EFFECT OF CONSERVATION TILLAGE ON THE PHYSICAL AND MECHANICAL PROPERTIES OF SILTY-CLAY LOAM SOIL

ABSTRACT

Effect of different tillage methods on the physical and mechanical properties of silty-clay loam soil was evaluated in corn-wheat system during 2011 in Fars Province, Iran. Field trial was conducted in the split plot design with two factors (tillage methods and soil depth) and six replications for soil bulk density and penetration resistance. Main plots were tillage methods including conventional tillage, reduced tillage, and zero tillage. Soil depth of 0-10, 10-20, and 20-30 cm were considered as sub plots. A randomized complete block design with three treatments and six replications was used for the soil coefficients of friction, adhesion, and cohesion. Soil bulk density, soil penetration resistance, coefficients of soil internal and external friction, adhesion, and cohesion were measured. Results showed that tillage methods had significant effect on the soil bulk density so that the conventional and reduced tillage methods had the lowest soil bulk density, and zero tillage method had the highest. Soil bulk density was also affected by soil depth in such a way that bulk density increased when soil depth increased from 0 to 20 cm, and then decreased by increasing soil depth from 20 to 30 cm. The maximum soil penetration resistance was recorded from the zero tillage, and the conventional tillage had the minimum soil penetration resistance. Soil penetration resistance increased with increasing soil depth from 0 to 30 cm. Results also indicated that zero tillage significantly decreased the coefficient of soil internal friction; whereas, the coefficient of soil external friction was not affected by tillage methods.

Keywords: Bulk density; Friction coefficient; Penetration resistance; Tillage methods

INTRODUCTION

Conventional tillage system is being replaced in the world by the conservation tillage method in which at least 30% of soil surface remains covered by crop residues (Afzalinia et al., 2012). Transition from the conventional tillage method to the conservation system may affect the soil physical and mechanical properties such as soil bulk density, soil penetration resistance, and soil internal and external coefficients of friction. Soil bulk density and penetration resistance are used as indices of soil compaction so that by increasing these two indices, soil compaction increases and increasing soil compaction may prevent water and crop root penetration in the soil. Soil bulk density and penetration resistance are also used to predict the depth of soil hardpan (Mehari et al., 2005). There are some contradictory results of research work conducted on the effect of conservation tillage on the soil bulk density and penetration resistance. Results of some studies show that conservation tillage methods (no-till and reduced tillage) increase the soil bulk density and penetration resistance compared to the conventional tillage (Liu et al., 2005; Taser and Metinoglu, 2005). Fabrizzi et al. (2005) evaluated the effect of conservation tillage on the soil temperature, compaction, water content, and crop yield and reported that soil had higher water retention during the critical growth stage of corn in no-till method. Their results also showed that no-till had the higher soil bulk density and penetration resistance, and lower soil temperature and corn yield compared to the minimum tillage method.

There are also some research results showing no significant effect of conservation tillage on the soil bulk density and penetration resistance (Rasouli et al., 2012; Afzalinia et al., 2012; Logsdon and Karlen, 2004). Touchton et al. (1984) reported that the winter legumes made no considerable variations in the soil nitrogen and bulk density, but increased the water infiltration rate when cotton was no-till planted into winter legumes compared to the cotton direct seeding in the fallowed soil. Soil bulk density and penetration resistance are also affected by soil depth. Results of a research work in a Rhodic Ferrasol in Parana, Brazil, revealed that soil bulk density had the highest value at the soil depth of 20 to 30 cm in a no-till system (Cavalieri et al., 2009). According to the results of a study conducted in Argentina, no-till increased soil resistance compared to the conventional tillage and soil resistance increment was greater in the shallow layers compared to the deep layers (Ferreras et al., 2000). Results of a study conducted in Kimberly, Idaho showed that soil bulk density was 16 to 18% greater in disk and no-till treatments compared to paratill (a type of tillage tool) in the soil depth of 15 to 20 cm (Aase et al., 2001). Results of this investigation also indicated that there was a linear relationship between soil bulk density and soil penetration resistance. On the other hand, coefficients of friction between soil-soil particles and soil-steel surface can directly affect soil engaging tools wear and draft. Soil texture and structure have significant effect on the soil coefficient of friction (Manuwa, 2012). There is a correlation between angle of soil internal friction and soil bulk density in such a way that angle of soil internal friction is a quadratic function of soil bulk density (Ngapgue et al., 2012). Tillage methods may affect soil structure, which in turn affects soil coefficients of friction, adhesion, and cohesion; however, no research work regarding the effect of conservation tillage on the soil coefficients of friction, adhesion, and cohesion was found in the previous literature. Objective of this study was to determine the effect of conservation tillage and soil depth on the soil physical and mechanical properties such as bulk density, penetration resistance, and soil coefficients of friction, adhesion, and cohesion.

