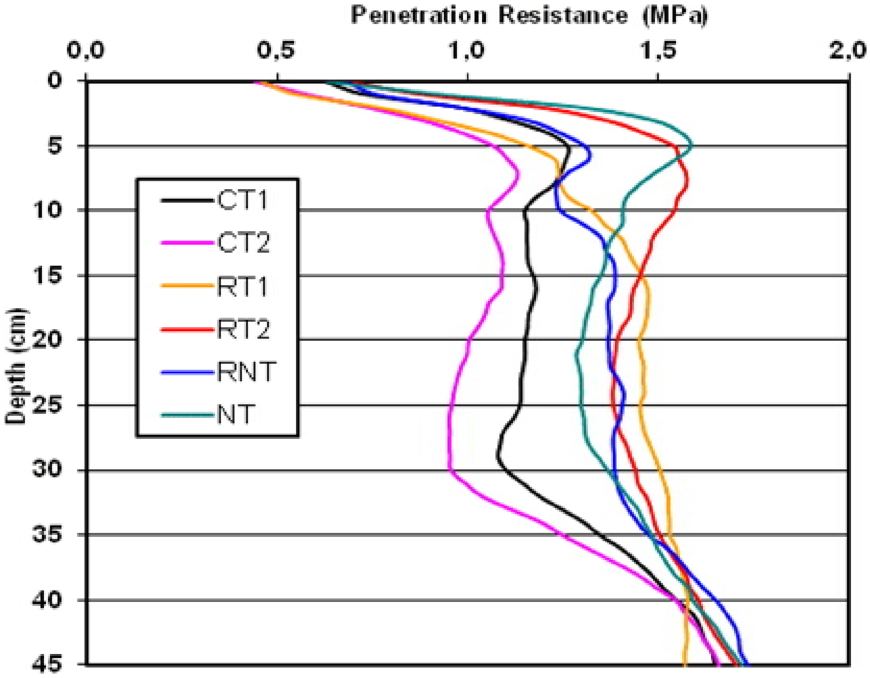

Figure 3. Changes of penetration resistance with long-term different tillage practices.

The PR values were increased with increased depth until 45 cm for all treatments. The PR values in conservative tillage practices were significantly higher compared to the conventional practices. The high clay content (mean 50%) of the Vertisols studied may have induced the increase in the soil compaction level at soil surface (Alvarez and Steinbach, 2009). The order of PR values for 15-30 cm depth was; RT1=RT2>RNT>NT>CT1>CT2. The variation of PR values within 0-45 cm depth was illustrated in Figure 3. Although OM content and AS under CT2 and CT1 were lower and do not support sustainable crop production, PR values within root zone is lower than conservative soil tillage practices. Moraes et al. (2016) indicated that higher PR values of surface soils in NT treatment may be associated with the absence of tillage and cumulative effects of agricultural machinery traffic.

Long-term tillage effects on porosity and bulk density

Soil tillage treatments had significant effect on porosity and bulk density of soils in 0-15 cm and 15-30 cm depths. The highest mean total porosity (0.546 cm^{3} cm^{-3}) in 0-15 cm was obtained in RT1 and the lowest total porosity (0.514 cm^{3} cm^{-3}) was in NT. For the soil depth of 0-15, the total porosity in CT1, CT2 and RT2 systems were slightly higher from NT and lower from RNT, but statistically not different from each other (Table 3).

The differences in the microporosity where water is held against gravity have been significantly affected by the soil tillage treatments. The highest microporosity composition was found in NT and RT1 treatments as 0.421 and 0.417 cm^{3} cm^{-3} and the lowest values of microporosity were found in conventional tillage practices as 0.378 and 0.381 cm^{3} cm^{-3} for CT1 and CT2, respectively (Table 3). The higher volume of micropores in untilled soils was also reported by many other researchers (Xu and Mermoud, 2001; Jemai et al., 2013). Jemai et al. (2013) compared 7 and 3 years of NT treatments for available water holding capacities. The seven-year NT treatment had significantly higher available water content compared to the 3-year NT treatment. Whereas, both 3 and 7-year NT treatments provided higher available water in root zone as compared to the CT treatments.

Table 3. Mean values of total, macro and micro porosities and bulk density for soil tillage systems and one way ANOVA.

