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Soil Saturated Hydraulic Conductivity: A Study on Path Analysis in Clayey Soils

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ABSTRACT : Saturated hydraulic conductivity (K_s) is an important soil physical property relating water and solute transport. The relationships between some soil physical and chemical properties such as clay content (C), organic carbon content (OCC), field capacity (FC), void ratio (e), and soil saturated hydraulic conductivity (K_s) were studied using path analysis on seventy seven surface soil samples (0-20 cm). The K_s showed positive relationships with OCC and e, and negative relationships with C and FC. The direct effects of some soil properties on K_s were determined as in the following order; C > e > OCC > FC. The indirect effects of the soil properties generally became through C and e. The clay content and void ratio were the most effective soil properties affected saturated hydraulic conductivity (K_s) in soils studied.

Key words: Saturated hydraulic conductivity, void ratio, path analysis.

Doygun Hidrolik İletkenlik: Killi Topraklarda Bir Path Analizi Çalışması

ÖZET : Doygun hidrolik iletkenlik, su ve çözünmüş madde taşınmasıyla ilişkili olarak toprağın önemli bir fiziksel özelliğidir. Bu çalışmada; toprakların kil içeriği (C), organik karbon içeriği (OCC), tarla kapasitesi (FC) ve boşluk oranı (e) gibi bazı fiziksel ve kimyasal toprak özellikleriyle doygun hidrolik iletkenlik (K_s) değerleri arasındaki ilişkiler, killi tekstüre sahip yetmiş yedi adet yüzey toprağında (0-20 cm) path analizi kullanılarak araştırılmıştır. Doygun hidrolik iletkenlik (K_s), OCC ve e ile pozitif; C ve FC ile negatif ilişkiler göstermiştir. Araştırmadaki toprak özelliklerinin K_s üzerine olan doğrudan etkileri büyükten küçüğe doğru; C > e > OCC > FC şeklinde sıralanmıştır. Toprak özellikleri doğrudan etkilerini genellikle C ve e üzerinden göstermiştir. Killi topraklar üzerinde yürütülen bu çalışmada; kil içeriği ve boşluk oranının, doygun hidrolik iletkenliği (K_s) etkileyen en önemli toprak özellikleri olduğu saptanmıştır.

Anahtar kelimeler: Doygun hidrolik iletkenlik, boşluk oranı, path analizi.

INTRODUCTION

Soil hydraulic conductivity is a measure of a soil's ability to transmit water. Soil hydraulic conductivity is influenced by some soil physical and chemical properties and is needed for the study of infiltration, drainage, irrigation, and solute movements. Also it is a key parameter for monitoring of soil and water management. Knowledge of soil's ability to transmit water is essential for determining the type of plants to be grown, plant spacing, yield, managing soil-water systems and erosion controlling. Compacted soils will have less pore volume, resulting in lower hydraulic conductivity in especially clayey soils (Lowery et al., 1996).

Flint and Selker (2003) studied on correlations of hydraulic properties with easily measured physical properties are useful for purposes of site characterization in heterogeneous sites explained the saturated hydraulic conductivity can be estimated by means of developed regression models.

A soil system can be thought as a network of soil characteristic. Path analysis may be used to observe the relations among soil properties. The path diagram gives a picture of network of relations among the characters, as quantitative evaluation is possible from the data (Wright, 1968).

The objective of the present study was to asses the relationships between some soil physical, chemical properties and the saturated hydraulic conductivity using path analysis.

MATERIAL AND METHOD

Site description

The study site is located at the Karadeniz Region, northern part of Turkey (Latitude, 41º21'N; Longitude, 36º15'W) at an elevation of 38 m above sea level. The sampling area has the typical Karadeniz climate. The average monthly temperature varies from 6.6 ºC to 23 ºC; the annual precipitation is 670.4 mm. The annual average temperature was 15.6 ºC and the precipitation was 648.6 mm in the sampling year (Anonymous, 2002). The study area was defined as pasture of Karaköy has relatively homogeneous vegetation.

