THE INFLUENCE OF SOME SOIL PROPERTIES ON SATURATED HYDRAULIC CONDUCTIVITY OF SOILS IN MAIDUGURI, NIGERIA

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ABSTRACT

A study was carried out to determine the influence of some soil properties on saturated hydraulic conductivity of Maiduguri soils. Soil properties measured includes soil particle density, organic matter, texture, sodium adsorption ratio and exchangeable sodium percentage. A total of 10 soil samples were analysed and used for measuring saturated hydraulic conductivity. Varied bulk densities of 1.01-1.49gcm^{-3} at six different compaction levels were used. Ksat decreases with increase in bulk density at different compaction levels for all sample studied. The texture of the soil is sandy loam and low levels of organic matter (0.1-0.35%) were obtained. The values of SAR and ESP are in the range of 0.05-0.14 and 0.1-0.85%. Based on the previous studies on soil properties in region, the level of exchangeable sodium indicates low Na exchange to affect permeability, which is good for crop production.

KEYWORDS: Saturated hydraulic conductivity, sandy loam soil, sodium adsorption ratio, bulk density, exchangeable sodium percentage.

1. INTRODUCTION

The term Saturated hydraulic conductivity K_{sat} and coefficient of permeability are often used interchangeably. They are defined as the rate of flow of a fluid per unit cross section of the medium normal to the direction of flow of fluid per unit hydraulic gradient. The physical dimension of K is length per unit time (LT^{-1}). Hydraulic conductivity is a function of properties of both the fluid and the medium such as swelling of soil and its attendant reduced porosity. This functional relationship is not known explicitly and because of the large number of properties involved it can be very complex (Abdullahi, 2002).

The knowledge of K_{sat} is of great importance in many engineering undertakings, such as geotechnics, groundwater resources and drainage projects. It is therefore desirable to have simple, accurate, reliable reproducible and relatively in-expensive method of estimating it. The conventional laboratory methods using core samples have too many unquantifiable assumptions to make them reliable and reproducible to fulfill the desired requirement of "simplicity". Quantifying the assumptions underlying the laboratory methods is necessary in order to make them reliable and reproducible and at the same time avoid rigour and tedium of the field methods. Several methods for measuring K_{sat} in the laboratory were described by ASTM (1954) and for measurement in the field by Talsma (1960). Falling head and constant head test are common laboratory methods. However, constant head permeameter test is more suitable for very permeable soils with $K = 10^{2} - 10^{-3}$ cm sec^{-1} and falling head permeameter test for fewer permeable ones from $K = 10^{-3} - 10^{-5}$ cm sec^{-1} (Bowles, 1979). He also suggest that soils having $K_{sat} = 10^{-3} - 10^{-9}$, field test is generally not practical. According to Reeve (1953) clean clay-free sand with uniform size and shape can be sampled and re-composed with little risk of having its K_{sat} changed. Care should be taken to maintain same porosity when packed in the permeameter as it had in nature. If there is appreciable variation of grain structure, it is extremely difficult that the natural arrangement of particles be produced in the laboratory. Furthermore, Abdullahi (2002) observed that, clay present additional uncertainties particularly if the material is dried before re-packing in the permeameter.

K_{sat} measurements of remoulded soils have been used as an indication of field percolation test rates (Fireman, 1944). This method is especially applicable in dealing with soils of arid region where soil structure is of lesser importance and where water, chemical compositions and concentrations are used. In making the laboratory measurement, provision should be made to support the sample and passage of the test fluid through the sample and determining the loss of hydraulic head in a given flow length. According to Strudley et al., (2008) two of the most commonly measured soil physical properties affecting hydraulic conductivity and other hydraulic properties are the soil bulk density and effective porosity, as these two properties are also fundamental to soil compaction and related agricultural management issues. In-situ saturated hydraulic conductivity is considered one of the most important parameters for water flow and chemical transport phenomena in soils (Reynolds and Elrick, 2002). Allmaras et el., (1977) determined that soil hydraulic conductivity was greater in chisel-plowed plots than untilled soil due to greater soil aggregation resulting from the chiseling practice. However, Chan and Mead (1989) noticed that untilled soil exhibited greater hydraulic conductivities than tilled soils and attributed the difference to decreased soil bulk density and mproved iporosity where there was no tillage.

