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DETERMINATION OF PERMEABILITY OF SOILS FROM FUNAAB AGRICULTURAL LAND USE, USING IMPROVISED CONSTANT HEAD PERMEAMETER

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ABSTRACT

The knowledge of material property of the pore space through which water flow in soil for the optimization of water supplies for agricultural and engineering projects is fast becoming challenging due to intricate geometries of the media porous structures. The study determines the permeability coefficients of soils at six different Federal University of Agriculture, Abeokuta, (FUNAAB) land-use (Hostel-Site, Cashew Plantation, FADAMA Farm, COLPLANT Farm, Forest nursery unit, FUNAAB health center) in order to estimate the flow rate through the soil using an improvised constant head permeameter. The soils were initially analyzed for their physical properties before determining the flow rate and permeability coefficients. The reliability of result of permeameter was compared with standards for validity. The result shows that the soils were slightly acidic with pH average of 6.8, organic carbon ranging from 0.78% to 4.49% with the highest at the Fadama site. The total nitrogen ranged between 0.1% and 8.0% and the available phosphorus ranged between 1.20 to 3.95 mg kg⁻¹ with the highest value experienced at cashew plantation. The improvised permeameter gave a reliable result with high positive correlation in volume rate of flow in soil and time of flow. The permeability coefficient of the soil samples (K) were in the range of 2.7×10^{-5} to 4.2×10^{-5} with the soil type ranging from sandy-loam to loamy sand similar to the result obtained during physical analysis. The soils were of relative permeability of semi-pervious, a characteristic of poor soil transmissivity.

Keyword: soil, permeability, pore, velocity, loamy

INTRODUCTION

Soil internal mechanism and comprehensive properties assessment is fast becoming necessary in sustainable crop production, geotechnical and engineering practice, particularly in this era of climate change. More so that there has been failure in soil response to applied force on flow conditions. In agricultural practice, the applied force is related to soil water potential which is dependent

on the size and shape of particles, the influence of stuffing fluid, the speed of motion, the compactness of structures and some other factors. Permeability is therefore considered one of the most important parameters in soil property related to rainfall induced slope failure (Joseph, 2009). Permeability is an indication of the ability of the soil to store water. The more permeable the soil is, the greater the seepage. Pore soil structure can

lead to excessive water loss from the soil surface as a result of reduce water entering (infiltration) into the profile. Hence, since soil moisture is critical to crop production in the tropics as well as other environmental applications such as for rainfall–runoff modelling, irrigation systems, design of the earth dams (Saniet *et al.*, 2011; Das, 2008), then the understanding of permeability is paramount. For instance, while poor soil structure can lead to excessive soil water and consequently causing inadequate soil aeration, flooding, limitation of the amount of oxygen and increase the formation of compounds that are toxic to plant roots, the water deficiency may not only reduce the yield of crop and reservoir, but also change the pattern of growth of crops and reservoir storage (Odjugo, 2010). Furthermore, the variation in moisture within the farming district could influence conditions of soil and natural vegetation. Similarly moisture fluctuation could lead to uncertainty thereby emphasizing the need for the application of appropriate technological devices in particular improved rain-fed management strategies within present farming system to minimize the effect of such fluctuations. The totality of the moisture effect with the responses it generates in terms of crop husbandry and application of technology determines the feasible farm systems vis-à-vis the kind, level and variability of food output. The prominent role of moisture as the basic input to crop production cannot be over-emphasis, hence the need for the determination of permeability of soils in the study area. There are various ways of assessing

permeability of soils, these includes estimation methods, laboratory and field methods. The widely used laboratory methods are costly and time consuming, hence the use of improvised permeameter in the study. Research into soil permeability assessment are enormous, this includes the works of Holtz and Kovacs, 1981; Fredlund *et al.*, 1994 and Gallage *et al.*, 2013 among others. The purpose of this study is to identify which soil permeability from FUNAAB agricultural land use, using improvised constant head permeameter .

