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Changes in penetration resistance of a clay field with organic waste applications

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Abstract

Effects of manure (M), hazelnut husk (HH), tobacco (TW) and tea (TEW) wastes on penetration resistance (PR) values in a clay field were determined after 8 months of organic wastes were incorporated into soil at four different rates (0, 2, 4 and 6 %) in a randomized plot design with three replicates. While bulk density (BD), relative saturation (RS) and PR values decreased, mean weight diameter (MWD), total porosity (F), gravimetric water (W) and organic matter (OM) contents of the clay soil increased with increasing the application rates of organic wastes. While the lowest PR (0.72 MPa) was determined in the highest application rate of HH which had the highest C:N ratio, the highest PR (1.72 MPa) was in the control. According to the control treatment, decreases in mean values of PR by the organic waste applications were in the following order; HH (52.10%) > TEW (42.07%) > TOW (30.73%) > M (25.17 %). PR values gave significant negative correlations with F (-0.551**), W (-0.439**) and MWD (-0.509**), and significant positive correlations with BD (0.550**) and RS (0.374*). Total porosity showed the highest direct effect (62.39%) on PR. The higher indirect effects of the other properties on PR were also obtained via F. Applications of the same doses of different organic wastes had different effects on the PR values with changing the structure of clay soil due to their C:N ratios.
Keywords: penetration resistance, agricultural wastes, soil physical properties

Introduction

Intensive agricultural practices have significant effects on soil degradation through loss of soil organic mater, decline of soil structure, resulting soil compaction and root growth (Usowics and Lipiec, 2009; Busscher and Bauer, 2003). Dexter (2004) reported that a measure of soil microstructure can be an index of soil physical quality that is consistent with observation on soil compaction, on effects of soil organic matter content and on root growth. Soil compaction, occurs usually loss or reduced in size of the largest pores, increases soil bulk density and soil strength, and decreases macro porosity, soil water infiltration and water-holding capacity (Dexter, 2004). Soil compaction also affects root penetration and consequently crop production (Hakansson et al. 1988). Penetration resistance is an empirical, easy and cheap measurement technique of soil strength, and widely used to assess soil compaction and the effects of soil management (O'Sullivan et al., 1987; Castrignanö et al., 2002). Numerous studies indicated that soil compaction depends on several factors such as; compressing loads of heavy machinery, type of parent materials, soil texture, moisture content, organic matter content, structural stability, sodicity and salinity (Soane, 1990; Baumgart and Horn, 1991; Barzegar et al., 1996; Hamza and Anderson, 2005). In this study, effects of manure (M),

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hazelnut husk (HH), tobacco (TW) and tea (TEW) wastes applications on penetration resistance (PR) in a clay field were investigated, and direct and indirect effects of the soil properties on PR were determined.

Material and Method

A field experiment was conducted at the Experimental Field of Agricultural Faculty in Ondokuz Mayıs University, Samsun in Nowember, 2001. Four different organic wastes, manure (M), hazelnut husk (HH), tea waste (TW) and tobacco waste (TOW), were incorporated within 0 - 15 cm soil depth as 0, 2, 4 and 6% treatment rates (0, 36, 67 and 100 ton ha^{-1}) with three replications in a randomized plot design. S The agricultural wastes were analyzed for some chemical and physical properties as listed in Table 1. Some chemical and physical characteristics of the soil were determined in soil samples as follows; particle size distribution by hydrometer method, bulk density (BD) by undisturbed soil core method (Demiralay, 1993), soil pH, 1:1 (w:v) soil:water suspension by pH meter, electrical conductivity ($EC_{25ºC}$) in the same suspension by EC meter, organic matter content by Walkley-Black method and exchangeable cations by ammonia acetate extraction (Kacar, 1994). After determining the BD, total porosity (F) was calculated using the equation; F=1-BD/2.65. According to the soil physical and chemical properties given in Table 2, the results can be summarized as; the textural class is clay, none saline, neutral in pH, high in organic matter (Soil Survey Staff, 1993).

