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RESEARCH ARTICLE

Hydraulic Conductivity Values of Soils in Different Soil Processing Conditions

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ABSTRACT

Hydraulic conductivity is an important indicator of water movement and pore structure in soil. Therefore, it is important to determine soil physical and hydraulic properties under different land use conditions. The present study was comducted under three different landuse; dry farming (D), irrigated land (I) and pastureland (P). Three samples were colected from each field (9 samples in total). Infiltration measurements were also tested at each sampling point in each field. The results of this study showed that although hydraulic conductivity was not significantly differentt under dry and irrigated agricultural lands, significant differences were observed between the pastureland and the tilled areas. Soil water infiltration was positively correlated with soil organic matter, aggregate stability and hydraulic conductivity, whereas infiltration was negatively correlated with bulk density. The lowest infiltration rate was found under pastureland compare to those are the highest under the irrigated lands. Therefore, increasing the organic matter content of the local soils will make significant contributions to sustainable soil management.

Introduction

The water use efficiency is increasingly important due to changes in the frequency and intensification of regional droughts under climate change scenarios. To develop climate change friendly management practices, effective management of irrigation water makes soil physical and hydraulic properties crucial especially those, soil hydraulic conductivity, texture, clay type, aggregate stability, and hence pore size distribution (Öztekin et al., 2007). Karahan and Erşahin (2016) documented the significance of soil texture, pore size distribution and total porosity are important to estimate the hydraulic state of the soil. Gülser et al. (2007) specifically mentioned that saturated hydraulic conductivity found to be most effective on water management strategies besides other soil physical properties.

Soil hydraulic conductivity can be defined as the ability of the water or a solution to pass through the soil pores at the particular time scale. Hydraulic conductivity is related to physical properties such as soil particle size distribution, shapes of the soil particles, effective porosity, and thus aggregation (Rosas et al., 2014). Moreover, hydraulic conductivity changes depend on the properties of the porous medium, and density and viscosity of the liquid (water or water solution) (Schwartz and Zhang, 2003; Ishaku et al., 2011). Besides on field experiments, laboratory studies also reported the soil hydraulic state as a soil health indicator (Boadu, 2000).

In addition to soil and environmental conditions, different management practices also make soil physical and hydraulic state crucial due to their direct effect on determining water usage and indirect impacts through modifying other soil properties. Osunbitan et al. (2005) reported significant differences in saturated hydraulic conductivity, soil volume weight and water retention as influenced by different soil tillage practices. Öztekin and Erşahin (2006), investigated the

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spatial variation of saturated hydraulic conductivity in soils under different tillage conditions and reported that saturated hydraulic conductivity in the tilled areas showed 2.5 times more variability than no-till areas. They stated that the reason of saturated hydraulic conductivity in the tilled areas is very large due to the compaction of the soil as a result of field traffic.

Materials and Methods

Study Sites and Soil Sampling

The study fields were located at Bigadiç district of Balıkesir province. The district of Bigadiç is located on Balıkesir-İzmir intercity road (38 kilometers from the city center) in the South-West Marmara region. The altitude of the field is 180 meters and the surface area is 1007 km² (Anonymous 2019a).

The sampling area is in the transition zone from the marine climate to the continental climate. The study field has continental climate characteristics. Summers are warm in the region; winters are dryer and rainfall is moderate. It has Mediterranean climate in terms of precipitation and continental climate in terms of temperature (Anonymous, 2019a). According to the eighty-year average data measured by Balıkesir Meteorological Station, the average temperature is 14.6 °C and the average annual rainfall is 583.2 mm. The highest precipitation falls in December (95.2 mm) (Anonymous, 2019b).

Soil samples were taken from 3 different points under irrigable cultivated agricultural areas, non-irrigated dry areas, and pastures (9 samples in total). Deteriorated soil samples were taken from each point at 3 replications at a depth of 0-20 cm and carried to the laboratory.