MATERIALS AND METHOD

Description of Study Area

The experimental soils were collected and analyzed at the Federal University of Agriculture, Abeokuta. The study area situated along Alabata road, Abeokuta (7° 15'N, 3°25'E) in Odeda Local Government Area of Ogun State, Southwest Nigeria (Fig. 1). The area is characterized by a tropical climate with distinct wet and dry seasons. The area has bimodal rainfall pattern and mean annual air temperature of about 30°C. The rainfall is characterized not only by seasonal variability but also includes year to year variability in the onset, cessation and duration of the rains which are also characterized by dry spells of unpredictable magnitude which may last from a few days to more than three weeks. The soil at the experimental site was categorized as a well-drained tropical ferruginous soil (A horizon of an OxicPaleudulf of Iwo series) with 83% sand, 5% silt and 12% clay and a pH of 6.0 (Olasantan, 2007).

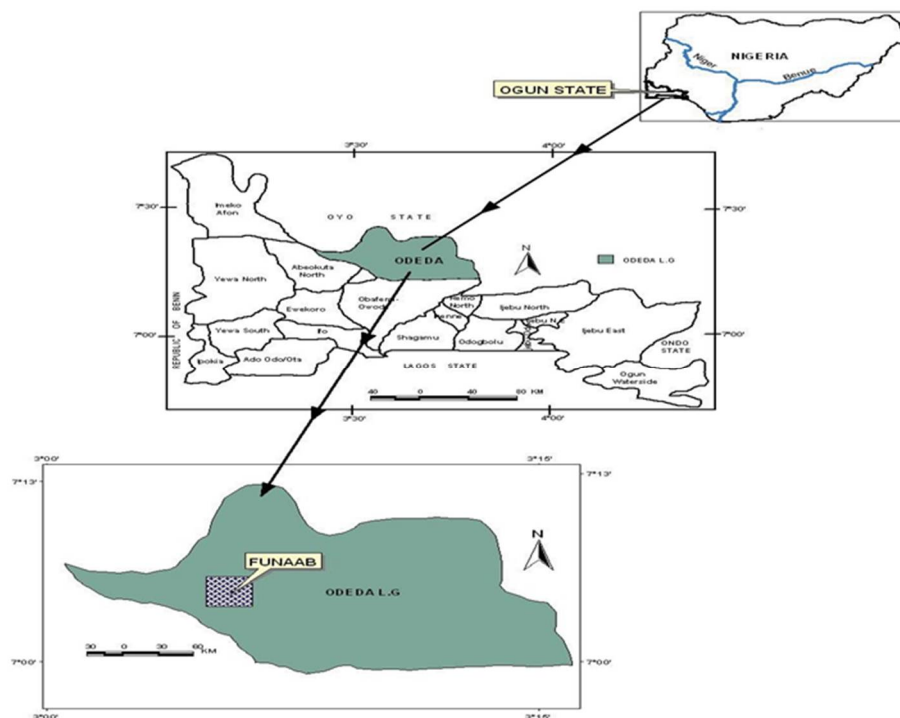


Fig. 1: Location of University of Agriculture, Abeokuta within Odeda Local Government Area in Ogun State, Southwestern Nigeria

Soil Sampling and Analysis

Six soil samples were collected randomly from different locations at 0-30 cm depth in the Federal University of Agriculture, Abeokuta. The locations included cashew plantation, Fadama area, Hostel site, Health-Centre area, Colplant farm and Forest reserve site. The choice of selection of locations of sampling was based on the zonal classification of land use of Federal University of Agriculture, Abeokuta according to Aiboni, (2001). The six soil samples were collected using hoe and auger into a polythene bag. The collected samples were air-dried and analyzed for physical and chemical characteristics of the experimental soil samples from different land-use using standard laboratory analysis procedures as highlighted.