MATERIALS AND METHODS

This filed experiment was conducted at a farm in Fars Province, Iran on the silty-clay loam soil having acidity of 8.4 and electrical conductivity of 0.79 dS m^{-1} (Table 1). The trial was conducted in the form of a randomized complete block design with three treatments and six replications for the soil coefficients of friction, adhesion, and cohesion. For soil bulk density and soil penetration resistance, a split plot experiment with the base of randomized complete block

Table 1. Soil physical properties of the experimental area.

pH	EC (dS m^{-1})	Silt (%)	Clay (%)	Sand (%)	Soil texture
8.4	0.79	54.73	40.94	4.33	Silty clay loam

design with two factors (tillage methods and soil depth) and six replications was used. In the main plots, three tillage methods such as conventional tillage (CT), reduced tillage (RT), zero tillage (ZT), and in sub-plots three soil depths such as 0 to 10, 10-20, 20-30 cm were evaluated. In the conventional tillage method, primary tillage was performed using a moldboard plow with working depth of 25 cm, and disk harrow and land leveler were used as the secondary tillage implements. A tine and disc cultivator, which was able to complete the primary and secondary tillage operations simultaneously, was used to prepare seed bed in the reduced tillage method (with working depth of 15 cm). BERTINI pneumatic direct planter (Rosario, Santa Fe, Argentina) was utilized to plant corn seed directly (planting depth of 5 cm) without any seed bed preparation in the no-tillage method. Standing crop residue was kept in the plots for all tillage treatments. Corn (*Zea mays* L., single cross 704) at the seed rate of 25 kg ha^{-1} and the row space of 75 cm was planted in 20mx6 m plots. Sprinkle irrigation system was used to irrigate the experimental plots of all treatments. Tillage treatments were applied for two years (2009-2011) in irrigated corn-wheat rotation.

Soil bulk density, soil penetration resistance (PR), soil internal coefficient of friction (coefficient of friction between soil particles), soil external coefficient of friction (coefficient of friction between soil and steel surface), adhesion coefficient, and cohesion coefficient were measured in September, 2011 at the harvest of corn crop. Collected data were analyzed (one way ANOVA) using SAS statistics software and Duncan's multiple range tests were used to compare the treatments means. Soil bulk density was measured at the soil depths of 0-10, 10-20, and 20-30 cm using core samplers. Samples were taken from three different locations of each plot and dried at 105 $^{\circ}$C for 24 hours.

Soil penetration resistance was measured using a cone soil penetrometer (Eijkelkamp 6.15 with cone diameter of 11.28 mm and penetration rate of 2 cm s^{-1}) up to the soil depth of 30 cm with 10 cm depth interval at the moisture content of 23% w.b. (field capacity). Average of 10 penetrations at each soil depth range was considered as the soil penetration resistance of each plot. Soil coefficient of internal friction and the coefficient of soil friction on a polished steel surface were determined in the laboratory using a shear box apparatus (Fig. 1). This apparatus consisted of a sample box (6cmx6cm) for holding the soil samples, a force transducer to record the frictional force, a linkage to apply the normal force to the sample, and an electrical motor to provide a relative motion for the variable half of the sample box with respect to its fixed half. Both coefficients were determined at the average soil moisture content of 18% (wb) and tests were carried out at three levels of normal pressures (100, 200, and 300 kPa). For each test, soil sample was put in the sample box and the bottom half of the sample box was subjected to a shear force by the electrical motor at a shear rate of 0.5 mm min^{-1} for each of the aforementioned normal pressures. The frictional forces and horizontal displacements were recorded by the shear box during the test running period.

