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Some Mechanical Properties and Workability of Soils in a Karadeniz Agricultural Research Institute Field

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Abstract: In this study, some physical and mechanical properties of Karadeniz Agricultural Research Institute soils such as field capacity (FC), bulk density (BD), relative saturation (RS), penetration resistance (PNR), Atterberg limits, consistency index (Ic), and suitable moisture contents for soil workability were investigated. Soil samples were taken from 0 to 20 cm depth. Soil in the Research Institute field was almost uniform according to clay content which ranged between 72.30 and 79.40%. Mean values for BD, FC and PNR of soils were determined as 1.06 g cm^{-3}, 40.36% and 0.72 MPa, respectively. Atterberg limits of clay textural soils ranged between 71.98 and 92.14% for liquid limit (LL), between 36.33 and 43.73% for plastic limit (PL), and between 32.68 and 48.41% for plasticity index (PI). Soils in the field are classified as highly plastic and inorganic silts of high compressibility. LL values of soils significantly correlated with PL (0.618*), PI (0.903**), FC (0.860**), and RS (0.665*). Ic values were significantly, negatively correlated with LL (-0.609*), PI (-0.758**) and FC (-0.759**). PNR values of soils showed significant negative correlations with BD (-0.639*), FC (-0.601*) and RS (-0.707**). Moisture contents for soil workability were 33.2, 39.32 and 49.50%, reference to Ic values of 1.15, 1.0 and 0.75, respectively. It was concluded that the soil in the Karadeniz Agricultural Research Institute field can be cultivated without structural deformation at field capacity (40.4%). Suggested upper and lower moisture limits for suitable cultivation of these soils were 40.4% and 33.2%, respectively.

Key words: Atterberg limits, consistency index, soil workability, penetration resistance.

INTRODUCTION

Management of soil mechanical properties is useful to people interested in soil workability. The ability to predict the timing of optimum soil workability depends on knowledge of the extent and structure of variability in main physical characteristics of the soil (Kværnø, 2007). Besides, the number of days available for field work is frequently central, either directly or indirectly, to farm planning decisions. The distribution and number of working days influences the type and acreage of crops grown, and the corresponding labor and machinery requirements (Earl, 1997). Two distinct but similar concepts of soil workability and trafficability have been used to describe weather conditions are suitable for a wheeled machine such as a tractor to work in a field (Cooper et al., 1997).

Workability limits are normally expressed in terms of the soil moisture status. Soil is considered workable when conditions are suitable for achieving the desired effect without structural damage such as smearing or compaction (Hoogmoed et al., 2003). Dexter and Bird (2001) defined "optimum soil water content for workability" as "the water content at which tillage produced the greatest proportion of small aggregates". While working in too dry or too wet conditions, farmers apply several passes of implements to reduce the size of aggregates in order to achieve an adequate. Thus, working under optimum soil moisture conditions also minimizes the number of passes (Hoogmoed et al., 2003).

Basic soil mechanical properties which are liquid limit, plastic limit and plasticity indexes known as Atterberg limits define soil consistency as related with soil moisture content (Terzaghi et al., 1996). Atterberg limits are used by engineers as guidelines for the range of moisture content. The liquid limit is the water content at which the soil changes from liquid to plastic. The plastic limit is the water content at which the remolded soil passes from a plastic to a friable or brittle condition. The plasticity index is the difference between the liquid limit and the plastic limit. This index indicates the range of moisture content over which a soil is plastic (Terzaghi et al., 1996; Mapfumo and Chanasyk, 1998). The plastic limit is generally regarded as the most suitable moisture content for soil cultivation and seedbed preparation (Kirchhof, 2002). Bushan and Ghildyal (1972) found that more small aggregates produced when tillage was done at 70% of PL than either 60 or 99% of PL.

Earl (1997) reported that the most influential factor in determining the suitability of land for field operations is the soil moisture status. When soils are worked when in an unsuitable condition, damage to the soil's structure and the consequent effect on crop production can persist for many years. The objective of this work was to determine some physical and mechanical properties of Karadeniz Agricultural Research Institute soils and suitable moisture contents for soil workability.

Material and Methods

Soil samples were taken 20 cm depth of 12 different points in the field of Karadeniz Agricultural Research Institute, Samsun-Turkey. Some chemical and physical characteristics of the soil samples were determined as follows; particle size distribution by hydrometer method (Day, 1965), soil reaction, pH, in the 1:1 (w:v) soil water suspension by pH meter, electrical conductivity (EC_{25^oC}) in the same soil suspension by EC meter, organic matter content by Walkley-Black method (Kacar, 1994). Moisture contents in field capacity (FC) were determined after the soil samples saturated and waited in the pressured plate set at 0.033 MPa. Relative saturation (RS) values were calculated by the following equation;

$$RS = \theta / F \quad (1)$$

Where, θ is volumetric water content of soil at field condition, F is the total porosity. Volumetric water content and porosity were estimated from the following equations; θ = gravimetric water content (g H_2O g^{-1} soil at the sampling time) x soil bulk density (g cm^{-3}) and F = [1 – (soil bulk density (g cm^{-3})/2.65 (soil particle density, g cm^{-3}))], respectively.