Study Analysis

Infiltration values of the soils were measured by infiltrometer (Hussen, 1999) in 2 replications at 9 points established in the field in dry, irrigated and pasture areas.

Soil texture (Gee and Bauder, 1986), pH measurements (McLean, 1982), $CaCO_3$ (Nelson, 1982), organic matter (Nelson and Sommers, 1982), aggregate stability (Kemper and Rosenau, 1986), hydraulic conductivity (Demiralay, 1993), bulk density (Tüzüner, 1990), particle density (Blake and Hartge, 1986), porosity (Danielson and Sutherland, 1986) and inflation rate determination (Hussen, 1991) were determined on soil samples.

Statistical Analysis

Data were analyzed by ANOVA, and Duncan's multiple range test to comparison of means under different land use with a significant value of $α<0.1$ (SPSS 1999). A principle component analysis was applied by using $α<0.05$ and SAS JMP software.

Results and Discussion

Data showed that D2 and D3 points in dry farming area and P1 sampling point in pasture area were classified as sandy clay loam texture, while the remaining samples were in sandy loam texture class. Texture plays a key role owing to its impacts on bulk density, hydraulic conductivity, aggregate stability, porosity and cation exchange capacity (Aksakal, 2004; Barik, 2011). In addition, the roughening of the soil texture helps soil to provide a better growing environment, decreases the resistance to tillage, and hence improve soil structure (Özdemir et al., 2018).

Table 1. Analysis findings obtained from soil samples

Samples Number		D1	D2	D3	I1	I2	I3	P1	P2	P3
Texture	Clay (%)	14.09	27.60	25.70	13.71	11.84	13.45	21.58	11.19	11.25
	Silt (%)	12.45	25.88	21.50	21.61	20.63	15.26	18.20	23.34	19.39
	Sand (%)	73.46	46.52	52.80	64.68	67.53	71.18	60.22	65.67	69.36
Bulk density, g (cm³)⁻¹		1.20	1.23	1.21	1.17	1.18	1.14	1.08	1.01	1.16
Particule density, g (cm³)⁻¹		2.53	2.54	2.53	2.50	2.48	2.54	2.54	2.44	2.61
Porosity (%)		52.65	51.49	52.17	53.22	52.43	55.12	57.49	58.61	55.56
Organic matter (%)		2.15	2.01	2.09	2.01	1.93	1.79	1.99	4.22	2.88
Aggregate stability (%)		46.03	32.13	32.17	21.62	16.86	17.22	61.42	88.28	75.85
Lime (%)		1.09	1.09	1.31	1.28	1.40	1.46	2.80	2.58	3.47
Hydraulic conduct, cm h⁻¹		6.04	4.63	5.09	5.25	4.55	4.75	7.35	8.98	9.56
pH (1:2.5 soil:water)		5.79	5.80	5.79	5.85	5.39	5.72	6.98	6.87	6.91

Table 2. Changes between land samples taken and land use status (p<0.05)

Usage	Organic matter (%)	Aggregate stability (%)	Bulk density g (cm³)⁻¹	Particle density g (cm³)⁻¹	Porosity (%)	Hydraulic conductivity cm h⁻¹	pH (1:2.5)	Lime (%)
Dry	2.08b	36.78b	1.21a	2.53	52.12b	5.25b	5.65b	1.16b
Irrigation	1.91b	18.57c	1.16a	2.53	53.52b	4.85b	5.79b	1.38b
Pastureland	3.03a	75.18a	1.08b	2.51	57.23a	8.63a	6.92a	2.95a

Organic matter content of these soils varies between 1.79% and 4.22%. The SOM content was slightly above 2% under the dry agricultural management (Table 1) which can be classified as moderate. In all irrigated fields, SOM content was lower

than 2% and classified as low. This can be because of the high mineralization which is can be attributed to the intensive cultivation of anchor plants in aqueous conditions (Tümsavaş, 2003). Soils under pasture were found to have moderate and rich SOM contents. According to multi-comparison analysis of SOM content, there were not any significant differences under dry agriculture in comparison to those under irrigated fields, while SOM content under pasture was significantly different ($p < 0.05$). It can be stated that SOM and nitrogen contents decreases with increases in frequency and intensification of tillage applications and enhanced effect of mineralization (Balesdent et al., 2000). SOM content was around and below 2% in all agricultural areas. Similarly, SOM under agriculture were classified as poor (Ülgen and Yurtsever, 1974). Overall SOM contents of this study area can be classified low (Tümsavaş, 2003).

