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COMPRESSIVE BEHAVIOR OF SOIL AS AFFECTED BY AGGREGATE SIZE WITH DIFFERENT TEXTURES IN TURKEY

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ABSTRACT

Soil compactability is affected by aggregate size distribution of soil. The objective of this study was to determine the effects of aggregate size on compressive behaviour of soils with different textures. The study was conducted on surface soil samples (0-20 cm) of; coarse textured (TC) and fine textured (TF) soils. Aggregates were separated into three different aggregate size groups (4.0-2.0 mm; 2.0-0.84 mm and <0.84 mm) by dry sieving. The dry bulk density and saturated hydraulic conductivity of the TC and TF soils for each aggregate size group was also determined under three different compaction efforts (0, 45, 90 KPa) for saturated condition of soil water content. The maximum dry bulk density values of aggregate size groups of the TC soil were significantly higher than those of the TF soil, but the optimum water content values of the TF soil were significantly higher than those of the TC soil. The dry bulk density and saturated hydraulic conductivity values of the TC soil were significantly higher than those of the TF soil. The results of this study clearly indicated that the compressive behaviour of aggregate size on soil compactibility with wide variation in soil dry bulk is mainly affected by soil texture and water content.

Key words: Aggregate size, soil compaction, bulk density, hydraulic conductivity

INTRODUCTION

Soil compaction is the process by which the soil grains are rearranged to decrease void space thereby increasing the bulk density. Soil compaction adversely affects soil physical fertility, through increasing soil bulk density, decreasing porosity, increasing soil strength, decreasing soil water infiltration, and water holding capacity (Hamza and Anderson, 2005). Soil compactability depends on soil texture, soil water, organic matter content, soil aggregation and compaction effort (Ekwue and Stone, 1995; Kay *et al*., 1997; Canbolat *et al*., 2002; Imhoff *et al*., 2004). Coarse textured soils are less susceptible to compaction than those with a fine texture (Horn and Lebert, 1994). The susceptibility to compaction increases as soil organic matter content decreases (Zhang *et al*., 1997). The water content of the soil is an important property that controls its compactive behaviour. As a quantitative measure of wetness of a soil mass, water content affects the level of compaction that a soil may reach under a compactive effort processes (Soane and Van Ouwerkerk, 1995). At all compaction levels, the penetration resistance increases with decreasing soil water potential (Lipiec *et al*. 2002). The intensive use of the soil without moisture control has been causing dissemination of the soil compaction (Pedrotti and Dias Junior, 1996). Dry bulk density is the most common measure of soil compaction. Díaz-Zorita *et al*. (2001) emphasized that the compactability of a soil could be determined from parameters derived from laboratory compaction curves generated using the Proctor test.

Soil aggregate dynamics are one of the key physical factors to maintain or improve their agricultural productivity, water movement and reduce soil physical degradation as compaction (Lal 2000). Little is known about the relationship between aggregate size and soil compaction. Shepherd *et al*. (2001) studied the effects of increasing cropping and soil compaction on aggregate stability and dry-sieved aggregate-size distribution. Imhoff *et al*. (2004) investigated the compressive behaviour of Hapludox. The relationship between the compression index, soil bulk density, and clay content was statistically significant with R^2 = 0.77. Organic matter and soil water content did not affect the compression index. The preconsolidation pressure was significantly related with soil bulk density, soil water content, and clay content (R^2 = 0.70), but was unaffected by organic matter. Lado *et al*. (2004) have stated that infiltrasion rate (IR) values were high and differences in IR among the three aggregate sizes in this soil were relatively high. The soil losses increased with increasing aggregate size, ranging from $4.5x10^{-3}$ to $6.6x10^{-3}$ kg/m^{-2} mm^{-1} in the low-OM soil, and from 1.2 to $3.8x10^{-3}$ kg m^{-2}mm^{-1} in the high-OM soil.

The overall objective of this study was to determine effects of aggregate size on compressive behaviour of soils with different textures. The specific objectives were to (i) quantify the compaction characteristics of different aggregate size groups, (ii) determine effect of aggregate size on dry bulk density of soils at different water contents against vertical compactive efforts, and (iii) obtain saturated hydraulic conductivity of compacted aggregate size groups.

