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ASSESSMENT OF CHANGES IN SOIL HYDRO-PHYSICAL PROPERTIES RESULTING FROM INFILTRATION OF MUDDY WATER

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ABSTRACT

Infiltration is one of the process which greatly influences the partitioning of irrigation water (especially rainfall) into surface runoff and subsurface flow and continues to occupy the attention of soil physicists and engineers. Most infiltration studies assume clear water entering into uniform soil profiles, and have limited application to poorly structured soils due to slaking of aggregates and dispersion of clay. A laboratory column study was conducted to investigate the impacts of different suspended soil particles at different concentrations in infiltrating water on some soil properties. Substantial changes in the soil properties investigated were observed following the infiltration tests. These modifications were due to surface deposition and clogging of pores by the suspended soil sediments. It was also revealed that, at higher sediment concentrations, the levels of changes were high. Additionally, finer sediments were found to be highly effective in altering soil properties, even at low concentrations.

1. INTRODUCTION

According to Hillel [1], infiltration can be considered as the process by which water from the surface moves into the ground. Under normal conditions, gravity and capillarity drive vertical infiltration, whereas capillarity alone drives horizontal infiltration [2]. Most recent reports [e.g. 3 – 7] have shown that the ability to quantify infiltration is of great importance in soil management, especially, in irrigation and drainage designs. For example, prediction of flooding, erosion, and pollutant transport depends on the rate of runoff which is directly affected by the rate of infiltration.

Quantification of infiltration is also necessary to determine the availability of water for crop growth and to estimate the amount of additional water needed for irrigation. Similarly, by understanding how infiltration rate is affected by surface conditions, measures can be taken to increase it and reduce the erosion and flooding caused by overland flow.

In agricultural fields, irrigated soils are frequently exposed to sequential periods of rapid wetting followed by drying. Soils that are subjected to these events, in due course, tend to have low aggregate stability [8, 9]. As a result, when water is applied to these soils, there is slaking of aggregates and/or dispersion of individual clay particles into suspensions.

For instance, the impacting force of raindrops causes breakdown and dispersion of soil aggregates. However, during the process of wetting, slaking may predominate over dispersion resulting from the mechanical effect of raindrop impact [10, 11]. This is clearly evidenced by the greater proportion of slaked fragments (20 to 60 μm) over clay particles (< 2 μm) [12]. In the event, smaller suspended sediment particles

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are filtered out at the surface as the water infiltrates and kept in place by the negative water phase pressure below the soil surface [13]. This may cause the soil to slump, lose porosity and become denser, resulting in surface sealing and hard-setting, which can greatly overshadow other factors affecting infiltration on bare soil surfaces. Therefore, the objective of the study was to investigate how suspended soil particles in infiltrating water interact with and modify soil properties.

2. MATERIALS AND METHODS

2.1. Soil sampling and laboratory analyses

Nta series or Gleyic Arenosol [14] obtained from the Department of Horticulture, KNUST was used for the study. The soils are poorly drained with coarse sand texture. They also have slow internal drainage, slow runoff, rapid permeability and low water holding capacity [15]. Collection of soil samples was done as described by Tuffour and Abubakari [16].

The hydrometer method [17] was used in the determination of the particle size. Soil water content was determined on volume basis before and after the laboratory infiltration tests by the gravimetric method [16, 18]. Bulk density and porosity were determined as described in Tuffour and Abubakari [16]. The saturated hydraulic conductivity (K_s) measurements were made on the cores in the laboratory using the modified falling head permeameter method similar to that described by Bonsu and Laryea [19].

The different soil particles were obtained by dry sieving through a series of graduated sieves with different mesh sizes [16]. The laboratory test was carried out with a series of ponded infiltration experiments with clear and muddy water [16].

3. RESULTS AND DISCUSSIONS

The measurement data obtained from the experiment are presented in Tables 1 and 2 below. The results revealed both significant and insignificant differences among treatment combinations for the various soil properties investigated. The results of initial analysis of soil physical and hydraulic properties of the study area are presented in Table. 1.

The results showed that the texture of the field surface (0 - 20 cm) was predominantly loamy sand, with sand, silt and clay fractions of 84%, 4.30% and 11.70%, respectively. The average bulk density was 1.34 g/cm^3 with total porosity of 49.43% .

The average antecedent and saturated moisture contents were 23.58% and 47.70%, respectively. Average saturated hydraulic conductivity was 0.0025 mm/s.