Even though soil bulk density was not significantly different under dry agriculture in comparison to those under irrigated management, pasture significantly increased soil bulk density ($p < 0.05$). Soil bulk density is a variable showed that no-till areas had lower bulk density due to better development of the structure. This might be due to differences in pore size distribution and SOM contents. In dry and irrigated agricultural

fields, intensive tillage management significantly decreased the soil porosity. This finding was also reported by Barik et al. (2014) in a study.

There were not observed significant differences in total porosity under dry agricultural compare to those under irrigated management whereas bulk density under pasture was significant different ($p < 0.05$) than all other managements. Soil particle density was not significantly different under any land use. Therefore, soil bulk density might be one of the few factors affecting porosity in these fields but not particle density.

Soils of these fields have strong acid and neutral pH conditions. Soil pH must be considered for fertilization. Agricultural practices that cause soil pH to drop should be avoided (Sezen, 2002). Considering the lime content of soils, lime application may be recommended to increase the pH since lime contents were also found to be low to provide sufficient nutrient availability for sustainable plant production under dry, irrigated, and pasture lands. Soil lime content ranged from 1.09% under dry management to 3.47% under pastureland. Therefore, lime fertilization to increase the lime content of these soils is recommended especially for those under irrigated conditions.

Table 3. Infiltration rates measured in soil samples (cm h^{-1})

Time (min)	D1	D2	D3	D avrg	I1	I2	I3	I avrg	P1	P2	P3	P avrg
1	39.00	34.00	36.00	36.33	35.80	30.00	24.00	29.93	33.00	35.50	34.00	34.17
4	24.00	23.25	20.55	22.60	16.30	14.75	13.75	14.93	20.47	21.22	21.97	21.22
9	15.00	18.00	10.97	14.66	11.80	8.33	8.33	9.49	14.30	14.64	13.05	14.00
14	8.57	9.21	5.87	7.89	6.44	5.57	4.93	5.65	9.54	9.11	6.86	8.51
19	5.37	5.84	3.62	4.94	4.69	3.32	3.32	3.78	6.97	6.97	5.35	6.43
24	4.13	4.38	2.80	3.77	3.55	2.75	2.00	2.77	5.85	5.72	4.22	5.26
29	3.41	3.41	2.16	3.00	2.70	2.28	1.97	2.31	4.69	4.59	3.69	4.32
34	2.47	2.65	1.62	2.25	2.36	1.85	1.41	1.87	4.32	4.23	3.31	3.96
39	2.92	2.38	1.53	2.28	1.95	1.46	1.15	1.52	3.82	3.59	3.10	3.50
44	2.39	1.91	1.25	1.85	1.64	1.36	0.95	1.32	3.42	3.36	2.88	3.22
49	1.96	1.71	1.16	1.61	1.39	1.16	0.86	1.14	3.17	3.11	2.76	3.02
54	1.78	1.61	1.13	1.51	1.30	1.06	0.78	1.04	2.97	2.97	2.61	2.85
59	1.63	1.42	0.91	1.32	1.17	0.92	0.76	0.95	2.85	2.75	2.58	2.73
64	1.50	1.08	0.91	1.16	0.97	0.75	0.75	0.82	2.70	2.61	2.47	2.60
69	1.39	1.00	0.87	1.09	0.97	0.78	0.57	0.77	2.49	2.45	2.24	2.39
74	1.22	1.01	0.83	1.02	0.85	0.73	0.65	0.74	2.51	2.43	2.21	2.38
79	1.29	0.87	0.79	0.99	0.75	0.65	0.53	0.64	2.34	2.34	2.37	2.35
84	1.11	0.86	0.73	0.90	0.73	0.57	0.46	0.59	2.26	2.36	2.33	2.32
89	1.08	0.74	0.70	0.84	0.61	0.54	0.44	0.53	2.22	2.25	2.23	2.23
94	1.02	0.70	0.68	0.80	0.63	0.51	0.41	0.52	2.15	2.21	2.23	2.20
99	0.94	0.64	0.69	0.76	0.56	0.48	0.33	0.46	2.09	2.21	2.17	2.16
104	0.89	0.63	0.68	0.73	0.52	0.46	0.35	0.44	2.04	2.15	2.18	2.12

