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RESEARCH ARTICLE

SOIL PHYSICAL, HYDRAULIC AND CHEMICAL PROPERTIES AS INFLUENCED BY DIFFERENT LAND USE AND SLOPE POSITIONS ALONG A TOPOSEQUENCE IN ADO EKITI, NIGERIA

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ABSTRACT

Several attempts have been made to relate soil properties to slope position for many landscapes essentially due to the realization of the role toposequence plays in influencing runoff, soil erosion and hence soil formation. However, information remains fragmentary on the relationship between toposequence and changes in the properties of soils of Ekiti State. In this study, selected physical, hydraulic and chemical properties of the soils along a toposequence in Ado Ekiti were evaluated. Textural class of the soils changed from loamy sand at the upper slope to sandy loam at the middle down to lower slope with sand content varying from 81.3, 73.4 to 72.3% respectively. Bulk density was highest at the upper slope with 1.72g/cm3 and lowest (1.61g/cm3) at lower slope. Total porosity and particle density of the soils followed similar trend as they decreased down the slope. However, hydraulic properties followed a different pattern. For instance, while water content values increased down the slope as follows: 9.6, 10.5, and 13.5%; Ksat ranged from 45, 30 to 20 cm/hr down the slope. In addition, infiltration rates also varied from 90, 70 to 55 cm/hr down the slope. The soils at the different slope sections were slightly acidic with pH of between 5.6 and 5.8 and they had low soil organic carbon (SOC)) content, generally below 2%; the highest being 1.9%. These findings demonstrated that soils deposited at the upper slope were more fertile and less prone to water erosion because of higher OM and greater permeability. Bush fallowing and appropriate tillage practices could assist in achieving sustainable crop production on these soils.

INTRODUCTION

Nigeria's human population is presently estimated to be 220 million (UN, 2022, NPC, 2022). Available arable land area for cultivation per head is now put at 0.238ha (NBS 2022) as a result of increased population density. Competition for arable land is further exacerbated by incidence of climate change, animal grazing, urbanization and its attendant infrastructural development. Thus, many lands hitherto considered marginal or unsuitable for the cultivation of arable crops are now being put under cultivation. Such lands generally occupy topographic positions considered unsuitable for cropping due to their susceptibility to water erosion, inherently low fertility status and their generally shallow and gravelly soil profile (Ogunkunle, 2003). Generally, an evaluation of such land and its soil properties is desirable. Studies on the soil nutrient availability across landscapes have become a crucial point of ecological study (Benning and Seastedt, 1995). Landscape position and land use may be the dominant factors of soil properties under a hill-slope and small catchment scale, landscape positions influence runoff and soil erosion and consequently soil formation (Kosmas *et al*., 2000). Soil properties mainly, soil texture and nutrient status, significantly differ along land use systems; whereas soil reaction (pH) do not vary, which is consistently affected by land use system (Lauber*et al*., 2008). For pasture land converted to cultivation, there was decrease in the soil aggregation and the hydraulic conductivity; in terms of soil erosion, soils under cultivation were severely subjected to raindrop effects as compared to forest (Celik, 2005). There have been several attempts to relate soil properties to physiograghic position for many landscapes (Wysocki*etal*., 2001). This may be partly due to the realization of the role toposequence plays in influencing runoff, soil erosion and hence soil formation (Babalola*et al*., 2017). Soil properties such as clay content has been found to be highly correlated with topographic position (Wang *et al*., 2001) while soil organic matter has been shown to vary with topographic position. Depending on the location on a slope, physical and chemical properties of the soil will also vary either minimally or maximally. Physiography influences soil texture, penetration resistance (Bruand*et al.,* 2004) root development (Busscher*et al*., 2001) exchangeable basic and acidic cations, soil exchange chemistry and nutrient budget hence important in fertilizer management (Paz-gonzalez*et al*., 2000).

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The objective of the present study was to evaluate the physical, hydraulic and chemical properties of soils on different slope positions along a toposequence.

MATERIALS AND METHODS

The Study Area: The study area consists of a toposequence located on the farmland of the Ekiti State Ministry of Agriculture and Natural Resources situated at Erifun, along The Federal Polytechnic Road, Ado Ekiti, Nigeria (Fig 1). The soils generally have been classified as an Alfisol with an annual rainfall in the area ranging from 2,500 to 3,000 mm. The mean temperature is 28°C and relative humidity 70-80% (Adeosun, 2020). The length of the toposequence is 380m. While the upper section of the slope is under bush fallow that is about 5 years old, the middle slope is cultivated to cassava. The lower slope is however under a teak plantation that is aged 3 years.

At the bottom of the hill is River Erifun with an evidence of a collapsed dam on its bank. From the crest of the toposequence down to the valley bottom, 3 sections were clearly identified and so demarcated, namely: Upper slope (7^0 16 30N, 5^0 14 21E), Middle slope (7^0 16 30N, 5^0 11 25E), and Lower slope (7^0 5 02N, 5^0 06 17E) with each occupying different elevation points respectively as follows: 383m, 376m, 362m above sea level.