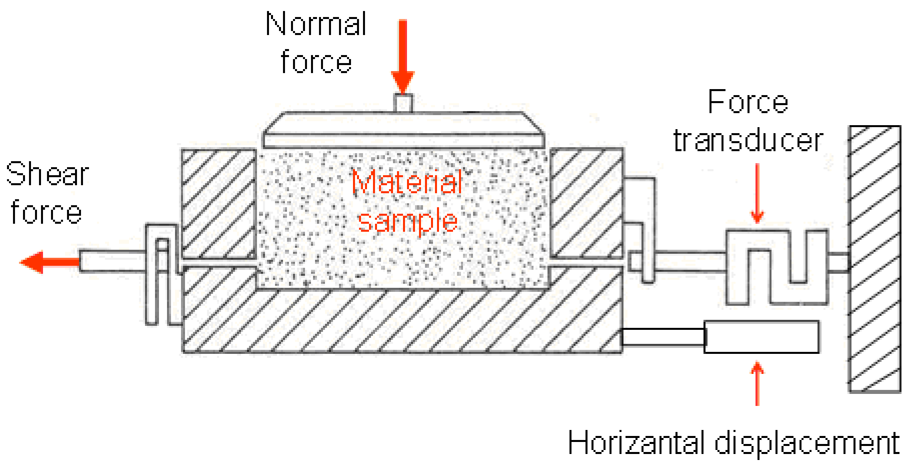

Fig. 1. Schematic of shear box apparatus.

Each test was repeated six times, and a new sample was used for each test. In the case of surface friction measurements, the steel surface was cleaned after running each test to remove the residue deposited on the surface. The maximum shear stresses were plotted versus the normal pressures for each replication. The slope of the best fit line to the plotted data was considered as the coefficient of friction of the sample at that replication based on Mohr-Coulomb's model. Mohr-Coulomb's model expresses shear stress as a function of normal stress, coefficient of friction, and adhesion or cohesion coefficients as follows (Lawton and Marchant, 1980):

$$\tau = C_a + \mu \sigma_n, \quad (1)$$

where:

τ = effective shear stress (kPa),

C_a = adhesion coefficient (kPa),

μ = coefficient of external friction (decimal) and

σ_n = effective normal stress (kPa).

In the coefficient of internal friction measurement, the *y*-intercept represents the cohesion coefficient (it is shown by C) and μ is the coefficient of internal friction.

RESULTS AND DISCUSSION

Results showed that tillage method ($p<0.05$) and soil depth ($p<0.01$) had significant effect on the soil bulk density; while, this parameter was not affected by interaction effect of tillage method and soil depth (Table 2). Soil disturbance intensity was different in various tillage methods; therefore, significant effect of tillage method on the soil bulk density was expected.

Table 2. Variance analysis of soil bulk density data.

Variation source	Degree of freedom	Sum squares	Mean squares	F values
Tillage method	2	0.027	0.014	9.08^{*}
Soil depth	2	0.146	0.073	48.51^{**}
Interaction between tillage method and soil depth	4	0.005	0.001	0.86^{ns}
Error	30	0.03	0.002	-

^{ns}: Non-significant; *: significant at $p<0.05$; **: significant at $p<0.01$.