MATERIALS AND METHODS

The soils used in the experiments were sampled from the arable layer of a Ustorthents (Soil Survey Staff 1999) with coarse (TC) and fine texture (TF). The soils were located at Agricultural Research Farm of the Atatürk University Erzurum, Turkey. The study area was cultivated with cereal and root crops for over 40 years. The region is characterized by a harsh-continental climate. The average annual temperature over 42 years is 6 °C. Temperature does not fall below zero from April to November, but it is usually lower than zero from December to March. The annual rainfall is 447 mm (Doğanay *et al*., 1998).

Soil analysed for texture (Gee and Bauder, 1986), organic matter content (Nelson and Sommers, 1982), exchangeable Na (Thomas, 1982), cation exchange capacity (Rhoades, 1982) and pH (McLean, 1982). The liquid and plastic limits were also determined by the procedure described in ASTM standards (American Society for Testing and Materials, 1992).

The aggregate size groups were separated by dry sieving. Soil samples were gently broken by hand, air-dried and sieved through 4 mm screen. Three air-dry aggregate groups, 4.0-2.0 mm, 2.0-0.84, and <0.84 mm, were separated by dry sieving. The particle size distribution curve of each aggregate size group was determined using the sieving method for >53 µm and hydrometer method for <53 µm (Gee and Bauder 1986).

Maximum dry bulk density and optimum water content were determined for each aggregate size group for both soils according to the standard ASTM method (American Society for Testing and Materials 1992) commonly known as the Proctor test.

The bottom movable direct compaction device was used for two compaction treatments. The vertical compaction efforts (45 and 90 kPa) were applied to each aggregate size group in the pots in addition to control (uncompacted pots) at all water contents.

Heights and weights of aggregate size groups in the pots were measured before and after wetting procedure and compaction test. The volume and the dry bulk density of each aggregate size group in the pot were calculated from these values. The saturated hydraulic conductivity experiments were in pots after applying selected vertical compactive efforts only for saturated condition (Klute and Dirksen 1986).

The ANOVA and Duncan's multiple comparison tests were performed according to Dowdy and Weardin (1983).

RESULTS AND DISCUSSION

Soil physical and chemical properties are given in Table 1. The sandy loam or coarse textured soil contains 66% sand, 24% silt and 10% clay, and 1.5% organic matter. The silt loam or fine textured soil contains 21% sand, 61% silt and 18% clay, and 2.9% g organic matter. The particle density of TC and TF soils are 2.68 and 2.64 Mg m^{-3}. The plastic and liquid limits of TC are 22% & 36 % of TF soils are 28% and 46%, respectively.

The particle size distributions of aggregate size groups of TC and TF soils are shown in Fig. 1. It is evident from the data that as the aggregate size group increased the amount of coarse particles also increased. The rate of increase of coarser particles was low in the TF soil than in the TC soil.

Effect of Aggregate Size on the Compaction Characteristics: The maximum dry bulk density (MBD) and optimum water content (OWC) from compaction characteristics of both soils for different aggregate size groups are presented in Table 2 The effects of soil type, aggregate size, and the interaction of soil type with aggregate size on MBD were significant $P<0.01$. The OWC for the MBD increased as the clay content increased and aggregate size decreased. Similar results were reported by Canbolat *et al.* (2002). In both soils, the MBD values of the 4.0-2.0 mm aggregate size were the highest among the aggregate size groups, but the OWC of the 4.0-2.0 mm aggregate size was the lowest as compared to the those of the others aggregate sizes. The ANOVA results indicated that the MBD and OWC were greatly affected by soil type and aggregate size at $P<0.01$. The TF soil had lower mean of the MBD and higher mean of the OWC The MBD values of the TC soil were significantly higher than those of the TF soil ($P<0.05$). Table 2 shows that the MBD decreases with decreasing aggregate size in both soils. These differences among the soils and aggregate size groups due to their textural disparity. Similar influences of texture were obtained by Adekalu and Osunbitan (2001). The decreasing rates in the MBD as compared with that of 4.0-2.0 mm of size group were 3.9% and 8.9% for the TC soil and 2.2% and 9.5% for the TF soil at 2.0-0.84 mm and <0.84 mm aggregate sizes, respectively. The OWC increased with decreasing aggregate size in both soils. The rates were 3.4% and 36% for the TC soil and 2.9% and 18.7% for the TF soil at 2.0-0.84 mm and <0.84 mm aggregate sizes as compared to 4.0-2.0 mm aggregate size, respectively.