Soil penetrations were measured at 0.20 m depth by using a hand held penetrometer with 16.60 mm in diameter and 30° in angle cone. Liquid limit (LL), plastic limit (PL) and plasticity index (PI) values of the soil samples were determined according to Black (1965). Index of consistency (Ic) at FC or any given soil moisture (W) was estimated using the following equation (Baumgartl, 2002);

$$Ic = (LL - W) / PI \quad (2)$$

Activity of clays (A) was calculated by the following equation (Baumgartl, 2002);

$$A = PI / (\% \text{ clay content}) \quad (3)$$

Correlations between the limit values and the other soil properties estimated using the SPSS software package program.

Some soil properties are given in Table 1. Soils in the Research Institute field were almost uniform according to clay content which ranged between 72.30 and 79.40% with a mean of 76.36%. The results can be summarized as follows; the textural class of soils is clay, low in organic matter, none saline according to EC value (Soil Survey Staff., 1993).

Table 1. Some properties of the soil samples.

	Minimum	Maximum	Mean	Std. Deviation
Clay, %	72.27	79.40	76.36	2.54
Silt, %	13.67	22.70	17.02	3.06
Sand, %	4.52	11.78	6.62	2.00
OM, %	1.44	1.84	1.62	0.12
EC, dS m^{-1}	0.43	1.15	0.71	0.18
pH (1:1)	6.49	7.86	7.14	0.45

Results and Discussion

Descriptive statistical results for some physical and mechanical soil properties and correlation matrix among them are given in Table 2 and 3. Bulk density values varied between 0.90 and 1.22 g cm^{-3}. It has been reported that an ideal soil bulk density to root growth is less than 1.10 g cm^{-3} for clay soils (Soil Qual. Staff, 1999). Mean soil BD of the soil samples was 1.08 g cm^{-3} which is too close to the limit value. It represents that soils in the field of Karadeniz Agricultural Research Institute have a potential risk for compaction if they are cultivated under unsuitable moisture conditions. Penetration resistance values at 0.20 m soil depth were between 0.36 and 1.32 MPa with a mean of 0.71 MPa. PNR values gave a significant negative correlations with BD (-0.639*), FC (-0.601*) and RS (-0.707**). Zhang et al. (2001) reported a significant increase in soil penetration resistance with little increase in bulk density. However in this study, ecreasing bulk density caused lower PNR values. It could be explained that increasing bulk density of clay soil had higher RS values at similar gravimetric water contents, and also there is significant positive correlation (0.795**) between BD and RS. Soils in higher bulk densities became too wet when compared with soils in lower bulk density. Mapfumo and Chanasyk (1998) also reported that penetration resistance was positively related to bulk density and negatively related to moisture content for the clay loam soil. It is known that a dry soil typically resists compaction because of its stiff matrix and high degree of particle-to-particle bonding, interlocking, and fractional resistance to deformation (Hillel, 2004). In this study, increasing soil moisture content in FC and RS caused decreases in PNR values. The higher correlation between PNR and RS values indicates that relative saturation is more important than BD for penetration resistance.

Atterberg limits of the soils varied between 71.98 and 92.14% for LL, between 36.33 and 43.73% for PL, and between 32.68 and 48.41% for PI. LL values of soils significantly correlated with PL (0.618*), PI (0.903**), FC (0.860**), and RS (0.665*). Ic values were significantly, negatively correlated with LL (-0.609*), PI (-0.758**) and FC (-0.759**). Similar relations among the limits and soil properties were also reported in different studies (Gulser and Candemir, 2004; 2006; Gulser et al., 2008). Jumikis

Table 2. Some physical and mechanical properties of the soil samples.

	Minimum	Maximum	Mean	Std. Deviation
BD, g cm^{-3}	0.90	1.22	1.08	0.10
PNR (at 20 cm), MPa	0.36	1.32	0.71	0.33
FC, %	36.51	47.77	40.39	3.59
RS, %	58.06	86.26	68.58	9.53
LL, %	71.98	92.14	79.99	5.32
PL, %	36.33	43.73	39.32	2.34
PI, %	32.68	48.41	40.66	4.29
Ic (at FC)	0.87	1.06	0.98	0.06
A	0.44	0.65	0.53	0.05

Table 3. Correlation matrix among the soil physical properties ad the limits.