Tillage Treatments[*]	Porosity (cm^{3} cm^{-3})			Bulk density (g cm^{-3})
	Total	Macro	Micro	
		0-15 cm		
CT1	$0.517^{\#b\&}$ ± 0.028	0.139^{a} ± 0.026	0.378^{c} ± 0.015	1.34^{b} ± 0.07
CT2	0.520^{b} ± 0.023	0.139^{a} ± 0.041	0.381^{c} ± 0.025	1.36^{b} ± 0.08
RT1	0.546^{a} ± 0.053	0.129^{a} ± 0.047	0.417^{a} ± 0.050	1.34^{b} ± 0.07
RT2	0.524^{b} ± 0.028	0.127^{a} ± 0.036	0.397^{bc} ± 0.031	1.37^{b} ± 0.07
RNT	0.537^{ab} ± 0.055	0.131^{a} ± 0.041	0.406^{ab} ± 0.047	1.30^{c} ± 0.06
NT	0.514^{b} ± 0.028	0.093^{b} ± 0.030	0.421^{a} ± 0.018	1.43^{a} ± 0.05
ANOVA	*	**	**	**
		15-30 cm		
CT1	0.504^{bc} ± 0.030	0.121^{b} ± 0.033	0.383^{b} ± 0.025	1.39^{c} ± 0.06
CT2	0.532^{a} ± 0.018	0.138^{a} ± 0.026	0.394^{b} ± 0.019	1.41^{c} ± 0.06
RT1	0.512^{b} ± 0.044	0.093^{c} ± 0.037	0.419^{a} ± 0.022	1.46^{ab} ± 0.04
RT2	0.492^{c} ± 0.026	0.099^{c} ± 0.029	0.392^{b} ± 0.024	1.45^{b} ± 0.05
RNT	0.498^{bc} ± 0.033	0.087^{c} ± 0.034	0.410^{a} ± 0.013	1.46^{ab} ± 0.05
NT	0.509^{bc} ± 0.029	0.087^{c} ± 0.024	0.422^{a} ± 0.029	1.49^{a} ± 0.03
ANOVA	**	**	**	**

* CT1: Conventional tillage with residue incorporated, 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 fallowed by no tillage for the second crop, NT: No tillage, direct planting.

[#] The numbers following ± indicate standard deviation.

[&] Mean values in a column followed by the same latter are not significantly different (Duncan, P≤0.05).

* Difference is significant at P≤0.05 level, ** Difference is significant at P≤0.01 level.

Aeration status of soils particularly those with high clay contents is an important limiting physical factor for crop growth (Hillel, 1980; Çepel, 1985; Yeşilsoy and Aydın, 1992). Macropores are responsible from infiltration and transport of air in soil profile. The volume of macropores in all plots decreased markedly with the depth. The macropore volume was significantly higher under all treatments in the 0-15 cm depth compared to that in the 15-30 cm depth (Table 3). The lowest macropore volume (0.093 cm^3 cm^{-3}) in surface soils was in NT treatment and other treatments were not statistically different from each other. Rasmussen (1999) also concluded that ploughless soil tillage decreased the aeration and air diffusivity in untilled layer was at critically low level (10.6% macropore). The macropore volume less than 11-14% is a threshold level for air and water transport (Hillel, 1980; Carter, 1990). The macropore volume in RT1, RT2, RNT and NT treatments were lower than the critical level. Nine years of reduced and no-till practices have significantly lowered the macropores to a level that might create aeration problem for crops. However, CT practices have resulted significantly higher macropores in subsurface soils and the values of macropores in 15-30 cm depth were in the order CT2>CT1>RT2=RT1=NT=RNT (Table 3). Higher macropore volume under CT treatments is clearly the result of yearly loosening effect of conventional tillage (Lipiec et al., 2006).

Different results in many studies regarding the effects of tillage systems on soil porosity have been reported (Lipiec et al., 2006). Some studies reported that porosity increases with the conventional tillage compared to no-till due to the loose-soft and fluffy structure in tilled layer (Miller et al., 1998; Logsdon et al., 1999; Green et al., 2003; Bhattacharyya et al., 2006) and some reported lower porosity under tilled conditions (Rasmussen, 1999). Low porosity values obtained under conventional tillage practices could result from low micro porosity. This situation was more clear in 0-15 cm soil depth (Table 3). On the contrary, Salinas-Garcia et al. (1997) indicated that tillage loosens soil and reduces the bulk density which leads to an increase in the surface soil macro porosity. The conversional reports on porosity probably related to the variation of soil type (Lipiec et al., 2006). Lower volume of macro-pores (>30 mm) on sandy soil and silty loam soils have been reported under NT system compared to CT, whereas under the same site conditions, the opposite effect was determined on a sandy loam soil (Schjønning and Rasmussen, 2000).