The lowest water stable aggregate value (16.86%) was determined under irrigated management (I2) in comparison those under pastureland (P2: 88.28%) (Table 1). Water stable aggregates were significantly influenced by land use (Table 2). The highest aggregate stability was measured under pasture. SOM in these fields can explain differences in aggregate stability (Canbolat and Demiralay, 1995). Barik (2011) stated that organic materials mixed into the soil significantly improve soil properties such as soil aggregate stability ($p < 0.05$). Soil, if not processed in the structure of the naturally occurring secondary structures will not dissipate to ensure maintained stability (Six et al., 2002). Aggregate stability under dry and irrigated agricultural fields with tillage applied, was higher

than those under irrigated-no-till agricultural land. This can be interpreted as the aggregate stability is weakened due to increased mineralization and the intensive tillage applications under irrigated agricultural lands (Aksakal, 2004). In addition, wetting and drying with low intensification of tillage applications may improve stability compared to aqueous conditions. There was no significant difference in soil aggregate stability between the dry and irrigated fields whereas those under pasture areas showed significant difference (Table 2).

Hydraulic conductivity is a measure of soil conductivity and depends on soil and water properties. Soil hydraulic conductivity is particularly affected by soil properties such as

texture, structure, volume weight, SOM and bulk density (Lake, 2002).

According to tabulated detail values of soil water infiltration on Table 3, the highest readings for soil water infiltration was observed under pastureland (P2) and the lowest under irrigated management (I3). Soil water uptake rates differed depending on the land use, whereas infiltration gradually decreased after the first 20 minutes. Infiltration measurements in the pasture area were measured higher than those used for tillage (Figure 1). It can be said that tillage has an adverse effect on infiltration. The high infiltration rate in unprocessed soils is due to the continuous and macro-pore networks of these soils (Erşahin, 2001).
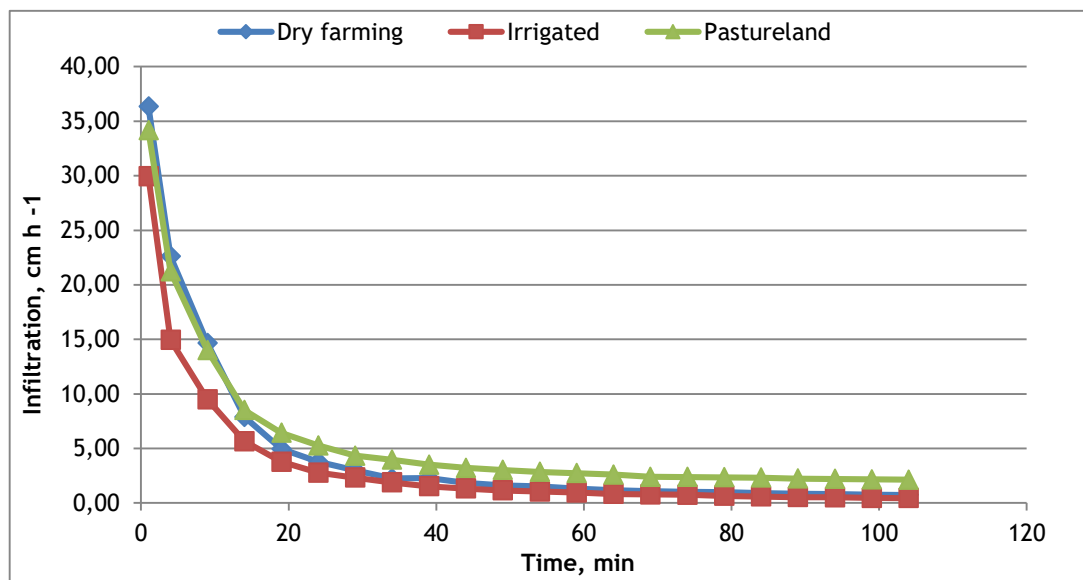