Table 1. Some chemical and physical properties of agricultural wastes

	OC, %	N, %	C:N	Na, %	K, %	Ca, %	Mg, %
TOW	38.40	1.97	19.46	0.09	1.03	5.72	0.80
M	15.62	1.95	7.98	1.08	1.97	6.58	0.94
HH	49.49	0.96	51.31	0.03	1.80	0.65	0.15
TEW	53.77	2.46	21.77	0.01	1.20	0.29	0.17

(TOW-tobacco waste, M-manure, HH-hazelnut husk, TEW-tea waste)

Table 2. Some physical and chemical properties of the soil

Sand, %	18.94	$EC_{25ºC}$, mmhos cm^{-1}	0.65
Silt, %	24.82	K, me/100g	1.15
Clay, %	56.23	Na, me/100g	0.21
Texture class	Clay	Ca, me/100g	34.87
Organic matter, %	3.85	Mg, me/100g	8.13
pH	6.95		

After eight months, soil samples were taken from each plot for the analyses. Penetration resistance (PR) in 0-15 cm depth was measured in each plot with five replications using a standard cone penetrometer which had a cone with a semi-angle of 30º, a base area of 2 cm^2 (Bradford, 1986). The mean weight diameter (MWD) of the soil samples was measured by dry sieving method, and calculated by the sum of the mass fraction recovered for each sieve multiplied by the average size between two adjacent sieves (Kemper and Rosenau, 1986). After volumetric water content (θ) values were determined multiplying natural moisture (gravimetric water, w) content of soil samples by the bulk densities (θ=w.BD), the relative saturation (RS) values were calculated dividing volumetric water contents by total porosity values (RS= θ/F).

Statistical analysis of the results was done by standard analysis of variance, pairs of mean values compared by least significant difference (LSD) (Yurtsever, 1984), and correlations between the soil properties, and direct and indirect effects of soil properties on PR were determined with path analysis using TARIST statistics program.

Results and Discussion

Effects of Organic Wastes on Soil Properties

The application of agricultural wastes increased organic matter content in the 0-15 cm soil layer (Figure 1a). The highest OM content (8.91%) was determined in 6% of M treatment. The increments in mean values of OM content with the application rates were significantly different from the control ($P<0.01$). The mean values of soil OM contents by the waste treatments ordered as follows; TEW (6.46%) > M (6.01%) > TOW

(5.67%) > HH (4.72%). There are numerous studies indicated that application of organic residues into soil increased soil organic matter content (İç and Gülser, 2008; Candemir and Gülser, 2011). Increments in the application rates of organic wastes significantly increased MWD values (P<0.05). The MWD values increased with increasing the application rates of TOW, HH and TEW, but, decreased with increasing the application rates of M (Figure 1b). Manure had the highest Na content among the organic wastes (Table 1). Ghosh et al. (2010) reported that when the manure was applied in to the Vertisol, dispersion index of the soil increased due to its high Na level. The mean values of MWD resulted by the waste treatments ordered as follows; HH (1.96 mm) > TEW (1.87 mm) > TOW (1.84 mm) > M (1.81 mm). Gülser (2006) reported that increasing organic matter content in a clay soil by the different forage treatments increased MWD values according to the fallow control treatment.

When the bulk density values reduced, total porosity values increased with increasing the application rates of the treatments significantly (P<0.01) (Figure 2 a, b). The lowest bulk density (0.63 g/cm^3) or the highest total porosity (76.38%) value was determined with the 6% of HH treatment. The increments in total porosity with the application rates were significantly different from the control application (P<0.01). In many studies, it is reported that addition of organic wastes into soils reduces bulk density and increases total porosity (Anikwe, 2000; Marinari et al., 2000; Candemir and Gülser, 2011).

Although the gravimetric water contents (W) generally increased according to the control, the volumetric water contents (θ) decreased due to reducing bulk densities by the application of organic wastes (Figure 3 a, b). While the highest θ content (39.79%) was determined in the control, the lowest θ content (28.48%) was determined in 6% of TEW treatment. Addition of organic matter to soils increases water holding capacity (Gupta et al., 1977; Candemir and Gülser, 2011). The relative saturation values also decreased with increasing the application rates of organic wastes (Figure 3c). Generally, increments in the total porosity caused decreases in the RS. Although the highest moisture content (52.50%) was determined in 6% of HH treatment, the lowest RS value (40.69%) was also found in the same treatment due to having the highest total porosity. When comparing with the other treatments, HH had the highest C:N ratio (Table 1). This indicates that HH had a lower mineralization rate than the other wastes. Therefore effect of HH on soil properties was expected to be longer than that of the other treatments.