The OWC for 4.0-2.0 mm, 2.0-0.84 mm and <0.84 mm aggregate size groups of TC soil were 22 % below the plastic limit. Similar trend was also observed for 4.0-2.0 mm aggregate size group of TF soil. These results suggested that the degradation of the soil structure during the field traffic process was more extensive in the TC soil than in the TF soil. Droogers *et al*., (1996) reported that an OWC for tillage exist for each soil. This optimum value is defined as the soil water content at which tillage can be performed without causing soil structure deterioration (Imhoff *et al*., 2004). The results of the MBD measurements indicated that aggregate size distribution and organic matter content improved the resistance of soils against compaction. The organic matter content stimulated the production of agents that bind aggregate soil particles into a more stable soil (Nemati *et al*., 2000).

In the present study the MBD of soils increased with increasing aggregate size, and OWC of soils decreased with increasing aggregate size. As an indication of compaction the MBD of a soil has been shown to be affected by its water content. Aggregate size was effective in reducing compactibility of cohesive soils at water content lower than 0.8 PL for the standard Proctor test (Barzegar *et al.*, 2005).

The TF soil had the lowest mean of MBD. This may indicate that organic matter and fine texture makes soil more resistant to compaction as stated by Canbolat (1992) and Arvidsson (1998). Díaz-Zorita and Grosso (2000) found that higher total organic carbon levels reduced the MBD and that the critical water content was independent from textural class. Similar results have been reported by (Kay and Dexter, 1992; Watts and Dexter 1997).

Soil Behaviour Against Compactive Efforts: The dry bulk density values of both soil samples as functions of the effectiveness of aggregate size groups (ASG) in soil compactibility at different water contents and compactive efforts are presented in Table 3. The effects of soil type, aggregate size group, water contents, compactive efforts, and their interactions on dry bulk density were significant $P<0.01$. The Duncan's multiple range test results showed that there were significant differences in the dry bulk density among soils, aggregate sizes, water contents and compactive efforts.

For TC soil the DB was 1.12, 1.31 and 1.41 Mg m^{-3}. The compactive efforts increased dry bulk density in both soils. The dry bulk densities in both soils decreased with decreasing aggregate size for each compactive effort. Typically the TC and TF soils present a linear relationship (r=0.98 and r=0.93) indicating an increase of the dry bulk density with compactive effort.

Soil water content at compaction effords had effect on dry bulk density. The water content of TC soil were significantly lower than those of TF soil at all SAGs. The highest levels of soil compaction were achieved at soil water contents corresponding to the SWC2 treatments. The low soil water content caused a smaller increase of dry bulk density and expected to reduce the effects of soil compaction. The water content of the soils affects compaction behaviour as each soil was considerably more susceptible to compaction when it was wet.

The dry bulk density increased with increasing aggregate size and sand content of TC soil at the same compactive effort and water content. This may indicate that the aggregate size groups in the coarse textured soil more positive effect on compaction. Koolen and Kuipers (1983) reported the high dry bulk density in sandy soils by the lack of micropores. The sandy loam soil with coarse texture in this study had lower organic matter content than silt loam soil with finer texture. Agricultural soils compressibility cannot be explained on the basis of the clay content or its mineralogical characteristics alone (Canillas and Salokhe, 2001) since organic matter content also strongly affects the relationship (Quiroga *et al*., 1999). O'Sullivan (1992), reported that DB was lower at a higher organic matter content for a given soil water content and stress.

