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Asian Journal of Agriculture and Rural Development

journal homepage: http://aessweb.com/journal-detail.php?id=5005

Hydraulic Conductivity Functions in Relation to Some Chemical Properties in a Cultivated Oxisols of a Humid Region, Delta State, Nigeria

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Abstract

The study was conducted to evaluate hydraulic conductivity functions in relation to some soil chemical properties in an oxisols of the tropics. Field and laboratory studies were carried out and data collected, subjected to statistical analytical procedure for computing coefficient of variability and correlation among soil properties. Results of the study showed that hydraulic conductivity functions varied spatially and temporarily across the experimental points with a moderate mean value of 0.0026 cm/h and a coefficient o variation of 31.45% soil chemical properties showed that the soils were acidic with a mean pH value of 5.12. Organic carbon, total nitrogen and available phosphorus were low with mean values of 1.29%, 0.68% and 4.43 $mgkg^{-1}$. Coefficient of variability among soil properties indicated less to moderately variable. Soil pH had negative correlation with all the soil properties evaluated.

Keywords: Hydraulic conductivity, soil chemical properties, oxisols, humid region, Nigeria

Introduction

The oxisols of the Sub-Saharan Africa are among the potential arable lands that are exhaustively exploited for crop production activities (Agboola *et al.*, 1997). They are highly weathered soils derived from the Pre-Cambrian basement complex which formed part of the African crystalline shield (Fasina *et al.*, 2005). The most important diagnostic features of these soils are the deep oxic sub-surface horizons that are high in clay-size particles and dominated by hydrous oxides of iron and aluminum (Brady and Weil, 2007).

Characteristically, oxisols have low activity clay that are non-sticky and usually resistance to compaction. They have a poor structural stability, low inherent fertility, low water holding capacity, various nutrients imbalances, and high susceptibility to water erosion (Agboola *et al.*, 1997; Egbuchua 2007). The high concentration of iron and aluminum oxides in this soil, allow it to bind so tightly with phosphorus end thus, deficiency of phosphorus is common (Egbuchua, 2007).

The hydraulic conductivity which is defined as the volume of water flux which passes through a unit cross-sectional area of a soil, in unit time, given a unit differences in water potential (Landon, 1991) is governed by two basic principles namely the law of continuity and resistance. Their combination provides a differential equation which describes water movement in soils (Miyazaki *et al.*, 1984). Soil hydraulic conductivity (ksat) and water constant (Θ) are key parameters for crop growth, drainage, irrigation and

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modelling of water flow and chemical transport through the soil (Suleiman and Ritchie, 2001). In many soils, hydraulic conductivity is not constant due to various chemical, physical and biological processes but changes as water permeates and flow through the soil. The chemical properties of a soil are '*a sine qua non*' or a major productive factor in crop growth, yield and yield components. Thus, the assessment of the productivity of a soil lies on its chemical properties. Amongst these properties are, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases are cation exchange capacity. A soil that is moderate to high is these properties, coupled with a slope gradient of about 0 - 2% an effective soil depth of > 60 cm, good texture/structure and a good drainage capacity are important for the growth of tropical crops (Esu, 2004). Because of the depleted chemical nature of most oxisols, and the intensity of cultivation on these soils, the objective of this study therefore is to evaluate the relationship between water transmissivity and soil chemical properties. The outcome of this study provides a guide on how best to use and manage the soil for sustainable crop production system.

Materials and methods

Description of the study area

The study was conducted at the Delta State University Research and Teaching Farm Anwai, Asaba, Nigeria. Anwai falls within the coordinates 06° 14¹ and 06° 49¹E and basically located in the humid rainforest zone of Nigeria. The annual rainfall is about 1,650mm with peaks in July and September and a dry season which appears to be coalescing in recent times. The mean annual temperature ranged from 25°C to 28°C. An isohyperthemic soil temperature and aquic moisture regime typify the general area. The geology is made up of coarse grained pegmatites derived from basement complex that are more acid than base (Egbuchua, 2011). The general landscape is undulating with pockets of rolling topography scattered all over the places. Land use is typically based on rain-fed agriculture and the major crops extensively cultivated include roots and tuber crops, pulses, grains and wide varieties of vegetable species.