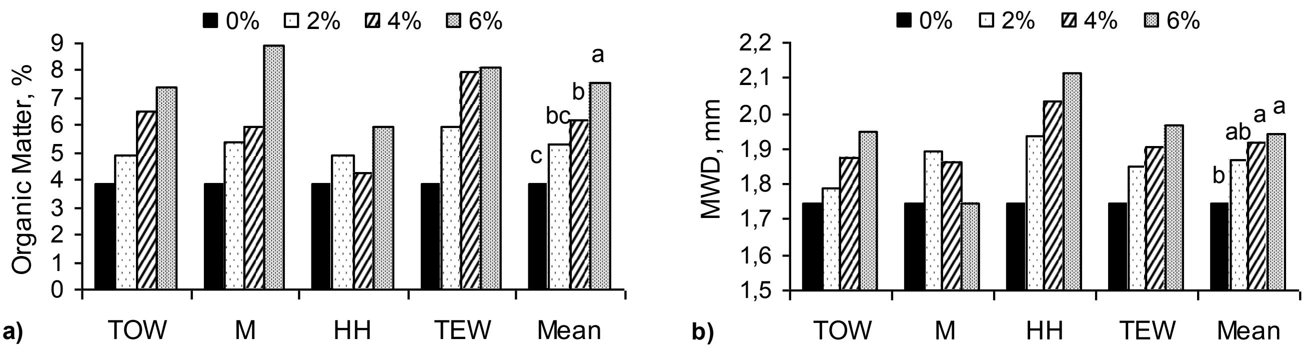

Figure 1. Effects of organic wastes on a) organic matter content (LSD:1.258) and b) mean weight diameter (MWD) of the soil (LSD:0.144). M:manure, HH: hazelnut husk, TOW:tobacco, TEW:tea wastes

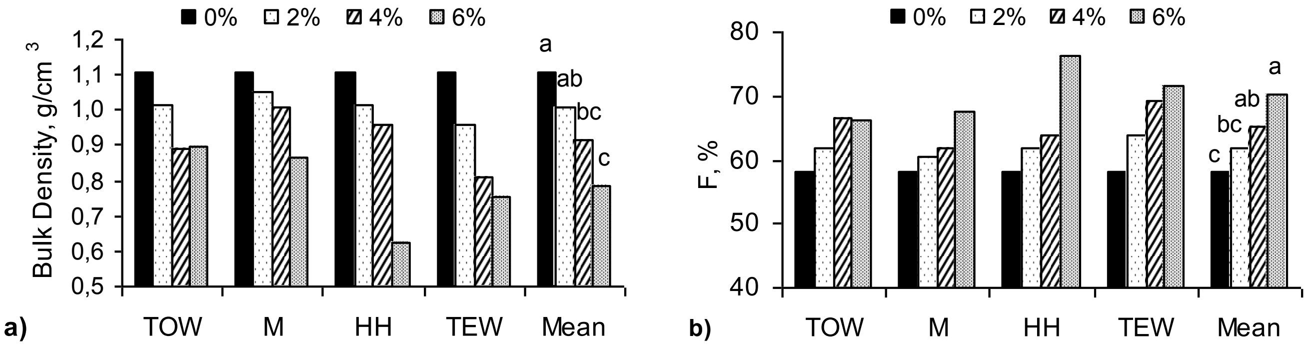

Figure 2. Effects of organic waste treatments on a) bulk density (LSD:0.145) and b) total porosity (F) of the soil (LSD:5.470). M: manure, HH: hazelnut husk, TOW: tobacco, TEW: tea wastes

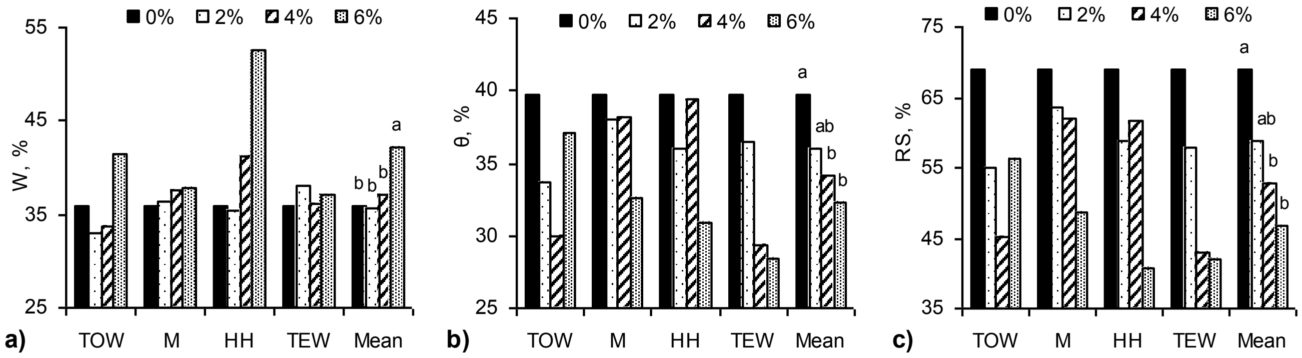

Figure 3. Effects of organic waste treatments on a) gravimetric water (W) (LSD:4.977 at 5%), b) volumetric water (θ) contents (LSD:4.596 at 5%) and c) relative saturation (RS) (LSD:13.431 at 1%). M:manure, HH: hazelnut husk, TOW:tobacco, TEW:tea wastes