Soil deformation increases with increasing water content (Bakker and Davis, 1995, Hakansson and Lipiec, 2000). The differences in susceptibility to compaction for both soils seems to be related to the mechanism whereby a decrease in soil water content increases the number of contacts between particles, which is directly dependent on soil texture. Results indicated that the TC soil was less susceptible to compaction than the TF soil for SWC_2 and SWC_3 Similar results were reported by Horn and Lebert (1994); McBride and Joose (1996) and Imhoff *et al.* (2004). The increase in strength with decreasing water content can be ascribed to an increase in the cohesive forces of capillary-bound water by decreased pore water pressure (Munkholm and Kay, 2002) and to increased effectiveness of cementing materials (Caron *et al*., 1992).

In addition, for given clay content, the soil becomes more susceptible to compaction as its dry bulk density decreases. Thus, soils with a potentially better structural quality associated with a lower dry bulk density and/or higher clay content will be more susceptible to degradation (Imhoff *et al*., 2004). These results emphasize the importance of controlling the weight of agricultural machinery to avoid deterioration of physical quality of the fine textured soil.

Effect of compacted different aggregate size groups on saturated hydraulic conductivity: The saturated hydraulic conductivity (HC) values of both soil samples as functions of the application of three different compactive effort (0, 45, and 90 kPa) at three 4.0-2.0 mm; 2.0-0.84 mm and <0.84 mm aggregates sizes for saturated condition of soil water content (SWC1) are presented in Table 4.

The effects of soil type, aggregate size and compactive effort, and their interactions on saturated HC were significant P<0.01.

Table 1. Selected properties of the soils used in the experiment

Soil property	Soils TC	TF
Sand (%)	66	21
Silt (%)	24	61
Clay (%)	10	18
Texture class	Sandy loam	Silt loam
pH (H_2O)	7.8	7.6
Organic matter content (%)	1.5	2.9
Cation exchange capacity ($cmol_c\ kg^{-1}$)	14.3	32.2
Exchangeable Na ($cmol_c\ kg^{-1}$)	0.76	0.12
Plastic limit (%)	22	28
Liquid limit (%)	36	46

The dry bulk density of soil samples increased with the applied compactive efforts resulting in decreased HC. This was due to that the dry bulk density of the soil increased with the increasing compactive effort, and this will decreased the volume of voids available for the flow of the water resulting in reducing the saturated hydraulic conductivity. Similar results have been reported by Attom (1997).

Table 2. Average compaction characteristics for different aggregate size groups of the two studied soils

Aggregate size Group (mm)	Maximum dry bulk density ($Mg\ m^{-3}$)		Optimum water content (%)	
	TC	TF	TC	TF
4.0-2.0	1.80 a	1.37 a	14.7 c	27.8 c
2.0-0.84	1.73 b	1.34 b	15.2 b	28.6 b
<0.84	1.64 c	1.24 c	20.0 a	33.0 a

Different lower case letters within a column denote significant differences at P< 0.05.

Table 3. Average dry bulk densities at three various water content and compaction effort for different aggregate size groups of the two studied soils

Aggregate size group (mm)	Compaction effort (kPa)	Soils TC			TF		
		SWC1	SWC2	SWC3	SWC1	SWC2	SWC3
4.0-2.0		(53.0)	(25.9)	(12.6)	(68.5)	(36.0)	(18.9)
	0	1.20	1.21	1.21	0.90	0.92	0.92
	45	1.42	1.43	1.34	1.09	1.10	0.93
	90	1.48	1.48	1.37	1.11	1.13	0.96
2.0-0.84		(56.7)	(28.4)	(13.9)	(69.9)	(36.0)	(19.6)
	0	1.08	1.09	1.09	0.89	0.88	0.89
	45	1.32	1.33	1.32	1.07	1.05	0.98
	90	1.45	1.46	1.35	1.12	1.14	0.99
<0.84		(58.1)	(29.5)	(14.9)	(71.6)	(38.1)	(19.7)
	0	1.06	1.06	1.07	0.85	0.84	0.87
	45	1.19	1.21	1.20	1.01	1.02	0.92
	90	1.42	1.42	1.27	1.09	1.12	0.93

Values in parentheses are the soil water contents.