The maximum soil bulk density was related to the zero tillage method which was significantly different from those of the reduced and conventional tillage methods (Table 3). The conventional and reduced tillage methods had identical soil bulk density. The higher soil bulk density in zero tillage was associated with the lack of soil disturbance in this tillage method. The similar results were also reported by Liu et al. (2005), Taser and Metinoglu

(2005), Fabrizzi et al. (2005), and Afzalinia and Zabihi (2014). Soil bulk density increased with increasing soil depth from 0 to 20 cm and then decreased when the soil depth increased from 20 to 30 cm; therefore, the maximum soil bulk density was occurred at the soil depth of 10 to 20 cm (Table 3). Reason for occurring the maximum soil bulk density at 10 to 20 cm soil depth was probably concentration of the pressure applied to the soil by agricultural machinery traffics at this soil depth. Increasing soil bulk density from the soil surface to a certain depth and its decreasing after that depth, has been also reported by Cavalieri et al. (2009).

Table 3. Average soil bulk density under different tillage methods and at different soil depths.

Tillage method	Bulk density (Mg m^{-3})	Soil depth (mm)	Bulk density (Mg m^{-3})
Conventional tillage	1.22 b	0-100	1.24b
Reduced tillage	1.22 b	100-200	1.29 a
Zero-tillage	1.26 a	200-300	1.16 c

a, b, c: averages with different letters in each column and group are statistically different at $p<0.05$.

Results of penetration resistance data analyses indicated that soil penetration resistance was significantly ($p<0.01$) affected by tillage methods, soil depth, and interaction between tillage method and soil depth (Table 4). The reason for the soil penetration resistance being significantly affected by the tillage methods and soil depth was diversity of soil disturbance intensity in various tillage methods and soil depths.

Table 4. Variance analysis of soil penetration resistance data.

Variation source	Degree of freedom	Sum squares	Mean squares	F value
Tillage method	2	2.36	1.18	117.33**
Soil depth	2	1.43	0. 72	71.11**
Interaction between tillage method and soil depth	4	0.36	0.09	8.85**
Error	30	0. 28	0.009	-

**: significant at $p<0.01$

Soil penetration resistance means comparison revealed that the maximum soil penetration resistance was occurred in the zero tillage because of the minimum soil disturbance in this method and the minimum amount of penetration resistance was related to the conventional method due to the maximum soil disturbance in this tillage treatment (Table 5). The higher soil penetration resistance (higher soil compaction) in the zero tillage method can reduce water infiltration and crop root penetration in the soil. Liu et al. (2005), Taser and Metinoglu (2005), and Fabrizzi et al. (2005) also reported a higher soil penetration resistance for the zero tillage compared to the conventional method. Soil penetration resistance increased when the soil depth increased from 0 to 30 cm so that the soil depth of 20 to 30 cm had the highest soil penetration resistance, and the soil depth of 0 to 10 cm had the lowest one (Table 5). The interaction effect of tillage methods and soil depth on the soil penetration resistance showed that there was a significant difference between tillage methods at all the soil depths (Table 6). Conventional tillage method at the soil depth of 0 to 10 cm had the lowest soil penetration resistance and zero tillage at the soil depth of 20 to 30 cm had the highest penetration resistance. The difference between cone indices of tillage methods increased with increasing soil depth so that the difference was the least at the soil depth of 0 to 10 cm and was the most at the soil depth of 20 to 30 cm. Although zero tillage method had the maximum value of soil penetration resistance, but it was lower than the critical soil penetration resistance for agricultural crops (about 2 MPa).

Table 5. Average soil penetration resistance under different tillage methods and at different soil depths.

Tillage method	Penetration resistance (MPa)	Soil depth (cm)	Penetration resistance (MPa)
Conventional tillage	0.48 c	0-100	0.55 c
Reduced tillage	0.78 b	100-200	0.76 b
Zero-tillage	0.99 a	200-300	0.94 a

a, b, c: averages with different letters in each column and group are statistically different at $p<0.05$.

Table 6. Interaction effect of tillage methods and soil depths on soil penetration resistance.