Figure 1. Infiltration curves of soils according to different land use conditions

The contribution of these surface-associated macropores to the infiltration rate is determined by their hydraulic properties, origins, shapes and bendability (Edwards, 1982). The decrease in soil infiltration over time is a result of changes in soil properties. The average infiltration values measured in the pastureland were higher than the readings in dry and irrigated areas where embroidered agriculture was carried out over time. This can be explained by the fact that the permeability of soils in pasture areas as dispersions is lower than that of embroidered areas (Erşahin, 2001).
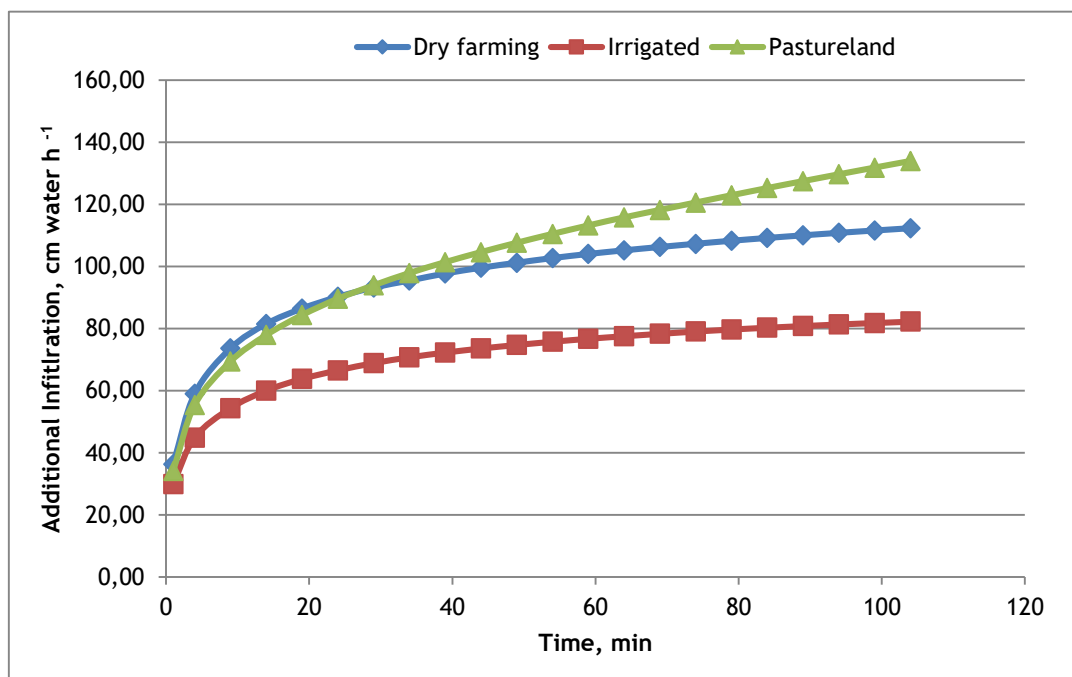

Figure 2. Additive infiltration graphs according to the use of soils

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Table 4. Additive infiltration values measured in soil samples (cm water h $^{-1}$)