Increasing the application rates of organic wastes significantly decreased the PR values according to the control treatment (Figure 4a). While the highest PR value (1.72 MPa) was determined in the control, the lowest PR value (0.72 MPa) was obtained wit the 6% of HH treatment. The mean PR values with the applications of HH (1.04 MPa) and TEW (1.17 MPa) were significantly lower than that with the applications of TOW (1.32 MPa) and M (1.39 MPa) (Figure 4b). According to the control treatment, decreases in mean PR values by the treatments were obtained in the following order; HH (52.10%) > TEW (42.07%) > TOW (30.73%) > M (25.17 %). On the other hand, the application rates of treatments significantly decreased the mean PR values in the following order; control (1.72 MPa) > 2% (1.17 MPa) > 4% (1.06 MPa) > 6% (0.98 MPa) (Figure 4c). It has been suggested that the critical PR value for optimum root growth should be vary between 1.7 and 2.0 MPa (Canarache, 1990; Arshad et al., 1996). In this study, PR values in organic waste treatments varied between 1.42 MPa with 2% of M and 0.72 MPa with 6% of HH application (Figure 4a). When comparing with the control, the PR values obtained by the organic waste treatments were found to be lower than the suggested critical levels for root growth.

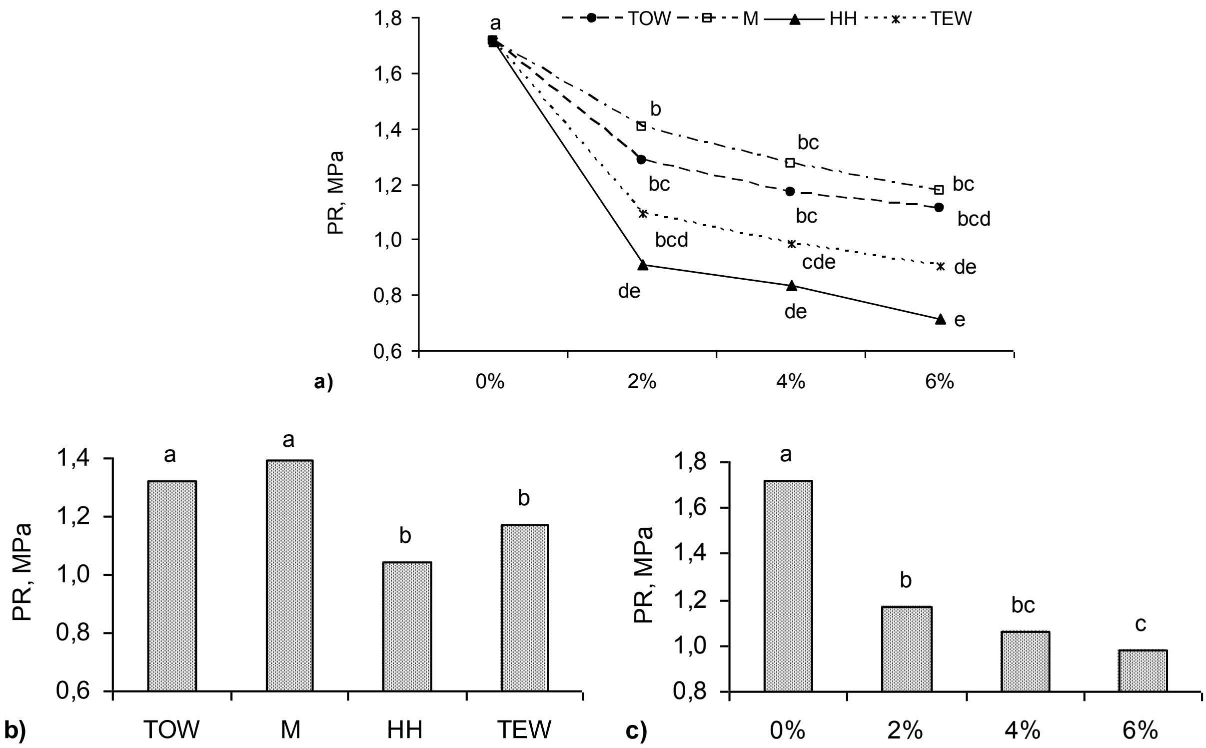

Figure 4. Effects of organic waste treatments on penetration resistance (PR) a) Interactions between treatments and doses (LSD:0.203 at 5%), b) Organic waste treatments (LSD:0.136 at 1%) and c) Application doses (LSD:0.136 at 1%). TOW:tobacco waste, M:manure, HH: hazelnut husk, TEW:tea waste