The differences between the tillage treatments in terms bulk density (BD) that can be used as an indication of compaction in agricultural soils (Abu-Hamdeh, 2003; Zornoza et al., 2015) were statistically significant ($P<0.05$) (Table 3). Nine years of different tillage treatments showed that the lowest BD within 0-15 cm depth was obtained under RNT treatment (1.30 g cm^{-3}); whereas the highest BD (1.43 g cm^{-3}) was obtained under NT treatment. In a 12-year of soil tillage experiment, Moret and Arrue (2007) also found the highest bulk density values under NT treatment. The order of BD values in 0-15 cm depth for tillage treatments was; NT>RT2=CT2=RT1=CT1>RNT. Similar to the values obtained in surface soils, the highest BD values in subsurface soils were occurred in NT treatment. The order of BD values in subsurface soils was; NT>RNT=RT1>RT2>CT2=CT1. Soils with higher bulk density have lower proportion of macropores compared to soils with higher bulk density (Table 3). Particle size distribution of soils in experimental site have been characterized as heavy clayey which has tendency of high soil bulk density, high mechanical resistance to penetration of root and low air and water permeability under NT treatment (Farooq et al., 2011; Nunes et al., 2014).

In all treatments, the BD values of 0-15 soil depth were lower compared to the 15-30 cm depth due to the higher organic matter content of surface soils. Obtaining higher bulk density values in the lower layers of soil profile is an expected case for soils have not been deeply tilled (Ghuman and Sur, 2001; Bronick and Lal, 2005) due to the natural compaction effect of above soil layers. Rasmussen (1999) also indicated that soil bulk density increases and porosity decreases below the depth of ploughless soil tillage. The high BD value obtained under reduced and particularly NT systems are in good agreement with the reports of others (Martino and Shaykewich, 1994; Jina et al., 2011; Soane et al., 2012).

The increase in BD under reduced and NT systems may lead to the restriction of some of soil functions and consequently over time negatively influence the crop growth (Salem et al., 2015). High BD usually has usually been connected to the lack of mechanical disturbances under NT which progressively results in compaction (Du et al., 2010). Whereas, low BD values in CT systems are attributed to the intensity of mechanical operations that lead to breaking apart the soil aggregates (Afzalinia and Zabihi, 2014; Dikgwatlhe et al., 2014). In contrast to the above reported findings, Horn et al. (1995) and Roscoe and Buurman (2003) found that CT treatments significantly increased the BD values compared to the NT treatment. Such contrasted findings might have resulted from the variation of climate and soil conditions of the experimental sites (Roscoe and Buurman, 2003). Tillage effects on BD are determined by several factors such as soil texture (Alvarez and Steinbach, 2009), soil layer (Logsdon et al., 1999), organic matter content (Mahboubi et al., 1993) and machinery traffic intensity (Mahboubi et al., 1993; Logsdon et al., 1999) leading to the discrepancies usually observed in the results. Different from reports on increase or decrease of BD with tillage, Anken et al. (2004) showed no significant changes in BD from 14-year of a tillage study. Işıldar (1998) also found similar results to that reported by Anken et al. (2004).

Soybean Yield

Effects of different tillage practices on soybean yield were presented in Table 4. The tillage practices had no significant effect on crop yield in 2014. The highest soybean crop yield was obtained under RT1 (4.15 t ha^{-1}) and the lowest (3.69 t ha^{-1}) yields were obtained under RT2 (Table 4). Soils under conservation tillage practices showed compaction tendency when considered PR (Table 2) and BD values (Table 3) which are indicators of soil compaction (Mehari et al., 2005; Afzalinia and Zabihi, 2014). Despite this adverse condition, long-term different tillage practices had no effect on soybean yield. Previous studies showed that tillage practices had no significant effect on soybean crop yield (Alvarez and Steinbach, 2009; Celik et al., 2011; Hati et al., 2015). On the contrary, some researchers reported that higher soybean yield was obtained under no-tillage compared to conventional tillage practices (Chen et al., 2011; Sharifi et al., 2016). 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 Mediterranean climate.

Table 4. Mean values of soybean yield for soil tillage systems and one way ANOVA.