Field study

A grid of 12 x 12m^2 was distinctly mapped out and pegged 3x4m^2 apart to give a total of 12 experimental points. At each point, core samples were taken at 0-20 cm soil depth for laboratory determination of hydraulic conductivity. Auger samples were also collected for the analysis of the chemical properties of the soils.

Hydraulic conductivity determination

A 12 cm iron-metal cylinder which was locally fabricated was very carefully driven fully into the soil. Thereafter, it was then excavated and both ends trimmed with a knife. The cylinder with its soil content was placed in a polythene bag, tied and taken to the laboratory for the determination of hydraulic conductivity. The hydraulic conductivity of the soil was finally calculated using Darcy's law according to Dhan and Varde (1976) as;

$$V = K \frac{(hst\ x)}{X}$$

Where,
V = Infiltration rate or saturated soil column
K = Hydraulic conductivity
hs = Surface head
X = length of the saturated soil column
T = time (minute)

Laboratory analysis

The auger samples collected from the experimental points were routinely processed by air-drying at room temperature of 25-27^{o}C, for 3 days, grinded using agape motor and sieved through a 2mm mesh. The sieved samples were carefully labelled and packaged for laboratory estimation of some chemical properties. The chemical properties evaluated were soil pH which was determined in a 1:1 soil/water ratio using electrometric digital pH meter. Organic carbon was determined by oxidizing soil samples with dichromate solution and later titrated with ferrous sulphate solution. Total nitrogen was determined using micro-Kjeldahl method. Available phosphorus was determined by the Bray No 1 method and P in solution determined colorimetrically by the molybdenum blue method. The exchangeable cations were extracted by leaching 5g of soil with 50 ml of ammonium acetate at pH 7. The potassium and sodium in the leachate were determined with column Model 21 Flame photometer. Calcium and Magnesium were determined with Atomic Absorption spectrophotometer. All the determinations were done following the procedures of Canadian Society of Soil Science (Cater, 1993)

Statistical analysis

Statistical analysis procedure for computing coefficient of variability and correlation (r) as described by Steel and Torrie (1980) were employed to determine relationship between hydraulic conductivity and soil chemical properties.

Results and discussion

Soil chemical properties

The soil pH (Table 1) measured in water ranged from 4.8-5.6 indicating very strong to moderately acid reaction. The acidic nature of the soil could be associated with erosion and leaching effects due to high rainfall characteristics of the area which in most cases exceed 1,650mm/annum. The organic carbon (1.29%); total nitrogen (0.68%); and available phosphorus (4.43 $mgkg^{-1}$) were generally low for the ecological zone (FMANR, 1990). The low content of organic carbon could be attributed to extensive cultivation of the soils, rapid mineralization of organic matter, non return of harvested crop residues back to the soil, rampant annual bush burning which is more of a ritual in the study area; and short fallow period in recent times due to increased demand for land for various purposes. The low content of total nitrogen on the other hand, could be attributed to crop uptake, low organic matter status of the soil and effects of soil erosion and leaching. Available phosphorus was generally low (< 15 $mgkg^{-1}$) reflecting the low status of reserved phosphate minerals in the soil and its parent material. It could also be attributed to the fixation of phosphate by sesquioxides and high acidic nature of the soil (Akpan-idiok *et al.*, 1996, Egbuchua, 2011). The exchangeable bases (Table 1) were generally low, with the mean values of 3.59 $cmolkg^{-1}$, for Ca; 0.82 $cmolkg^{-1}$, for Mg; and 0.15 $cmolkg^{-1}$ for K. The low content of these basic cations may have been caused by intensive weathering of the environment, excessive leaching which may have caused looses of colloidal materials and low activity clay of the parent material (Egbuchua, 2011).