The Relationships among the Soil Properties and Penetration Resistance

Soil organic matter content gave the significant positive correlation with F (-0.419**) and significant negative correlations with BD (-0.419**), θ (-0.390*) and RS (-0.433**) (Table 3). Increasing soil organic matter content by the organic waste treatments caused decreases in BD, θ and RS with increasing the total porosity. Gülser (2004) found that increasing organic matter content in the soil due to crop treatment increased total porosity with decreasing bulk density. The highest positive correlation (0.961**) was found between RS and θ content. PR values had significant positive correlation with BD (0.550**), RS (0.374*) and significant negative correlation with W (-0.439**), F (-0.550**) and MWD (-0.509**). PR values decreased with increasing W, F and MWD values by the organic waste treatments. Gülser (2006) found that MWD increased by the forage cropping treatments over the control had significant negative correlations with BD and PR values. Veronese-Junior et al. (2006) reported that decreases in soil moisture content increased penetration resistance in soil. In another study, Gülser et al. (2011) studied spatial variability of PR values in a cultivated soil and reported that PR values had negative correlations with gravimetric water contents.

The correlation coefficients between PR and the soil properties were divided into direct and indirect effects by path coefficients. The percentages of direct or indirect effects of the variables on PR were determined according to the path coefficients (Table 4). Most soil properties were significantly correlated with PR. However, according to the path analysis, total porosity had the strongest direct effect (62.39%) on the PR. Direct effects of the other soil properties on PR were in the following order; MWD > W > RS. The other soil properties had also higher indirect effects on PR mediated by F. Although the soil properties significantly correlated with PR, the result of path analysis showed that F and MWD were more effective properties on PR than W and RS. Gülser (2006) reported that increasing macroaggregation in a clay soil due to forage cropping caused increases in MWD and decreases in bulk density and penetration resistance.

Table 3. The correlations among the soil properties

	OM	BD	F	W	θ	RS	MWD
PR	-0.170	0.550**	-0.550**	-0.439**	0.234	0.374*	-0.509**
OM		-0.419**	0.419**	-0.004	-0.390*	-0.433**	-0.104
BD			-1.000**	-0.411**	0.752**	0.886**	-0.394*
F				0.411**	-0.752**	-0.886**	0.394*
W					0.253	0.021	0.316
θ						0.961**	-0.149
RS							-0.251

** Correlation is significant at the 0.01 level,* Correlation is significant at the 0.05 level. PR: penetration resistance, OM: organic matter, BD: bulk density, F: total porosity, W: gravimetric water content, θ: volumetric water content, RS: relative saturation, MWD: mean weight diameter.

Table 4. Direct and indirect effects of soil properties on penetration resistance

	Direct Effect, %	Indirect Effect, %			
		F	W	RS	MWD
F	62.39	-	5.53	18.35	13.72
W	26.65	50.73	-	0.85	21.76
RS	24.36	65.04	0.33	-	10.27
MWD	50.57	35.71	6.18	7.54	-

F: total porosity, W: gravimetric water content, RS: relative saturation, MWD: mean weight diameter.

Conclusion

Addition of organic wastes into the clay soil decreased PR and increased F by reducing bulk density and increasing MWD. According to the control treatment, decreases in mean values of PR and increases in mean values of F by the different treatments were generally in the same order as follows; HH > TEW > TOW > M. The results indicated that total porosity was one of the most important soil properties that affected PR directly in the clay textured soil. Indirect effects of the other soil properties on PR were also mediated by F. The different organic wastes had different effects on PR of clay soil due to changing soil structure with increasing MWD and F. It can be concluded that all organic waste application had positive effects on improving soil properties; the same application rates of different organic wastes had different effects on the

PR values with changing the structure of clay soil. The effects of HH and TEW on PR were more effective than TOW and M treatments in clay soil due to their high C:N ratios.

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