Tillage treatments*	Yield (t ha^{-1})
CT1	$4.06^{\# a \&} \pm 0.10$
CT2	$3.84^{a} \pm 0.51$
RT1	$4.15^{a} \pm 0.50$
RT2	$3.69^{a} \pm 0.13$
RNT	$3.71^{a} \pm 0.65$
NT	$3.82^{a} \pm 0.23$
ANOVA	0.246^{ns}

* CT1: Conventional tillage with residue incorporated, 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 fallowed by no tillage for the second crop, NT: No tillage, direct planting.

[#] The numbers following ± indicate standard deviation.

[&] Mean values in column followed by the same latter are not significantly different (Duncan, $P \leq 0.05$).

Nitrate Leaching

The changes in porosity induced by loosening effect of tillage had a significant effect on nitrate leaching under different soil tillage systems. Katupitiya et al. (1997) stated that tillage had impacts on nitrate leaching by regulating soil mineralization and water movement and changing the physical and chemical properties as well as the biological environment of the soil. The total NO_3-N concentration of leachates was significantly ($P<0.05$) greater in CT2 (1440.8 mg L^{-1}) where conventional tillage is applied with burning the wheat residue compared to the other tillage systems. Lipiec et al. (2006) also found the highest infiltration rate throughout the time of water application under CT treatment. Similar to the findings of our study, Spiegel et al. (2002) indicated that nitrate leaching potential of intensively tilled soils is greater as compared to the soils under minimum tillage practices. In CT2 system, soil is tilled with a chisel plow to 35-38 cm depth fallowing the stubble burning of wheat. Deep plowing with chisel probably increased the hydraulic conductivity and resulted in higher nitrate leaching. The lowest total NO_3-N (774.8 mg L^{-1}) leaching was obtained in RT1 system followed by RNT practices (Table 5). Nitrate concentration of leachates collected (except the first irrigation) was always lower in RT1 than the rest of the tillage treatments.

Significant differences ($P<0.05$) were occurred among tillage systems in the first and the third irrigation events of soybean production. In the first irrigation event, the highest nitrate leaching from CT2 (331.4 mg L^{-1}) and the lowest leaching was observed in the NT plots (126.5 mg L^{-1}). Consistent with this, Weed and Kanwar (1996) reported lower nitrate concentration in groundwater under NT treatment by decreasing the rate of leaching. Lower nitrate leaching under NT and RT treatments might be associated to the higher compaction of soils compared the CT treatments. The BD and PR values under conservative tillage practices were mostly higher than the conventional tillage practices (Tables 2 and 3, Figure 3). Compaction under conservative tillage systems significantly decreased the amount of macropores (Table 3) that probably restricted water movement (Richard et al., 2001; Pagliai et al., 2003).

The higher amount of nitrate in CT2 plot could be related to the use of a chisel plow working at 35-38 cm depth was used (Table 1). Chisel plow rips the soil till the 38 cm depth, thus increases the water flow to deeper layers. Matthews et al. (2000) also indicated that deep tillage creates short diffusion paths in the soil, which then increases nitrate leaching. The largest differences between CT2 and other treatments were observed in the first and the fourth leaching events. Although nitrate concentration in CT2 was higher, the difference between nitrate concentrations of leachates from other tillage practices was not statistically significant in the second leaching events (Table 5). Nevertheless, the amount of nitrate under CT2 was greater with no significance (538.4 mg l^{-1}) compared to the other treatments in the second event. But the amount of nitrate under CT2 was significantly higher (212.9 mg l^{-1}) than the other treatments in the fourth event.

Table 5. Mean values of nitrate concentration at each irrigation/rainfall events for different soil tillage systems and one way ANOVA.