Time (minute)	Dry farming Average	Irrigation Average	Pastureland Average
1	36.33	29.93	34.17
4	58.93	44.87	55.39
9	73.59	54.36	69.38
14	81.47	60.00	77.89
19	86.42	63.78	84.32
24	90.18	66.55	89.58
29	93.18	68.86	93.91
34	95.43	70.73	97.86
39	97.71	72.26	101.36
44	99.56	73.58	104.58
49	101.17	74.71	107.60
54	102.67	75.76	110.45
59	103.99	76.71	113.18
64	105.16	77.53	115.77
69	106.24	78.31	118.17
74	107.26	79.05	120.55
79	108.25	79.69	122.89
84	109.15	80.28	125.21
89	109.99	80.81	127.44
94	110.79	81.33	129.64
99	111.55	81.79	131.80
104	112.28	82.23	133.92

Infiltration is influenced by soil organic matter content, aggregate stability, pore, and thus bulk density, and texture and hydraulic conductivity. In the correlation test, significant positive relationships were determined between infiltration and aggregate stability (r=0.937), hydraulic conductivity (r=0.818) and organic matter (r=0.787), whereas a negative correlation was found for infiltration and bulk density (r=-0.428). When the total amount of water passing from the soil samples was evaluated, the highest water passed through pasture soils with 133.92 cm water and the lowest under irrigated agriculture (82.23 cm). This situation reveals the negative impact of embroidered agriculture (Edwards, 1982). Traffic on land, animal grazing, plant roots, soil management, soil processing and so on. As a result of the activities surface soil compacts, volume weight increases, infiltration decreases (Dao, 1993). This sequence of events is also in seasonal change in a cultivated soil.

According to Table 5, calculated infiltration rates, the highest infiltration rate (21.59) was calculated for the irrigated areas and the lowest infiltration rate (6.60) was calculated for the pasture lands. The low infiltration rate is a measure of the degree of degradation of soils over time. Accordingly, in the pasture infiltration measurements, soils were exposed to less distribution than dry and irrigated lands and as a result, they provided higher incremental infiltration value. In general, the main indicators of infiltration rate are soil properties (Arshad and Martin, 2002). The effect of organic matter on physical properties in soils rich in organic matter also increased the infiltration rate (Hawkes, 1984). The hydraulic conductivity of the soils was found highest in the pasture lands. This is an indication that pasture soils have higher water transmission capabilities than embroidered agricultural areas. In this case, it is not correct to claim that there is no problem in pasture areas. Pasture areas usually consist of sloping lands may adversely affect the movement of water in the soil in these areas. For this reason, pastureland grazing in a plan will help to keep it covered. While the coarse structure of the soils initially leads to high infiltration, the decrease in the rate of infiltration over time may be due to the soil's easy dispersion depending on the organic matter content and the clogging of the pores rapidly. In this case, since the development of soil organic matter in the tilled areas will affect the stability positively, it will also decrease the tendency to erosion by reducing surface flow (Erşahin, 2001).

Table 5. Permeation rates determined in soil samples

Usage	Permeation Rate	Average
D1	16.77	
D2	28.36	20.46
D3	16.25	
I1	22.64	
I2	18.06	21.59
I3	24.07	
P1	7.02	
P2	6.80	6.60
P3	5.98	

Results from the principle component analysis showed that all three landuse were statistically different when we consider the total effect of all soil properties ude in the present study. Soil bulk density and clay content was key determinance for K,

whereas, lime content, SOM, and porosty showed to be key factors for M.

Conclusion

Soils of the present study were identified as rough texture. There was a high variability in soil pH. Irrigated lands provide strong acidic conditions, while non-irrigated dry lands showed moderate acidity, and pasture areas neutral conditions. Soils of these fields were classified as lime-free. Calcification in dry and irrigated areas both for raising the pH and for insufficient lime addition in soils will affect production and soil properties positively. According to the infiltration curves of the soils, it is inevitable that the surface flow will occur as a result of the rapid fall of the infiltration in the tilled areas and as a result of this, negative impacts due to soil erosion may increase. Usage areas where this situation is felt the least are pasture areas. This is directly related to SOM content and the high stability of soil aggregate. Therefore, increasing SOM content in the soils of tilled agriculture will significantly reduce the tendency of soils to erosion. Therefore, increasing the organic matter content of the local soils will make significant contributions to sustainable soil management.