	PNR	FC	RS	LL	PL	PI	Ic
BD	-0.639*	0.535	0.795**	0.481	0.612*	0.263	-0.192
PNR		-0.601*	-0.707*	-0.409	-0.293	-0.347	0.529
FC			0.843**	0.860**	0.640*	0.718**	-0.759**
RS				0.665*	0.704*	0.441	-0.497
LL					0.618*	0.903**	-0.609*
PL						0.220	0.006
PI							-0.758**

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

(1984) reported a PI<7 indicates that a soil is of low plasticity, 7<PI<17 indicates medium plasticity while PI>17 indicates high plasticity. Soils in the field of Karadeniz Agricultural Research Institute according to these guidelines values and "Plasticity Chart" (Terzaghi, et al., 1996) are classified as highly plastic and inorganic silts of high compressibility, respectively. Activity of clays (A) are classified as: i) A>1.25: active soil with high capacity of swelling and shrinking (smectite, salt influenced clays); ii) 0.75<A<1.25: normal soils (illite); iii) A<0.75: inactive clay with only little swelling-shrinking activity (kaolinite) (Baumgartl, 2002). In this study, A values varied between 0.44 and 0.65 with a mean of 0.53 which was less than 0.75. This indicates that soils in the field have inactive clays with only little swelling-shrinking activity.

Index of consistency value defines consistency condition of a soil at any given soil moisture content. If Ic value is becoming 1.0, soil is in plastic formation (PL at Ic=1.0), if this value is becoming 0, soil is in liquid formation (LL at Ic=0) (Baumgartl, 2002). In this study, Ic values were determined using the soil moisture contents at FC. Baumgartl (2002) reported that optimal range of water contents for agricultural use is present when the soil is stiff and has a compression strength of >100 kPa and index of consistency between 0.75 and 1.00. If a soil is cultivated when Ic is less than 0.75, soil structural deformation will occur. Gülser and Candemir (2006) found that optimum soil moisture contents near FC for workability of soil series in Ondokuz Mayis University. Ic values at FC in this study ranged between 0.87 and 1.06 with a mean of 0.98. Therefore, it seems that soil cultivation at FC would not have structural deformation in clay soils of the field. However, Mapfumo and Chanasyk (1998) reported that FC for fine textural soils lies in the danger zone for soil workability and cultivation of these soils at or near FC would results in severe compaction. Furthermore, Muller et al. (2003) found that maximum soil water content for optimum tillage of cohesive soils was at a consistency index of 1.15 and 90% of PL. In this study, calculated moisture contents (w) at consistency indexes of 0.75, 1.0 and 1.15 and 90% of PL are given in Table 4 and mean w values in Figure 1. Although, optimal range of water contents for agricultural use suggested by Baumgartl (2002) are between 0.75 and 1.00 of index of consistency, it can be dangerous cultivation of these cohesive soils near Ic=0.75 (49.5%) or over the FC (40.4%). It seems that soil moistures at Ic=1.0 or PL (39.3%), Ic=1.15 (33.2%) and 0.9% of PL (35.4%) are suitable for these soils cultivation. Therefore, the upper moisture limit for suitable cultivation of the soils was suggested as 40.4 % or FC, and the lower moisture limit was 33.2%.

Table 4. Calculated soil moisture levels for suitable workability.

	Minimum	Maximum	Mean	Std. Deviation
W (at Ic=0.75)	47.07	55.83	49.49	2.78
W (at Ic=1.00 or PL)	36.33	43.73	39.32	2.34
W (at Ic=1.15)	29.43	37.26	33.22	2.28
W (at 0.90 PL)	32.70	39.36	35.39	2.10

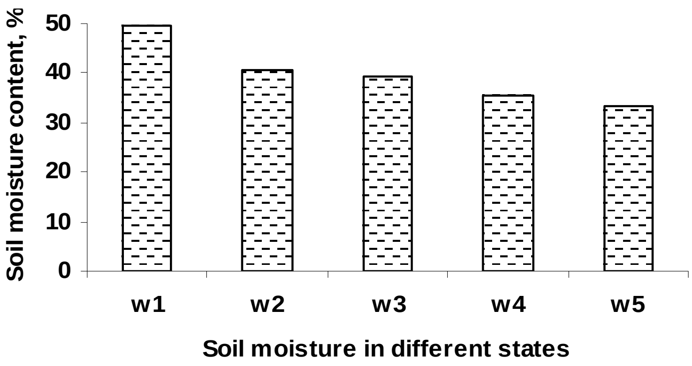

Figure 1. Soil moisture contents for suitable workability (w1 at Ic=0.75; w2 at FC; w3 at Ic=1 or PL; w4 at 0.9PL; w5 at Ic=1.15)

CONCLUSION

It was found that in a same soil textural class, effect of RS on PNR was greater than BD. Soils in the field of Karadeniz Agricultural Research Institute are classified as highly plastic and inorganic silts of high compressibility according to their Atterberg limit values. Soil moisture content between 90% of PL and 1.15 of consistency index can give us an ability to cultivate cohesive soils without structural deformation (Muller et al., 2003). Consistency index value (0.98) at FC was near 1.00. It can be suggested that the upper and lower moisture limits for suitable cultivation of the soils in Karadeniz Agricultural Research Institute were 40.4 and 33.2%, respectively.

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