In both the TF and the TC soils, the saturated hydraulic conductivity in uncompacted columns decreased with the decreasing in aggregate size. The HC for 4.0-2.0 mm aggregate size group was the highest and <0.84 mm aggregate size was the lowest.

This was because of the larger pore volume in the soils with the 4.0-2.0 mm aggregates than with <0.84 mm aggregates. Similar results have been reported by Lado *et al*. (2004) and Park and Smucker (2005). For the three aggregate sizes the saturated hydraulic conductivity values of the TC soil were significantly higher than those of the TF soil except for 90 kPa compactive effort of 2.0-0.84 mm aggregate size group and 45 and 90 kPa compactive efforts of <0.84 mm aggregate size groups of

Table 4. Average saturated hydraulic conductivity for different aggregate size groups of the two studied soils

Aggregate size group (mm)	Compaction effort (kPa)	Soils TC	TF
4.0-2.0	0	18.98	14.72
	45	1.68	0.82
	90	0.75	0.42
\2.0-0.84	0	11.23	9.02
	45	0.68	0.64
	90	0.23	0.40
<0.84	0	4.27	3.64
	45	0.35	0.75
	90	0.10	0.25

TF soil. Similar results also have been reported by Twomlow (1994). The results indicate that pore structure of soils (wet) was affected by aggregate size (Park and Smucker, 2005) and compactive efforts. TF soil with well developed structure and high aggregate stability has greater strength to resist compression than TC soil.

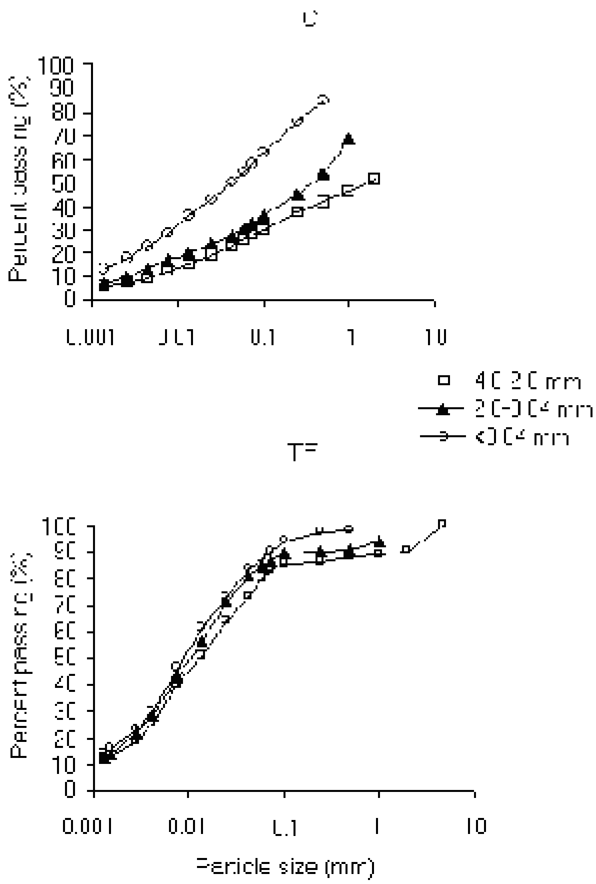

Fig. 1. Particle size distribution curves of three aggregate size groups for coarse textured (TC) soil and fine textured (TF) soil.

Conclusions: The aggregate size is the dominant factor in compressive behaviour of soil. The MBD values decreased and the OWC content increased with decreasing of aggregate size. The compressibility of aggregate sizes was dependent on the structural condition of the soil, especially on their initial dry bulk density and water contents. The dry bulk density values of the TC soil were significantly higher than those of the TF soil. The dry bulk density values decreased with decreasing of aggregate size. The saturated hydraulic conductivity under saturated soil condition of the TC soil was significantly higher than that of the TF soil due to sand content in TC soil. The present study confirmed that the compressive behaviour of aggregate size on soil compactibility with wide variation in soil dry bulk is mainly affected by soil texture and water content.

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