Acknowledgements

References

Agyare, W.A., Vlek, P.L.G., Dikau, R., Andreini, M., and Fosu, M., 2005. Soil Characterization and Modeling using Pedo-Transfer Functions and Artificial Neural Networks. Status Conference, Cologne, Germany, May 17-19.

Aksakal, E.L., 2004. Soil Compaction and Its Importance for Agriculture, J. of Agricultural Faculty of Atatürk Univ., 35(3-4): 247-252.

Anonoymus, 2019a. http://www.bigadic.gov.tr/geographic situation

Anonoymus, 2019b. https://www.mgm.gov.tr /data evaluation /province and districts statistics .aspx?m=BALIKESIR

Arshad, M., and Martin, S., 2002. Identifying Critical Limits for Soil Quality Indicators. Agriculture, Ecosystems & Environment, 88(2): 153-160.

Balesdent, J., Chenu, C. and Balabane, M., 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil & Tillage Research. 53(3-4): 215-230.

Barik, K., 2011. Effects of Barnyard Manure and Beet Pulp Addition on Some Soil Properties. J. of Agricultural Faculty of Atatürk Univ., 42(2): 133-138.

Barik, K., Aksakal E., Islam K.R., Sari S., and Angin I., 2014. Spatial variability in soil compaction properties associated with field traffic operations, Catena 120: 122-133.

Blake, G.R., and Hartge, K.H., 1986. Particle Density in Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods (Ed. A, Klute). American Society of Agronomy, Madison, Wisconsin, USA.

Boadu, F.K., 2000. Hydraulic conductivity of soils from grain-size distribution: new models. J. Geotech. Geoenviron. Eng., 126(8): 739-746.

Canbolat, M., and Demiralay, İ., 1995. The relationship among aggregate stability, bulk density of briquet, modulus of rupture of organic material added soils. Soil Science Society of Turkey. Soil and Environment Symposium. Vol. 2 pp: A-116 A-124, Ankara.

Danielson, R.E., and Sutherland, P.L., 1986. Porosity. Methods of soil analysis. Part 1. Physical and mineralogical methods, 443-461.

Dao, T.H., 1993. Tillage and Winter Wheat Residue Management Effects on Water Infiltration and Storage. Soil. Sci. Soc. Am. J. 57: 1586-1595.

Demiralay, İ., 1993. Soil Physical Analysis Methods. Ataturk Univ. Agricultural Faculty Publications. Erzurum, 111-120.

Edwards, W.M., 1982. Predicting tillage effects on infiltration. ASA, CSSA, SSSA Books. ASA Special Publications 44: 105-115.

Erşahin, S., 2001. Toprak Amenajmanı. GOÜ Ziraat Fakültesi Ders Notları Serisi No: 21: 44-57.

Gee, G.W., and Bauder, J.W., 1986. Particle-Size Analysis. Methods of Soil Analysis.Part 1. Physical and Mineralogical Methods. 2nd Edition. Agronomy No: 9. 383-411.

Gülser, C., Candemir, F., İç, S., and Demir, Z., 2007. Pedotransfer Modellerle İnce Bünyeli Topraklarda Doygun Hidrolik İletkenliğin Tahmini. V. Ulusal Hidroloji Kongresi, Bildiriler Kitabı, 5-7 Eylül, ODTÜ Ankara, p. 563-569.

Hawkes, G.E., Powlson, D.S., Randall, E.W., and Tate, K.R., 1984. Nuclear Magnetic Resonance Study of the Phosphorus Species in Alkali Extracts of Soils from Long-term Field Experiments. J. *Soil Sci*, 35: 35–45.

Hussen, A.A., 1991. Measurement of Unsaturated Hydraulic Conductivity in the Field, Ph.D. dissertation,150 pp., Univ.of Ariz., Tucson.