Table 1 Summary of initial soil physical and hydraulic properties

Soil property	Value
Saturated hydraulic conductivity (mm/s)	2.50E-03
Bulk density (g/cm^3)	1.34
Total porosity (%)	49.43
Volumetric moisture content (%)	23.58
Saturated moisture content (%)	47.70
Moisture deficit (%)	24.12
Sand (%)	84.00
Silt (%)	4.30
Clay (%)	11.70
Texture	Loamy sand

Table. 2 presents the summary of the results of the measured physical and hydraulic properties after the infiltration experiment. Comparison of Tables. 1 and 2 indicated substantial changes in the soil properties after the infiltration experiment.

Repeated measures one-way ANOVA and Tukey's multiple comparisons test also showed significant differences among the means of the measured parameters under the different treatments.

Therefore, the observed changes could not have arisen by chance. Generally, there were no detectable changes in the fraction percentage of the original soil after the infiltration experiments. Hence, the texture of the soil remained as loamy sand.

Table 2 Summary of soil physical and hydraulic properties after infiltration

Soil property	Fluid												
	Clear water	Clay suspension†				Silt suspension†				Fine sand suspension†			
		10	20	30	40	10	20	30	40	10	20	30	40
K_s (mm/s)	2.5E-3	1.0E-4	5.0E-5	3.3E-5	2.5E-5	2.0E-3	1.0E-3	6.7E-4	5.0E-4	5.0E-3	2.5E-3	1.7E-3	1.3E-3
ρ_b (g/cm^3)	1.34	1.37	1.45	1.53	1.55	1.37	1.43	1.48	1.52	1.36	1.41	1.45	1.47
f (%)	49.43	48.30	45.28	42.26	41.51	48.30	46.04	44.15	42.64	48.67	46.79	45.28	44.53
θ_v (%)	23.58	21.01	19.28	17.28	16.65	21.74	20.44	19.21	18.04	22.53	21.38	19.61	18.97
θ_s (%)	47.70	43.50	42.60	40.90	40.10	45.00	44.40	43.50	42.30	46.30	45.70	43.30	42.60

†*Mass of sediment particles in suspension;* θ_v *(%) = Volumetric water content at field capacity;* ρ_b *(g/cm*^{3}*) = Bulk density;* f *(%) = Total porosity;* θ_s *(%) = Saturated water content;* K_s *(mm/s) = Saturated hydraulic conductivity*

As expected, differences were observed in the soil properties after the infiltration tests, however, no change could be observed in terms of suspensions with 10 g sediment particles, clear water and the initial values of soil properties, except for the K_s of the surface from clay sediment. Final conductivity of the seal ranged from 96% to 99% and 20% to 98% less that of the layer below the surface arising from the clay and silt sediments, respectively. However, for the sand sediments, final seal conductivity increased by 100% that of the sub-seal soil. Yet, upon increasing the concentration of sand sediments the conductivity dropped by 48%. The lower saturated hydraulic conductivity of the clay and silt seals were primarily a result of the thinner seal thickness rather than lower seal resistance. Another point to be emphasized is that the bulk density, 1.34 g/cm^3, was the same after infiltration with clear water since the soil was a well aggregated stable soil which did not show any clear sign of sediment settlement during the flow process. However, from the results significant increase in bulk density and reduction in total porosity, moisture content, and saturated hydraulic conductivity were observed after infiltration of the muddy water. The reduction in porosity of the soil column was dependent on the particle diameter and concentration of the suspension. In comparing the results obtained for the different sediment materials, it was realised that deposition of clay resulted in the maximum reduction in porosity and permeability, followed by silt and sand, respectively. This result led to the conclusion that fine grains at higher concentrations provide more likelihood of clogging than coarse grains. The reduction in porosity operated mainly at top layer of the soil column, leading to the drastic permeability reduction and thus clogging. Thus, the decrease was mainly observed at the entrance of the column due to development of a surface seal (or surface depositional layer) resulting from settling of particles in pores and on the soil surface. These changes were responsible for the loss of nearly all drainable macropores in the soil, which was evidenced by the considerable reduction in cumulative infiltration amounts and rates [7]. The increase in bulk density resulted from the occurrence of pore clogging (i.e. compaction) during the formation of the surface seal [20]. The ensuing reduction in hydraulic conductivity was also the reason for the substantial reduction in infiltration, and moisture content after infiltration. These changes suggest that formation of surface seals can result in considerable damage of soil structure in agricultural fields. Under field conditions, erosion may set in [21] with a concomitant decrease in water use efficiency and opportunity to store rainfall and irrigation for crop growth. However, it is worthy to note that seal formation is not always accompanied by decrease of total porosity, hydraulic conductivity and soil water content [22] as evidenced by the surface deposition of 10 and 20 g fine sand.