In general, the hydraulic conductivity of light to heavy soils may range from 10^{-2}-10^{-7}cm/sec. (Ghildyal and Tripathi 2005). Several factors affect movement of water through soils and cause difficulty in making permeability determination. Abdullahi, (2002) reported that K_{sat} depends strongly on the arrangement of pore, and it does not remain constant due to various physical, chemical and biological processes. For example, on tilled soil K_{sat} varies from time to time in response to tillage and consequent setting of particles. In general, K_{sat} decreases with decreasing concentration of electrolytic solutes, high bulk density of the sub-soil due to swelling and dispersion phenomena affected by cations present.

Saturated hydraulic conductivity is affected by entrapped air bubbles which may block the pore passages. When the soil is allowed to saturate with water, it is not possible to replace all the air by water and some of the air is trapped in the pores. This trapping of air bubbles obstructs the flow of water. A number of physical, chemical and biological processes occurring in the soil may also change the hydraulic conductivity of soil, for example the nature and amount of exchangeable cations may greatly affect the hydraulic conductivity of soil, as may happen in salt-affected soils. It is well known that sodic soils with high exchangeable sodium have poor hydraulic conductivity, also when a normal soil is irrigated with saline water, a change in the exchangeable ion status of the soil, accompanied by changes in hydraulic conductivity, takes place.

According to Bowles (1979), any well-performed field test gives a more reliable value of K_{sat} than a laboratory test, except on remoulded or disturbed soil used for completed fills. Some of the limitations in the laboratory are:

i. Soil *in situ* is generally stratified, and it is hard to duplicate in situ conditions in the laboratory test. The horizontal value K_h is usually needed, but tube samples are likely to be tested for vertical values, K_v.
ii. No method is available to evaluate K for other than saturated steady state soil conditions, yet many flow problems will involve partially saturated soil-water flow.
iii. When K is very small (10^{-5} – 10^{-9}) cmsec^{-1} the time necessary to perform the test will cause evaporation and equipment leak's to become very significance factors.
iv. The small size of laboratory samples leads to effects of boundary conditions, such as the smooth sides of the test chamber affecting flow and air bubbles either in the water or trapped in the test sample space affecting the test results.

In this paper, the saturated hydraulic conductivity for disturbed sandy loam soil of Maiduguri was measured with varied bulk densities. Physical and chemical properties of soil influencing K_{sat} were also determined.

2. MATERIALS AND METHODS

2.1 Experimental Site

Soil samples used in this study were collected from University of Maiduguri along the North-South transect quadrant. Maiduguri, in Borno State is located at latitude $11^0 51'$ N and Longitude, $13^0 05'$ E and lies 354m a.m.s.l. The state occupies the greater part of the Chad basin formation in Nigeria. The mean annual rainfall of 604 mm was recorded in the past two decades annual precipitation arrange between 450 mm – 600 mm in the extreme North and the Southern part of the state. Mean monthly temperatures are 19.9^0C and 35.8^0C respectively. The soil of the study area is sandy loam, classified as Typic uptisament based on USDA classification system (Rayar, 1984, and Olu and Folorunso, 1990).

2.2 Sample Treatment

Ten soil samples were collected from the field in April 1999. Ten pits 300m apart were dug 0.5m x 0.5m, a total of ten samples at 0-30 cm depth was taken to Agricultural Engineering Laboratory, University of Maiduguri. Samples are air-dried and passed through 2-mm sieve size to obtain fine earth fraction suitable for K_{sat} determination and physico-chemical analysis.

2.3 Saturated Hydraulic Conductivity

Falling head permeability method was used as suggested by Bowles (1979). A cylindrical permeameter 10-cm internal diameter and 11.6 cm height was used to compact the samples at varied bulk densities (γ_d) of 1.01-1.49 (gcm^{-3}). The soil is compacted with 2.5kg standard proctor hammer using 0, 5,10,15,20 and 25 levels of compaction. The moisture content of 12% and 2.5 kg standard proctor hammer were chosen. This is according to the consistency limits of sandy loam determined by Olu and Folorunso (1989), and Delvin and Mery (1989). The weight of the sample for each test is obtained from the known volume of the mould and the varied bulk density.