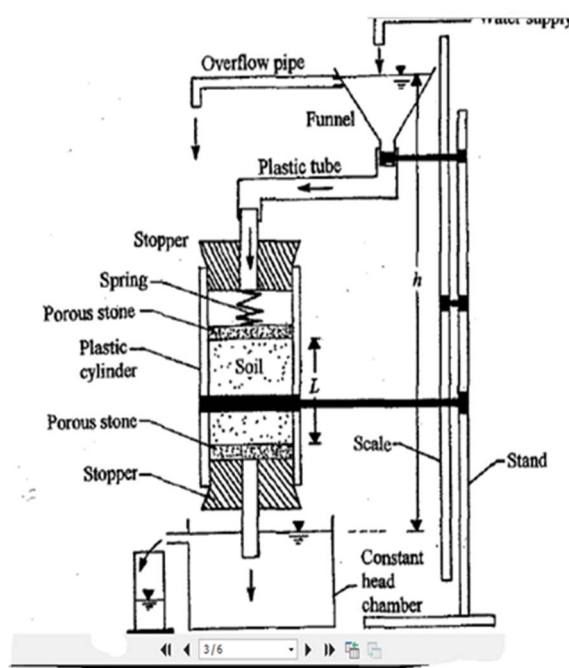
1. Particle size analysis was done by pipette method following (Gee and Bauder, 1986).
2. Soil samples were mixed with distilled water in a 1-2 ratio, stirred on mechanical shaker for 5 minutes and the pH determined using pH meter with a combination electrode.
3. Organic-matter was analyzed using the Walkley Black dichromate oxidation method. The percentage organic matter was calculated by multiplying the values of organic carbon by the conventional Van Bemmeler factor of 1.724 based on the assumption that soil organic matter contains 58 % carbon (Nelson and Sommers, 1982).
4. The exchangeable bases in soil such as

calcium and magnesium were determined by flame Atomic Absorption Spectrophotometer (FAAS) in IM ammonium acetate (pH 7.0) extract while sodium and potassium were determined in IM ammonium acetate (pH 7.0) extract by flame photometry (Okalebo *et al.*, 1993).

5. Exchangeable acidity (H^+) was determined by extracting with 1N KCl and determined by NaOH titration (Sims, 1996).
6. Effective cations exchange capacity (ECEC) was estimated by summing the

exchangeable bases plus exchangeable acidity cations.

7. The soil total nitrogen was determined by Kjeldahl method (Jackson, 1962).
8. Available phosphorus was extracted by 0.03 M NH_4F + 0.025 M HCl (Bray and Kurtz, 1945) and the Phosphorus in the extractant was determined by colorimeter.
9. The permeability of soils was determined using an improvised constant head permeameter as shown in plate arranged in schematic diagram in figure 2 and procedures further highlighted.



**Figure 2: An improvised calibrated permeameter and schematic arrangement
Procedures for permeameter usage**

Procedures for permeameter usage

1. Couple the apparatus with other devices (set-up)
2. Slip the bottom porous stone into the permeameter, and then fix the bottom rubber stopper to the permeameter.
3. Collect air-dried sand in a container, use a spoon, pour the sand into the permeameter in small layers, and compact it by vibration and/or other compacting means.
4. When the length of the soil sample is about two-third the length of the permeameter, slip the top porous stone into the tube to rest firmly on the specimen.
5. Place a spring on the top porous stone.
6. Fix a rubber stopper to the top of the permeameter. Note: The spring in the assembled position will not allow any expansion of the specimen volume, and thus the ratio, during the test.
7. Measure the length (L) of the compacted specimen in the tube.
8. Assemble the permeameter near a sink, as shown in figure above.
9. Run water from the water supply source (drip tube) to the permeameter through a rubber tube from the water inlet. The water will flow through the soil to the constant head chamber. After some time, the water will flow into the graduated cylinder (1000 ml) through the outlet in the constant head chamber. Note: Make sure that water doesn't leak from the permeameter tube
10. Adjust the supply of water to the drip tube so that the water level in the drip tube remains constant. At the same time, allow the flow to continue for about 3 minutes in order to saturate the specimen. Note: Some air bubbles may appear in the permeameter tube connecting the drip to the permeameter.

Remove the air bubbles.