Soil analysis

Selected soil physical and chemical properties were determined by the following methods: particle size distribution by hydrometer method (Gee and Bauder, 1979), pH and electrical conductivity in 1:2.5 (w/v) in soil:water suspension by pH-meter and EC-meter (Rowell, 1996), lime content by Scheibler calsimeter (Soil Survey Staff, 1993), exchangeable Na by ammonia acetate extraction; cation exchange capacity according to Bower method (Rowell, 1996), the soil organic carbon content was measured by a modified Walkley-Black method (Rowell, 1996), bulk density was determined by the clod method (Blake and Hartge, 1986). Field capacity was measured at 33 kPa on a ceramic plate (Klute, 1986). The saturated hydraulic conductivity based on the application of the Darcy equation of undisturbed field soil cores was determined in the laboratory (Demiralay, 1993). The void ratio (e) is given by $e = (\rho_p - \rho_b) / \rho_b$ where ρ_b is the measured bulk density and ρ_p is the particle density (particle density was used as 2.65 Mg m^{-3}) (Ragab and Cooper, 1990).

The K_s was selected as dependent variable to determine relationships among selected soil properties (C, OCC, FC, and e). Also direct and indirect effects of the variables were determined using path analysis by TARIST computer package program.

RESULTS AND DISCUSSION

Descriptive statistics for some soil physical and chemical properties are given in Table 1.

Soils studied have very fine in texture, light to neutral in pH, very high in organic carbon content, low in lime content, and free sodium problem (Soil Survey Staff, 1993).

The correlation coefficients on selected soil properties and the soil saturated hydraulic conductivity are given in Table 2.

The correlation coefficients between some soil properties and the soil saturated hydraulic conductivity are given with direct and indirect effects of the variables on the soil saturated hydraulic conductivity in Table 3.

Table 1. Descriptive statistics on soil physical and chemical properties.

Soil Properties		Mean	Min.	Max.	S_d	S_e
Particle size distribution, %	Sand (S)	25.7	14.8	45.0	5.59	0.637
	Silt (Si)	27.5	22.2	32.7	1.96	0.223
	Clay (C)	46.9	32.0	55.9	4.69	0.534
Bulk density (ρ_b), Mg m^{-3}		1.57	1.35	1.71	0.07	0.008
pH (1:2,5 soil: water suspension)		7.13	6.07	7.73	0.44	0.050
Electrical conductivity (EC), dS m^{-1}		0.21	0.09	0.46	0.06	0.007
Lime content (LC), %		2.35	0.00	15.94	3.59	0.409
Organic carbon content (OCC), g kg^{-1}		2.70	1.55	4.22	0.50	0.057
Exchangeable sodium (Exc-Na), cmol kg^{-1}		0.26	0.24	0.33	0.02	0.002
Cation exchange capacity (CEC), cmol kg^{-1}		33.6	27.5	41.1	2.61	0.297
Field capacity (FC), g water 100 g^{-1} soil		39.5	26.4	52.0	3.88	0.442
Void ratio (e)		0.69	0.55	0.97	0.07	0.008
Saturated hydraulic conductivity (K_s), cm h^{-1}		0.75	0.25	1.65	0.36	0.040

S_d; standard deviation, S_e; standard error

Table 2. The correlation coefficients on selected soil properties.

	C	OCC	FC	e	K_s
C	-				
OCC	0.03	-			
FC	0.58**	0.15	-		
e	0.23*	0.58**	0.14	-	
K_s	-0.34**	0.25*	-0.30**	0.23*	-

* significant at $p<0.05$ and ** significant at $p<0.01$

Table 3. Path analysis on selected soil properties and saturated hydraulic conductivity.

Dependent variable	Soil properties	r		Direct effect %	Indirect effects %			
					C	*OCC*	*FC*	*e*
K_s	*C*	-0.34	**	63.7	-	0.96	23.83	11.51
	OCC	0.25	*	46.3	2.57	-	8.75	42.38
	FC	-0.30	**	46.0	40.86	5.58	-	7.56
	e	0.23	*	57.0	15.63	21.39	5.98	-