The cation exchange capacity (Table I) was also low with a mean value of 7.06 $cmolkg^{-1}$. The low value has been reported to be an indication of the dominance of kaolinitic clays in the fine earth fraction (Egbuchua, 2007). It could also be attributed to low organic matter content of the soils which was reflected in this study.

Hydraulic conductivity

Hydraulic conductivity varied widely both spatially and temporarily in response to differences in land use. It is known to be influenced by physical factors such as porosity, structure and exchangeable sodium percentage of the soil. In this study, the values ranged from 0.0012 cm/h to 0.038 cm/h with a mean 0.026 cm/h which is relatively moderate for the ecological zone (FMANR, 1990). This may be due to the reduction in the turtuosity of pores for water movement by some aggregating agents and hence transmissivity of water.

Relationship between hydraulic conductivity and some soils chemical properties

Results of correlation analysis (Table 2) showed that hydraulic conductivity correlated poorly (r = -0.44) with soil pH.

Probert and Keating (2002) associated this poor correlation to soil acidification resulting from in balance in uptake of cations and anions in the soil. Organic carbon showed moderate correlation (r = 0.51*) with hydraulic conductivity. According to Franzeluebber (2002), soil organic matter has an inverse impact on soil porosity. It is also associated with increased aggregation and permanent pore development as a result of biological activities in the soil. Total nitrogen (r = 0.19); available phosphorus (r = 0.05); calcium (r = --0.86); magnesium (r = 0.23) and potassium (r = 0.32) were all negatively correlated with hydraulic conductivity (Table 2). Cation exchange capacity on the other hand, correlated positively (r=0.82**) with hydraulic conductivity. The poor correlation associated with nitrogen could simply be adduced to leaching of nitrates due to the climatic environment of the study area, while that of calcium could be as a result of the aggregating agent which binds soil particles together and as such, reduced the water transmissivity in the soil through reduction on tortuosity of soil pores. This fact has been buttressed by Anikwe *et al.* (2004) in their study of hydraulic conductivity in different soils of South-East, Nigeria.

Coefficient of variability

The coefficient of variation values determined for the eight (8) soil chemical properties and hydraulic conductivity are shown in (Table 1). When grouped by the methods of Wilding and Dress, (1978) that is, CV < 15% = less variable, CV = 15 - 35% =moderately variable and CV > 35% = highly variable, the results show that soil pH, available phosphorus; exchangeable calcium, magnesium and cation exchange capacity were less variable. Organic carbon; total nitrogen; exchangeable potassium and hydraulic conductivity on the other hand, were moderately variable (Table 1). The results also showed that the experimental sites were more homogenous in terms of pH as they were characteristically acidic in reaction. The results also indicated that the soil chemical properties evaluated varied spatially and temporarily. This could be attributed to differences in land use and management practices employed in the study area. The correlation matrix among soil chemical properties (Table 3) showed that soil pH correlated negatively with all the soil properties. On the other hand, organic carbon, total nitrogen, available phosphorus and exchangeable potassium correlated positively (Table 3). The negative correlation was an indication that soil pH could affect the availability of these soil properties.

Summary and conclusion

Hydraulic conductivity functions and their relationship with some soil chemical properties were studied in a cultivated Oxisols both in the field and laboratory.

The field study involved a grid of 12 x12m^2 that was mapped out into 12 experimental points (sites). Auger soil samples were randomly collected for the measurement of hydraulic conductivity using Darcy’s equation and laboratory determination of soil chemical properties using appropriate procedures. Data obtained were subjected to correlation analysis and relationship between soil properties and hydraulic conductivity were also evaluated using regression models. Results of the chemical data of the study area, showed that the soils were generally acidic in nature and low in inherent fertility. Hydraulic conductivity was found to vary widely both spatially and temporarily but relatively moderate. The correlation studies showed that, hydraulic conductivity correlated poorly with soil pH, which invariably, had negative correlation with all the soil properties evaluated. On the other hand, organic matter, total nitrogen, available phosphorus and exchangeable potassium were all positively correlated.