Tillage method	Soil depth (cm)	Penetration resistance (MPa)
Conventional tillage	0-10	0.40 e
Conventional tillage	10-20	0.46 e
Conventional tillage	20-30	0.57 d
Reduced tillage	0-10	0.46 e
Reduced tillage	10-20	0.78 c
Reduced tillage	20-30	1.10 ab
Zero-tillage	0-10	0.77 c

Zero-tillage	10-20	1.02 b
Zero-tillage	20-30	1.16 a

a, b, c, d, e: averages with different letters in each column and group are statistically different at $p<0.05$.

Data analysis of coefficients of soil internal friction, external friction, cohesion, and adhesion indicated that coefficient of soil internal friction and adhesion coefficient were significantly affected ($p<0.05$) by tillage methods; while, the effect of tillage treatments on the coefficient of soil external friction and cohesion coefficient was not statistically significant (Table 7).

Table 7. Variance analysis of coefficients of soil internal friction, external friction, cohesion, and adhesion (F values).

Variation source	Internal friction	External friction	Cohesion	Adhesion
Replication	0.85^{ns}	0.68^{ns}	1.59^{ns}	6.84^{*}
Tillage method	3.23^{*}	0.14^{ns}	1.85^{*}	3.45^{*}

^{ns}: non-significant; *: significant at $p<0.05$.

Coefficients of soil internal friction and cohesion in different tillage methods are shown in table 8. Reduced and conventional tillage methods had the highest coefficient of internal friction; whereas, the lowest coefficient of internal friction was obtained from the zero tillage. Reduction of soil coefficient of internal friction in the zero-tillage method was probably because of improving soil structure in this tillage system. Since soil specific resistance was significantly influenced by the soil coefficient of internal friction, zero-tillage method can reduce soil specific resistance by reducing the coefficient of internal friction. The maximum cohesion coefficient was related to the zero-tillage method, which was statistically different from those of the conventional and reduced tillage treatments. The minimum cohesion coefficient was obtained from the reduced tillage method (Table 8).

Table 8. Average coefficients of soil internal friction and cohesion in different tillage methods.

Tillage method	Coefficient of internal friction	Cohesion coefficient (kPa)
Conventional tillage	0.44 a	13.2 b
Reduced tillage	0.45 a	10.5 b
Zero-tillage	0.35 b	21.0 a

a, b: averages with different letters in each column and group are statistically different at $p<0.05$.

There was not a significant difference between tillage treatments for coefficient of soil external friction (Table 9). However, this coefficient had slightly higher amount in the reduced tillage method compared to the conventional and zero-tillage treatments. Results of this study also showed that the difference between the tillage methods for adhesion coefficient was significant in such a way that the largest amount of soil adhesion coefficient was obtained from the zero tillage and the smallest one was related to the reduced tillage method.

Table 9. Average coefficients of soil external friction and adhesion in different tillage methods.

Tillage method	Coefficient of external friction	Adhesion coefficient (kPa)
Conventional tillage	0.27 a	15.5 b
Reduced tillage	0.30 a	9.6 c

Zero-tillage	0.27 a	18.1 a

a, b, c: averages with different letters in each column and group are statistically different at $p<0.05$.

CONCLUSIONS

It can be concluded from the results of this investigation that zero-tillage method had the maximum soil bulk density and penetration resistance, and conventional tillage treatment had the minimum soil bulk density and penetration resistance. Penetration resistance increased with increasing soil depth from 0 to 30 cm; whereas, bulk density increased when soil depth increased from 0 to 20 cm and then decreased with increasing soil depth from 20 to 30 cm. It was also observed that tillage method had a significant effect on the coefficient of soil internal friction and adhesion coefficient; while, the coefficient of soil external friction and cohesion coefficient were not significantly affected by the tillage treatments. The zero-tillage method reduces the coefficient of soil internal friction which may in turn reduce the soil specific resistance and power required to cultivate the soil.

RECOMMENDATION FOR FUTURE WORK

According to results and limitations of this study, the following recommendation was made to make the future studies more effective in this area. Since the coefficients of soil friction were measured at one level of moisture content in the present study, the interactive effect of soil moisture content and tillage methods on the coefficients of soil internal and external friction, adhesion, and cohesion may be evaluated in the future research.

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