Tillage Treatments*	Nitrate concentrations (mg l^{-1}) fallowing the irrigations and a rain						
	1	2	3	4	5 Irrig+rain	6 Rain	Total
CT1	$198.5^{\#b\&}\pm50.2$	$424.3^{a}\pm106.8$	$116.0^{bc}\pm26.6$	$128.6^{ab}\pm30.9$	$63.8^{a}\pm11.9$	$131.1^{ab}\pm29.9$	$1048.3^{b}\pm137.6$
CT2	$331.4^{a}\pm12.8$	$538.4^{a}\pm62.8$	$228.3^{a}\pm16.7$	$212.9^{a}\pm90.1$	$45.6^{a}\pm10.2$	$130.4^{ab}\pm74.8$	$1440.8^{a}\pm74.9$
RT1	$134.6^{b}\pm14.4$	$345.1^{a}\pm86.2$	$65.7^{c}\pm10.0$	$55.4^{b}\pm19.5$	$39.7^{a}\pm11.4$	$80.3^{b}\pm51.8$	$774.8^{b}\pm56.5$
RT2	$160.1^{b}\pm9.0$	$453.8^{a}\pm99.1$	$201.8^{ab}\pm55.7$	$72.3^{b}\pm19.8$	$59.5^{a}\pm13.2$	$162.0^{a}\pm9.3$	$1106.9^{ab}\pm183.2$
RNT	$151.2^{b}\pm18.2$	$358.9^{a}\pm79.3$	$85.9^{c}\pm24.5$	$70.8^{b}\pm19.7$	$80.9^{a}\pm19.4$	$130.5^{ab}\pm54.1$	$880.3^{b}\pm138.9$
NT	$126.5^{b}\pm26.2$	$433.6^{a}\pm55.9$	$119.5^{bc}\pm12.3$	$86.8^{b}\pm17.0$	$47.3^{a}\pm7.5$	$120.1^{ab}\pm32.7$	$923.5^{b}\pm76.3$
ANOVA Sig.	0.003**	0.643^{ns}	0.002**	0.051^{ns}	0.254^{ns}	0.125^{ns}	0.016*

* CT1: Conventional tillage with residue incorporated, 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 fallowed by no tillage for the second crop, NT: No tillage, direct planting.

[#] The numbers following ± indicate standard deviation.

[&] Mean values in a column followed by the same latter are not significantly different (Duncan, $P \leq 0.05$).

* Difference is significant at $P \leq 0.05$ level, ** Difference is significant at $P \leq 0.01$ level.

Macropores particularly in fine-textures soils transmit water along with chemicals in a short period of time to lower part of soil profile, bypassing the denser surface layers (Jarvis et al., 1999; Jarvis, 2007). The volume of macropores in surface and subsurface soils under stubble burning treatment (CT2) was at the highest rate which caused to highest total nitrate leaching (Tables 3 and 5). In addition, nitrate concentrations of the first, second, third and fourth leachates in CT2 plots were higher than the rest of the treatments (Table 5). Higher nitrate leaching from burned plots could also be attributed to the fire induced soil water repellency by volatilizing hydrophobic organic compounds (Dlapa et al., 2013) along with higher volume of macropores.

Although there are similar results with regard to the effects of leached soil NO_3-N under different tillage methods, many contradictory results have also been reported. Elmi et al. (2003), Hansen et al. (2010) and Premrov et al. (2014) indicated no significant effects of tillage on nitrate leaching, whereas Mkhabela et al. (2008) found lower nitrate leaching under NT treatment. They have associated low nitrate leaching to both high mineralization rate under conventional tillage and high denitrifaction under no-tillage. In contrast to above results, higher nitrate leaching due to the continuous permanent pores in NT have been reported (Paul and Clark, 1989; Schreiber and Cullum, 1992).

Conclusions

The long-term (nine years) effects of six different tillage practices on soil compaction indicators and nitrate leaching potential of a high clay soil were evaluated. Nine years of different soil tillage treatments have produced marked differences in organic matter content, aggregate stability, penetration resistance, micro, macro and total porosity, bulk density and nitrate leaching in a winter wheat, maize and soybean rotation in East Mediterranean region of Turkey. The results revealed that compaction tendency reduced when conventional tillage practices are used compared to the reduced and no-till practices. Although soils under conservation tillage practices showed relatively compaction tendency, tillage practices had no significant effect on soybean yield. Soil surface in CT1 and CT2 plots have been loosened by continuous ploughing with conventional tillage equipment which reduces bulk density. The summer and fall crop residue burning with conventional tillage treatment resulted in the lowest organic matter content, the lowest aggregate stability and the lowest penetration resistance. The results are the evidence of being the most highly degradation occurred over the 9-year period with the stubble burning.

Cumulative effects of machineries used in planting and harvest in no-till and reduced tillage practices increased the bulk density and penetration resistance particularly in surface soil compared to conventional tillage practices. Nonetheless conservational tillage practices are certainly viable alternatives in the long run that have positive effects on organic matter content and aggregate stability. In addition, nitrate leaching from reduced tillage and no-till plots were significantly lower than that of the conventional tillage plots. Conventional tillage practices have the potential to cause nitrate leaching from root zone even at high clay soils. Higher efficiency of nitrate fertilizer along with the increased organic matter content provided by conservative tillage will have positive effect on crop quality and quantity of crop production.

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