Table 1: Soil chemical properties and hydraulic conductivity (Ksat) rates of the study area

S/No	Soil pH (H_2O)	Organic Carbon (%)	Total Nitrogen (%)	Available P ($mgkg^{-1}$)	Exchangeable Cations ($Cmolkg^{-1}$)			CEC ($Cmolkg^{-1}$)	Hydraulic Conductivity (cm/h)
					Ca	Mg	K		
1	5.4	1.76	0.63	4.35	3.45	0.76	0.19	7.25	0.028
2	4.8	1.87	0.48	3.86	3.32	0.81	0.10	6.35	0.026
3	5.6	0.98	0.65	4.76	3.48	0.83	0.17	7.30	0.025
4	5.3	0.94	0.86	4.56	3.62	0.78	0.16	7.25	0.027
5	5.5	1.25	0.72	4.67	3.54	0.89	0.18	8.10	0.027
6	4.8	0.86	0.51	3.96	3.48	0.76	0.12	6.45	0.025
7	5.2	0.92	0.82	4.24	3.76	0.82	0.16	6.72	0.024
8	5.3	0.96	0.87	4.62	3.66	0.81	0.18	6.85	0.038
9	5.5	1.23	0.81	5.08	3.48	0.91	0.14	8.13	0.039
10	4.8	1.82	0.54	4.21	3.25	0.84	0.09	6.40	0.012
11	4.9	1.95	0.48	4.35	4.15	0.80	0.11	6.55	0.012
12	5.3	0.98	0.82	4.50	3.88	0.83	0.15	7.35	0.025
Mean	5.12	1.29	0.68	4.43	3.59	0.82	0.15	7.06	0.026
Std deviation	0.39	0.43	0.15	0.34	0.25	0.05	0.03	0.62	0.01
CV%	7.68%	33.17	22.07	7.73	6.92	5.58	23.11	8.73	31.45

Table 2: Relationship between hydraulic conductivity and some soil chemical properties of the study area

Dependent Soil Properties	Regression Model	r
Soil pH (H_2O)	Ksat = 72.4x+ 372.4	-0.44^{ns}
Organic Carbon (%)	Ksat = 89.8 x+ 235.1	0.51
Total Nitrogen (%)	Ksat = 0.172 x+ 0.0210	0.19^{ns}
Available Phosphorus ($mgkg^{-1}$)	Ksat = 236.8 x+ 1338.7	0.05^{ns}
Exchangeable Cations ($Cmolkg^{-1}$)		
Ca	Ksat = 114.2x+ 414.92	-86**
Mg	Ksat = 19.76 x+ 35.28	0.23^{ns}
K	Ksat = 102.38 x- 92.24	0.32^{ns}
CEC ($Cmolkg^{-1}$)	Ksat = 802.4 x+ 016.4	0.82**

NS= Not Significant * = Significant at P = 0.05, ** = Significant at P = 0.01

Table 3: Correlation matrix showing correlations among selected soil chemical variables in the study area

Variable	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1		0.58*	0.06^{NS}	0.42	0.35^{NS}	0.17^{NS}	0.13^{NS}	0.15^{NS}
X_2			0.65**	0.58*	0.54*	0.52*	0.50*	0.61**
X_3				0.57*	0.61**	0.57*	0.67**	0.65**
X_4					0.56*	0.52*	0.58*	0.60*
X_5						0.61**	0.58*	0.63**
X_6							0.51*	0.61**
X_7								0.58*
X_8								

Note: X_1 = Soil pH; X_2 = Organic Carbon; X_3 = Total Nitrogen; X_4 = Available Phosphorus; X_5 = Exchangeable Calcium; X_6 = Exchangeable Magnesium; X_7 = Exchangeable Potassium; and X_8 = Cation exchange capacity (CEC). NS = not significant, * = Significant at 0.05, ** = Significant at 0.01 levels of probability.

The outcome of this study clearly showed that an understanding of the relationship between hydraulic conductivity and soil chemical properties will provide a basis for sustainable crop growth and modeling of water flow and chemical transport through the soil especially in degraded oxisols.

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