11. After a steady flow is established (that is, once the head difference 'h' is constant, record the value for 'h').
12. Collect the water flowing out of the constant head chamber (V) in a graduated cylinder, ranges from 250 ml to 300 ml (making six trials for each soil sample). Record the collection time (t) for each trial with a stop watch.
13. Repeat step 12 for each sample you are working on, in order to get the time with corresponding volumes.
14. The effective discharge (q) of water through the soils was determined from the slope of the linear graph obtained from the relationship between the quantity of volume of water discharged (Q cm³) and the time (t sec) taken for water to flow through the soil as determined using stop watch and the Coefficient of permeability (K) for a constant head test is given estimated according to Darcy, 1856:

$$K = Q / (iAt) \text{ (Darcy's equation)}$$

Where I is Hydraulic gradient (h/L), h is effective head (cm), L is Length of the soil sample in the permeameter (cm) and A = total cross-sectional area of the permeameter (cm²). Thus, the equation will be

$$K = qL/(hA)$$

The improvised permeameter has L = 20 cm and h = 120 cm. The area (A) allotted for soil as calculated from equation

$$\text{of area of a cylinder} = 2\pi r^2 + 2\pi r h ,$$

where radius of circular part of permeameter r = 4.95 cm is given as 3886.16 cm². Therefore: I = h/L = 120/20 = 6 cm, then, Ai = 6 x 3886.16 = 23316.97 cm²

where:K then gave (q/Ai)

2.4 Verification of result

The result of permeability constant (K) obtained using the improvised permeameter was compared with the results of Bear, 1972 to verify the reliability of instrument. The plate. 1 below shows the range of val-

ues of hydraulic conductivity for various geological materials. Values are for typical fresh groundwater conditions — using standard values of viscosity and specific gravity for water at 20°C and 1 atm.

K (cm/s)	10 ²	10 ¹	10 ⁰ =1	10 ⁻¹	10 ⁻²	10 ⁻³	10 ⁻⁴	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰
K (ft/day)	10 ⁵	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷
Relative Permeability	Pervious			Semi-Pervious				Impervious					
Aquifer	Good				Poor				None				
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel		Very Fine Sand, Silt, Loess, Loam								

Source: Modified from bear, J. 1972

Plate1: The saturated hydraulic conductivity (K) values found in nature

RESULTS AND DISCUSSION

Results of the initial analysis of the soil samples as presented in Table 1 shows that the texture of the soils ranged from loamy sand to sandy loam with slightly acidic pH values ranging from 6.8 to neutral pH of 7.0. The organic carbon was within the range of 0.78% to 4.49% with the highest at the Fadama site. The total nitrogen ranged between 0.1% and 8.0% while the available phosphorus (determined by Bray-1- method) ranged between 1.20 and 3.95 mg kg⁻¹ with the highest value at cashew plantation and fadama land use respectively. The exchangeable calcium varied between 2.95 and 4.80 cmol kg⁻¹, exchangeable magnesium ranging from 1.15 to 1.80, exchangeable potassium ranged between 0.02 and 0.63 cmol kg⁻¹ and exchangeable sodium ranging from 0.02 to 0.49 c mol kg⁻¹.

From the result of hydraulic conductivity of FUNAAB soils at the different land-uses as determined from graphs of the relationships

between quantity of volume of water discharged (Q cm³) and the time (t sec) taken for water to flow through as presented in figure. 3 and tabulated to show the volume, time, discharge, regression and hydraulic conductivity (K) values obtained using improvised constant head permeameter as presented in table 2. It was observed that there was above 95% correlation between volume of water and time for water to flow through the soil except for that of the COLPLANT soil with 77% correlation. The attempt made to determine the hydraulic conductivity of different land-uses shows that the Health-center and COLPLANT soils has the lowest discharge (6.371 x 10⁻⁷ and 7.919 x 10⁻⁷, respectively) and hydraulic conductivity (0.000027 and 0.000034 respectively). While the other soils has discharge ranges from 8.654 X 10⁻⁷ to 9.861 X 10⁻⁷ m³/s and hydraulic conductivity ranging from 0.000037 to 0.000042 cm/sec. This could explain reason for the lower regression obtained in the COLPLANT soil which can be attributed to the nature of the soils at the points. The