* significant at $p<0.05$ and ** significant at $p<0.01$

According to Table 3, clay content showed significant negative correlation with the soil saturated hydraulic conductivity at $p<0.01$. Direct effects of clay content and void ratio on K_s were found to be higher than that of the other soil properties. Also, the soil properties had higher indirect effects through clay content on the soil hydraulic conductivity. It indicates that clay content and void ratio were the most important soil properties affecting saturated hydraulic conductivity. In the indirect effects of clay content were through the other soil properties on OCC (2.57 %), FC (40.86 %) and e (15.63 %). However, the indirect effect of C through FC (23.83 %) was found to be the most effective soil property on K_s. On the other hand the direct effect of FC on K_s (46.0 %) was the lowest value. Thus, the clay fraction of soil plays important roles on water holding. The surface adsorptive forces of clay minerals greatly affect water retention because of the permanent negative charge of clay mineral particles and the polar nature of water (Petersen et al., 1996). A bed of clay with a conductivity of 10^{-6} cm sec^{-1} would allow the seepage of no more than 1 mm day^{-1}, much less than the expectable rate of evaporation. If the clay dispersed to further reduce its hydraulic conductivity (Hillel, 1982). The OCC gave the significant positive relation with K_s at $p<0.05$ level. Also, the higher indirect effects of OCC on the soil saturated hydraulic conductivity became through void ratio (Table 3). Void ratio increases with increasing organic carbon concentration. Soil organic matter influences water infiltration and adsorption because of its influence on soil structure (Klute, 1986). Increasing soil organic matter increase soil saturated hydraulic conductivity (Kern, 1995). The field capacity gave the significant negative correlation with K_s at $p<0.01$ level. As known that field capacity increases with increasing clay and organic matter content in soil. It is expected that water infiltration also decreases with decreasing organic matter content and increasing clay content (Hillel, 1982). The total porosity of clayey soils is the higher than that of coarse textured soils. But infiltration is higher in coarse textured soils than that of fine textured. For this study, it can be expected that decreasing in K_s increasing the water adsorption so decreasing water percolation because of the high clay content of the soils. The void ratio gave the significant positive correlation with K_s at $p<0.05$ level. Also direct effect of the void ratio on K_s was found to be relatively higher (57.0 %). The behavior of pore volume in soils might be the similar to coarse fractions of soil texture. The pores are important for transmitting (in macropores) and adsorption (in micropores) pathways of water. Therefore increasing the void ratio may increase water infiltration due to the increasing pores. The saturated hydraulic conductivity is expected to relate with macropores in soils. Thus, void ratio gave highly significant correlation with organic carbon content (r=0.58**) as seen Table 2.

In conclusion, soil saturated hydraulic conductivity gave the significant positive correlations with OCC and e at $p<0.01$ and negative correlations with C and FC. Clay content and void ratio showed the higher direct effects on K_s. The indirect effects of the soil properties were generally became through clay and organic carbon content and void ratio. The clay content and void ratio were found to be the most effective soil properties that influenced water infiltration in very fine textured soils.

REFERENCES

Anonymous, 2002. Samsun Climatic Data (1974-2001). State Meteorological Services (DMI), Unpublished, Ankara, Turkey.

Blake, G.R., Hartge, K.H., 1986. Bulk Density. Methods of Soil Analysis, Part 1, Soil Sci. Soc. Am., 363-376, Madison, WI, USA.

Demiralay, İ., 1993. Toprak Fiziksel Analizleri. Atatürk Üniversitesi Ziraat Fakültesi Yayınları No:143, s:96-104, Erzurum.

Flint, L.E., Selker, J.S., 2003. Use of porosity to estimate hydraulic properties of volcanic tuffs. Advances in Water Resources, 26(5):561-571.

Gee, G.W., Bauder, J.W., 1979. Particle size analysis by hydrometer: A simplified method for routine textural analysis and a sensitivity test of measured parameters. Soil Sci. Soc. Am. J., 43:1004-1007.

Hillel, D., 1982. Introduction to Soil Physics. Academic Press Limited, 24-28 Oval Road, London.

Kern, J.S., 1995. Evaluation of soil water retention models based on basic soil physical properties. Soil Sci. Soc. Am. J., 59:1134-1141.

Klute, A., 1986. Water Retention: Laboratory methods. In A. Klute (ed.), Methods of Soil Analysis, Part I, Second edition, Agron. Monogr. p: 635-662, 9 ASA and SSSA, Madison, WI.

Lowery, B., Arshad, M.A., Lal, R., Hickey, W.J., 1996. Soil water parameters and soil quality. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA,Madison, WI.

Petersen, L.W., Moldrup, P., Jacobsen, O.H., Rolston, D.E., 1996. Relations between specific surface area and soil physical and chemical properties. Soil Sci. Vol. 161, No. 1, 9-20, USA.

Ragab, R., Cooper, J.D., 1990. Obtaining Soil Hydraulic Propertis from Field, Laboratory and Predictive Methods. Institue of Hydrology, p: 47, Wallingford, Oxforshire, UK.

Rowell, D.L., 1996. Soil Science: Methods and Applications. 3rd Ed. Longman. London, UK.

Soil Survey Staff, 1993. Soil Survey Manuel. USDA Handbook No:18, Washington, USA.

Wright, S., 1968. Path Analysis: Theory, Evolution and The Genetics of Populations, Volume: 1, 299-324, The University of Chicago Press.