Hussen, A.A., and Warrick, A.W., 1993. AlgebrASc Models for Disc Tension Permeameters, Water Resour.Res, 29: 2779-2786.

Ishaku, J.M., Gadzama, E.W. and Kaigama, U., 2011. Evaluation of empirical formulae for the determination of hydraulic conductivity based on grain-size analysis. Journal of Geology and Mining Research, 3(4): 105-113.

Karahan, G., and Erşahin, S., 2016. Predicting saturated hydraulic conductivity using soil morphological properties. Eurasian J Soil Sci., 5(1): 30 – 38.

Kemper, W.D., and Rosenau, R.C., 1986. Aggregate Stability and Size Distribution. Methods of Soil Analysis.Part 1. Physical and Mineralogical Methods. 2nd Edition. Agronomy No: 9: 425-442.

McLean, E.O., 1982. Soil Hand Lime Requirement. Methods of Soil Analysis Part 2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2. Edition P: 199- 224.

Nelson, D.W., and Sommers, L. E., 1982. Organic Matter. Methods of Soil Analysis Part 2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2. Edition P: 574- 579.

Nelson, R.E., 1982. Carbonate and Gypsum. Methods of Soil Analysis Part 2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2. Edition P: 191- 197.

Osunbıtan, J.A., Oyedele D. J., and Adekolu K. O., 2005. Tillage Effects on Bulk Density, Hydraulic Conductivity and Strength of a Loamy Sand Soil in Soutwestern Nigerya. Soil 8 Tillage Research, 82:57-64.

Özdemir, N., Öztürk, E., and Durmuş, K.Ö.T., 2018. Organik Düzenleyici Uygulamalarının Yapay Yağış Koşullarında Toprakların Bazı Fiziksel Özellikleri ve Toprak Kaybı Arasındaki İlişkiler Üzerine Etkileri. Turk J Agric Res. 5(3): 191-200.

Öztekin, T., and Erşahin, S., 2006. Saturated hydraulic conductivity variation in cultivated and virgin soils. Turk J. Agric. For. 30: 1-10.

Öztekin, T., Cemek, B., and Brown, L.C., 2007. Pedotransfer Functions for the Hydraulic Properties of Layered Soils GOÜ. Ziraat Fakültesi Dergisi. 24(2): 77-86.

Rosas, J., Lopez, O., Missimer, T.M., Coulibaly, K.M., Dehwah, A.H.A., Sesler, K., Lujan, L.R., and Mantilla, D., 2014. Determination of hydraulic conductivity from grain-size distribution for different depositional environments. Groundwater, 52(3): 399–413.

Sezen, Y., 2002. Toprak Verimliliği. Atatürk üniversitesi Yayınları No: 922. Ziraat fakültesi Yayınları No: 339. Ders Kitapları Serisi 86, Erzurum.

Schwartz, F.W., and Zhang, H., 2003. Fundamentals of Groundwater. John Wiley & Sons, Inc., p. 583.

Six, J., Conant, R.T., Paul, E.A., and Paustian, K., 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils J. Plant and Soil 241: 155-176.

SPSS, 1999. SPSS for Windows, Release 10.0.5., SPSS Inc., USA.

Tümsavaş, Z., 2003. Bursa İli Vertisol Büyük Toprak Grubu Topraklarının Verimlilik Durumlarının Toprak Analizleriyle Belirlemnesi. Uludağ Üniversitesi Ziraat Fakültesi Dergisi 17(2): 9-21.

Tüzüner, A., 1990. Toprak Ve Su Analiz Laboratuvarları El Kitabı. Tarım Orman ve Köy İşleri Bakanlığı, Köy Hizmetleri Genel Müdürlüğü, Ankara.

Ülgen, N., ve Yurtsever, N., 1974. Türkiye gübreler ve gübreleme rehberi. Toprak ve Gübre Araştırma Enstitüsü Müdürlüğü, Teknik Yayınlar No:28. Ankara.