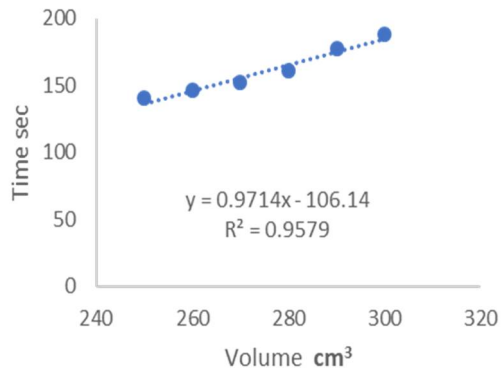
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Health-center and COLPLANT soils from table 1 show that the soil texture is a sandy loam while others are Loamy sand. The soil types were also confirmed by verification of result obtained using improvised perme- ameter with that of Bear's values which gave hydraulic conductivity of fine sand and loam in the range of 10^{-3} to 10^{-5} , thus making them semi pervious in nature and varying from very fine sand to silt, loess and loam.

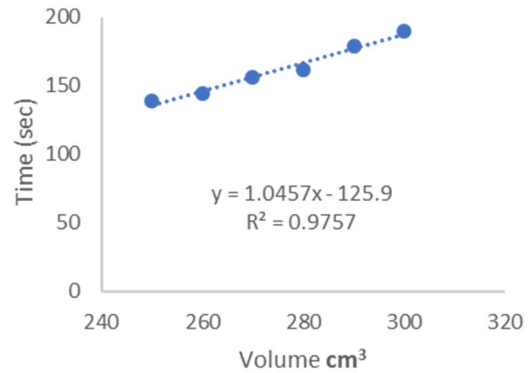
Table 1: Some chemical properties of experimental soil samples from 6 locations

Sample	Fadama	Health-center	Colplant-Farm	Forest site	Hostel-site	Cashew plantation
pH:H ₂ O 1:2	6.95	7.02	7.02	7.01	7.01	6.98
O.C(%)	4.49	0.91	1.72	1.21	1.15	0.78
AV. P(mgkg ⁻¹)	3.95	2.72	1.65	1.52	1.20	1.55
Na ⁺ cmol ⁻¹ kg ⁻¹	0.02	0.08	0.49	0.16	0.18	0.09
K ⁺ cmol ⁻¹ kg ⁻¹	0.02	0.48	0.58	0.19	0.36	0.63
Ca ⁺⁺ cmol ⁻¹ kg ⁻¹	2.95	4.32	3.63	4.80	4.36	3.98
Mg ⁺⁺ cmol ⁻¹ kg ⁻¹	1.80	1.22	1.54	1.15	1.19	1.66
H ⁺ cmol ⁻¹ kg ⁻¹	0.20	0.50	0.18	0.20	0.20	0.25
T. N (%)	1.36	1.20	0.10	1.40	1.22	8.0
Sand (%)	83.1	68.6	75.6	74.8	73.8	74.6
Clay (%)	11.3	17.2	10.1	11.6	11.7	11.4
Silt (%)	5.5	13.4	13.8	13.6	13.8	13.6
O.M (%) mg g ⁻¹	7.74	1.60	2.96	2.09	1.98	1.34
ECEC cmol ⁻¹ kg ⁻¹	5.33	6.60	6.34	6.30	6.29	6.62
Textural class	Loamy sand	Sandy loam	Sandy loam	Loamy sand	Loamy sand	Loamy sand