Each sample in the permeameter was soaked in water basin, whose level is just below the top of the sample. The bottoms of the permeameters were covered with a muslin using rubber band to prevent spillage. The samples in this condition were left for 36 hours to facilitate saturation. The coefficient of permeability is computed on the basis of the observed rate at which the water level decreases in the tube. An expression given by Lambe and Robert (1969) in the form:

$$K_{sat} = \frac{2.303aL}{A\Delta T}\log_{10}\frac{h_1}{h_2}$$

Where: K_{sat} = hydraulic Conductivity, (cm sec^{-1}); a = cross-sectional area of the stand pipe, (cm^2); L = length of soil in the permeameter, (cm); A = cross-sectional area of the permeameter, (cm^2); h_1, h_2 = total head losses through the sample at lapse time ΔT, (cm); ΔT = time increment when water level in the stand pipe is at h_1 and h_2 (sec.).

2.4 Soil Texture, Organic Matter Content and Exchangeable Cations

The soil particle distribution was carried out by hydrometer method while percentage organic matter of the soil was determined from organic carbon by titration using wet oxidation, Juo(1979). The exchangeable cations were determined using Ammonium saturation method. These methods were described by Walkley and Black (1934) given by Juo(1979).Calcium and magnesium was extracted using Atomic Adsorption spectrophotometry AAS. While sodium and potassium were determined using flame photometer (Smith, 1983).

The real particle density of soil was obtained based on Archimedes principles using pyknometer. Other parameters like soil particle density, viscosity of fluid (water), fluid density etc; were obtained from standard mathematical tables (Hillel, 1971).

3 RESULTS AND DISCUSSION

3.1 Saturated Hydraulic Conductivity

Table 1 shows the result of laboratory measured saturated hydraulic conductivity. The results show that hydraulic conductivity is affected by variation in bulk density at different compaction levels. Ksat decreases with increase in bulk density at different compaction level for all sample studied. The result is in agreement with a research conducted by Miyazaki, (1996) and Felton, (1995). Felton (1995) studied the variation of hydraulic properties on municipal soil waste and found the adverse effect of reduced Ksat was due to high bulk density of the samples. Some of the change in the pattern of the K_{sat} values may be attributed to the soil arrangement in the cylindrical permeameter which may be affected by boundary condition (smooth surface of the permeameter) causing flow of air bubbles either in the water or trapped in the soil sample. This is clearly manifested in sample 1, 5 and 10 at bulk density of 1.32.

Table 1. Measured saturated hydraulic conductivity, K_{m}x10^{-5} (cm sec^{-1}) of Soils in Maiduguri *

Compaction levels	Bulk density (γ_d) gcm^{-3}	Sample 1	2	3	4	5	6	7	8	9	10
0	1.01	1.697	2.270	5.695	4.715	7.657	3.232	3.529	2.935	3.705	6.196
5	1.13	1.359	1.305	4.598	3.771	6.230	2.932	2.218	2.930	3.629	5.474
10	1.21	1.218	1.285	4.336	2.377	4.946	2.331	1.981	2.274	3.247	4.615
15	1.32	0.896	0.983	3.713	2.410	4.480	1.911	1.917	1.983	2.844	3.434
20	1.40	0.778	0.968	3.361	1.554	3.030	1.275	1.545	1.652	2.113	3.136
25	1.49	0.663	0.519	2.286	1.045	2.847	1.413	1.327	1.349	1.625	3.040

*Mean of 3 measurements

3.2 Soil Physical and Chemical Properties

3.2.1 *Texture*

The detailed result of soil properties from the test site is shown in Table 2. The texture of the soil samples determined was sandy loam. It was found in the following range: sand 62-81%, silt 4-21% and clay 16-19% respectively. This is consistent with the result obtained by Ohu and Folorunso (1990), they determine some physical and chemical properties of major wheat growing soil of Borno State.