4. CONCLUSIONS

In this study, the soil physical changes affecting infiltration were noticeable at the soil surface in the form of a thin surface seal. These structural changes to the soils as they got wetted under no, minimum or maximum sediment-deposition conditions had great effect on the saturated hydraulic conductivity, total porosity, bulk density and moisture content, such that, their effects were difficult to isolate. Thus, this work has revealed the significant features of the contributions of different soil sediments on surface sealing/crusting. The study has also provided a quantitative measure of how surface seals modify soil physical and hydraulic properties.

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6. REFERENCES

[1] Hillel, D. 1998. Environmental Soil Physics. Academic Press. San Diego, CA.

[2] Philip, J.R. 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. Soil Science, 84: 257-264.

[3] Khalid, A.A., Tuffour, H.O. and Bonsu, M. 2014. Influence of Poultry Manure and NPK Fertilizer on Hydraulic Properties of a Sandy Soil in Ghana. International Journal of Scientific Research in Agricultural Sciences, 1(2): 16-22.

[4] Parhi, P.K. 2014. Another look at Kostiakov, modified Kostiakov and revised modified Kostiakov infiltration models in water resources applications. International Journal of Agricultural Sciences, 4(3): 138-142.

[5] Tuffour, H.O., Bonsu, M. and Khalid, A.A. 2014a. Assessment of soil degradation due to compaction resulting from cattle grazing using infiltration parameters. International Journal of Scientific Research in Environmental Sciences, 2(4): 139-149.

[6] Tuffour, H.O., Bonsu, M., Khalid, A.A. and Adjei-Gyapong, T. 2014b. Scaling approaches to evaluating spatial variability of saturated hydraulic conductivity and cumulative infiltration of an Acrisol. International Journal of Scientific Research in Knowledge, 2(5): 224-232.

[7] Tuffour, H.O. and Bonsu, M. 2015. Application of Green and Ampt Equation to infiltration with soil particle phase. International Journal of Scientific Research in Agricultural Sciences. (In Press).

[8] Caron, J., Kay, B.D. and Stone, J.A. 1992. Improvement of structural stability of a clay loam with drying. Soil Science Society of America Journal, 56: 1583-90.

[9] Rasiah, V., Kay, B.D. and Martin, T. 1992. Variation of structural stability with water content: Influence of selected soil properties. Soil Science Society of America Journal, 56: 1604-1609.

[10] Le Bissonnais, Y., Renaux, B. and Delouche, H. 1995, Interactions between soil properties and moisture content in crust formation, runoff and interrill erosion from tilled loess soils. Catena, 25(1-4): 33-46.

[11] Le Bissonnais, Y., Benkhadra, H., Chaplot, V., Fox, D., King, D. and Daroussin, J., 1998. Crusting, runoff and sheet erosion on silty loamy soils at various scales and upscaling from m^2 to small catchments. Soil Tillage Research, 46(1-2): 69-80.

[12] Young, I.M. and Mullins, C.E. 1991. Water-suspendible solids and structural stability. Soil Tillage Research, 19: 89-94.

[13] Brown, M.J., Kemper, W.D., Trout, T.J. and Humpherys, A.S. 1988. Sediment, erosion and water intake in furrows. Irrigation Science, 9: 45-55.

[14] FAO-UNESCO 1988. Soil map of the world, 1:5,000,000. Revised Legend. 4th draft.

[15] Adu, S.V. 1992. Soils of the Kumasi Region, Ashanti Region, Ghana. Soil Research Institute, CSIR, Ghana. Memoir 8: pp. 81-85.

[16] Tuffour, H.O. and Abubakari, A. 2015. Effects of water quality on infiltration rate and surface ponding/runoff. Applied Research Journal. (In Press).

[17] American Society for Testing Materials 1985. Standard test method for particle size analysis of soils. D422-63(1972). 1985 Annual Book of ASTM Standards. American Society for Testing and Materials, Philadelphia, 04.08: pp. 117-127.

[18] Gardner, W. 1986. Water Content pp. 493-544. *In*: A. Klute (ed.) Methods of Soil Analysis. Part 1, 2nd ed. Soil Science Society of America, Madison, WI.

[19] Bonsu, M. and Laryea, K.B. 1989. Scaling the saturated hydraulic conductivity of an Alfisol. Journal of Soil Science, 40: 731-742.

[20] Moss, A.J. 1991. Rain-impact soil crust. I. Formation on a Granite-derived soil. Australian Journal of Soil Research, 29: 271-289.

[21] Zejun, T., Tingwu, L., Qingwen, Z. and Jun, Z. 2002. The sealing process and crust formation at soil surface under the impacts of raindrops and polyacrylamide. Paper presented to 12th ISCO Conference, Beijing.

[22] Castilho, S.C.D., Cooper, M. and Juhasz, C.E.P. 2011. Influence of crust formation under natural rain on physical attributes of soils with different textures. Revista brasileira de ciencia do solo, 5(6): 1893-1905.