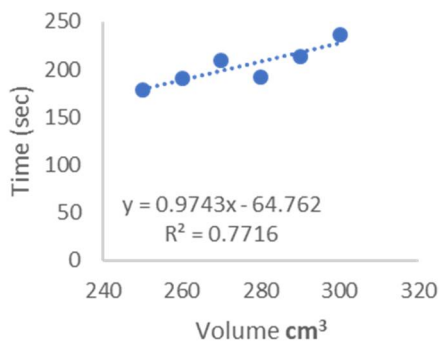
O.C= Organic Carbon, T.N= total nitrogen AV. P= available phosphorus, ECEC= Effective Cation Exchange Capacity, O.M= Organic matter



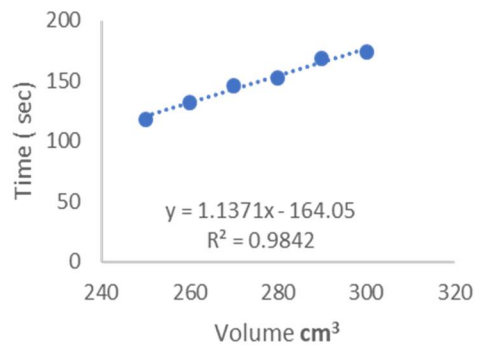
Fadama soil



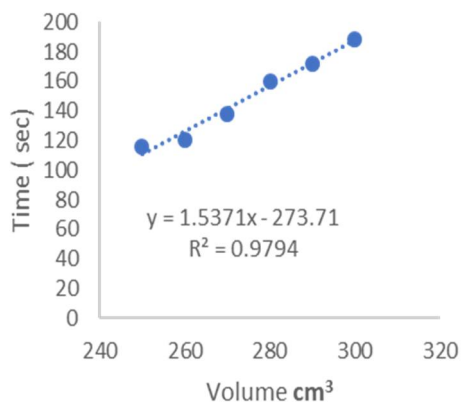
Forest-Site soil



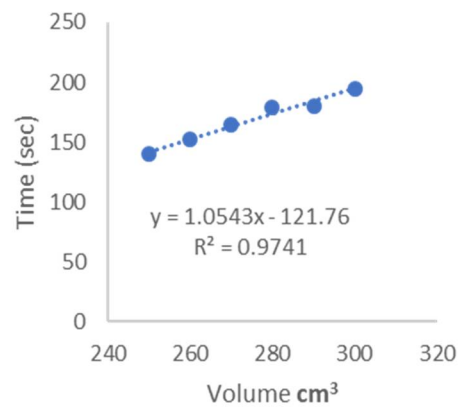
COLPLANT Farm soil



Hostel-Site soil



Health Center soil



Cashew Plantation soil

Figure 3: The graph of Volume rates against times for FUNAAB different Land-use

Table 2: The volume, time, discharge and hydraulic conductivity (K) values of improvised constant head permeameter for FUNAAB land-use

FUNAAB Land-use	Soil Textural Class	Out-flow, Volume (cm ³)	Average Time (Sec)	Discharge (m ³ /s)	Linear Regression R ²	HYDRAULIC CONDUCTIVITY K(cm/sec)
Fadama soil	Loamy sand	250	161	9.861 X 10 ⁻⁷	0.96	0.000042
Forest Site	Loamy sand	260	162	9.330 X 10 ⁻⁷	0.98	0.00004
Colplant Farm	Sandy loam	270	203	7.919 X 10 ⁻⁷	0.77	0.000034
Hostel-Site	Loamy sand	280	149	8.654 X 10 ⁻⁷	0.98	0.000037
Health Center	Sandy loam	290	149	6.371 X 10 ⁻⁷	0.98	0.000027
Cashew Plantation	Loamy sand	300	168	9.239 X 10 ⁻⁷	0.97	0.000039

CONCLUSIONS

It has been shown that soil permeability constant 'K' as determined using the improvised permeameter gave a reliable result when compared with the range provided with Bear's result. There was high positive correlation in volume rate of flow in soil and time of flow. The permeability coefficient of the soil samples (K) were in the range of 2.7×10^{-5} to 4.2×10^{-5} with the soil type ranging from sandy-loam or loamy sand and the relative permeability for the soil samples being semi-pervious and of poor aquifer.

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