3.2.2 *Organic Matter*

A proportion of 0.1-0.35% OM in Table 2 was obtained in the study area; the organic matter levels are related largely to the parent materials, nature of vegetation and topography. Farmers and their advisers are interested in soil OM due to its effect on soil tilth, nutrient and water retention for plant growth (Franzmeir et al 1985). They also observed that the lower level of OM in the semi-arid soils may be attributed to bush burning and pesticides application in which organic carbon are easily affected.

Table 2. Physical and Chemical Properties of Soils in Maiduguri

Standard Diagnostic, Characteristics	Sample									
	1	2	3	4	5	6	7	8	9	10
Particle Density, pd (gem-3)	2.671	2.416	2.625	2.571	2.697	2.360	2.611	2.800	2.248	2.932
Relative Density	2.692	2.435	2.646	2.591	2.718	2.378	2.631	2.822	2.500	2.955
Organic Carbon %	0.14	0.16	0.04	0.06	0.08	0.15	0.13	0.07	0.20	0.17
Organic Matter, OM (%)	0.24	0.28	0.07	0.10	0.12	0.26	0.22	0.12	0.35	0.29
Sand content (%)	62.64	66.64	62.62	68.64	69.36	70.70	76.00	80.60	77.0	64.64
Silt content (%)	21.28	17.28	21.28	13.28	14.56	10.90	5.0	15.56	4.00	18.28
Clay content (%)	16.08	16.08	16.08	18.08	16.08	18.40	19.00	19.40	19.00	17.08
Textural Class	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
Bulk Density (gem-3)	1.47	1.52	1.59	1.59	1.57	1.50	1.45	1.57	1.40	1.55
ESP (%)	0.302	0.194	3.918	0.121	0.935	1.449	3.465	1.127	0.752	0.85
SAR	0.012	0.007	0.144	0.005	0.047	0.050	0.114	0.035	0.018	0.023

*Mean of 2 measurements

3.2.3 *SAR and ESP*

The values of SAR and ESP are in the range of 0.05-0.14 and 0.1-0.85% Table 2. Pearson and Bernstein 1958, Mustapha (1996) indicates that SAR and ESP have direct effect on plant growth due to their influence on structure, permeability and infiltration. The USDA (1954) has shown that ESP>15 generally affects the structural and hydraulic characteristics of soils. Based on the results in Table 2, there is low sodium hazard on the soil. Zata et al (2007) studied the variability in properties of soils in Maiduguri. They showed that, low level of exchangeable sodium indicates a low level of sodium on the exchange complex which is good for crop production. Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) may also exert a direct affect on plant growth. This is due to the negative effects they have on the structure, permeability and infiltration of soils (Pearson and Bernstein, 1958). By reducing infiltration, surface seal will increase run off, thereby affecting the K_{sat} of the soil. Texture and organic matter content influence surface seal formation. It is also affected by tillage practices, cropping history, method of cultivation and, rainfall intensity and duration. (Allison, 1956; Mannering, 1967; Ahmad and Robin, 1971).

According to U. S. salinity Laboratory staff (1954) ESP > 15 generally affects the structural and hydraulic characteristics of soils. Some investigators such as Shainberg etal.(1981) have suggested that this threshold may need reconsideration because degradation of soil can take place even at lower ESP values in dilute solutions. Sumner (1993) explain that establishment of critical ESP threshold may be very arbitrary because the properties of exhibited by the so-called classic sodic soils.

4. CONCLUSION

Saturated hydraulic conductivity of Maiduguri soil (sandy loam) has been determined. The results show that hydraulic conductivity is affected by variation in bulk density at different compaction levels. Ksat decreases with increase in bulk density at different compaction levels for all sample studied. The change in the pattern of the K_{sat} values may be also due to the soil arrangement in the cylindrical permeameter. The texture of the soil is sandy loam and low levels of organic matter (0.1-0.35%) were obtained. The values of SAR and ESP are in the range of 0.05-0.14 and 0.1-0.85%. ESP>15 generally affects the structural and hydraulic characteristics of soils, the level of exchangeable sodium from the study indicates a low sodium proportion on the exchange complex.

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