The Field Study: On each of the 3 sections of the toposequence, a land area of 30 m by 20 m was delineated. Two sets of soil samples were collected. One set of soil sampling was done with the use of a 100 cc core samplers. From each slope position, two sets of 20 core soil samples were randomly collected from the top 0 – 20cm of each soil. To be able to evaluate the gravimetric water content, sampling was done 24 hrs after a heavy rainfall in June, 2021. One set was therefore used to determine gravimetric water content and bulk density while the other was used for saturated hydraulic conductivity measurements. In addition, 20 bulk and disturbed samples were randomly collected for determination of particle size and chemical properties of each soil. Each soil sample was immediately tucked inside two polybags and clearly labelled before being transported to the laboratory.

The Laboratory Study: The bulk samples were air-dried at room temperature and afterwards were gently crushed using a porcelain pestle and mortar. They were then sieved using a 2-mm (mesh 10) separating the gravel from the sample. The gravel was bagged and labelled differently from the 2-mm sieved air-dried soil sample and then the routine analysis was carried out. The following soil parameters were determined from the soil samples made to pass through 2-mm sieve using the following standard laboratory procedures: particle size distribution (Gee and Or, 1986), particle density (xxx), organic matter ( ), pH in 1:1 water-soil suspension by Sparks(1996), and cation exchange capacity(Na, K, Ca, and Mg) by . The core samples for water content and bulk density were oven dried until constant weight was obtained. The gravimetric water content was estimated using the formula below:

$$GWC = \frac{mass\ of\ water}{mass\ of\ dry\ soil} = \frac{(massof\ wet\ soil - massof\ dry\ soil)}{mass\ of\ dry\ soil}$$

The bulk density of the soil was calculated using the equation below (Klute, 1996):

Bulk density (g/cm^3) =weight of oven dried soil (g) ÷bulk volume of soil (cc)

Saturated hydraulic conductivity, Ksat was measured using the constant head method according to (klute and Dirkson 1986 and EMPRAPA, 2011). Ksat was calculated using the following equation:

$$Ksat = \frac{Q \times L}{A \times H \times t}$$

Infiltration tests, using double ring infiltrometer method, were run at the centre of the experimental plot on each of the 3 sections demarcated along the toposequence. Infiltration rates were then calculated using the equation proposed by Klute (1965).

RESULTS

The results of selected physical and chemical properties of soils along the to posequence in Ado- Ekiti are shown in Table 1.

Particle Size Distribution: Sand content of the soil ranged from 75.6% to 86.6% at the upper slope with the mean value of 81.3%. At the middle slope, the sand content varied from 68.6% to 81.6% with the average value of 73.4% while the sand content at the lower slope ranged from 68.6 % to 75.6% averaging 72.3%. The clay content ranged from 7.3% to 13.4% with the mean value of 10.9% at the upper slope whereas at the middle slope, the mean was 15.1% while it was 15.7%. Silt content ranged from 6.0 % to 10% with the mean value of 7.8% at the upper slope. At the middle slope, the silt content averaged 11.3% while it was 11.9 % at the lower slope.

Particle Density (PD) and Bulk Density (BD): The particle density (PD) of each slope along the toposequence ranged from 2.06 g/cm^3 to 2.5 g/cm^3 with the mean value of 2.29 g/cm^3 at the upper slope. At the middle slope, the particle density averaged 2.29 g/cm^3 while at the lower slope it varied from 2.23 g/cm^3 to 2.5 g/cm^3 with the mean value of 2.33 g/cm^3. The bulk density (BD) was highest at the upper slope with a mean value of 1.72 g/cm^3. At the middle slope BD varied from 1.51 g/cm^3 to 1.86 g/cm^3 with the mean value of 1.64 g/cm^3 while at the lower slope the BD had mean value of 1.61 g/cm$^{3.}$

Total Porosity (TP): TP ranged from 13.11 % to 32.4 % with the mean value of 24.82 % at the upper slope. At the middle slope the TP averaged 28.14 % while at the lower slope it had the highest mean value of 30.5 %.

Gravimetric Water Content (GWC): The gravimetric water content (GWC) increased down the slope along the toposequence. It ranged from 7.8 % to 10.7 % with the mean value of 9.51 % at the upper slope; its mean increased to 10.5 % at the middle slope and was highest at the lower slope with a mean of 13.33 %.

Saturated Hydraulic Conductivity (Ksat): Saturated hydraulic conductivity (Ksat) of each location along the toposequence showed a decrease down the slope. For instance, Ksat ranged from 15.98 cm/hr to 70.05 cm/hr with the mean value of 45.67 cm/hr at the upper slope.

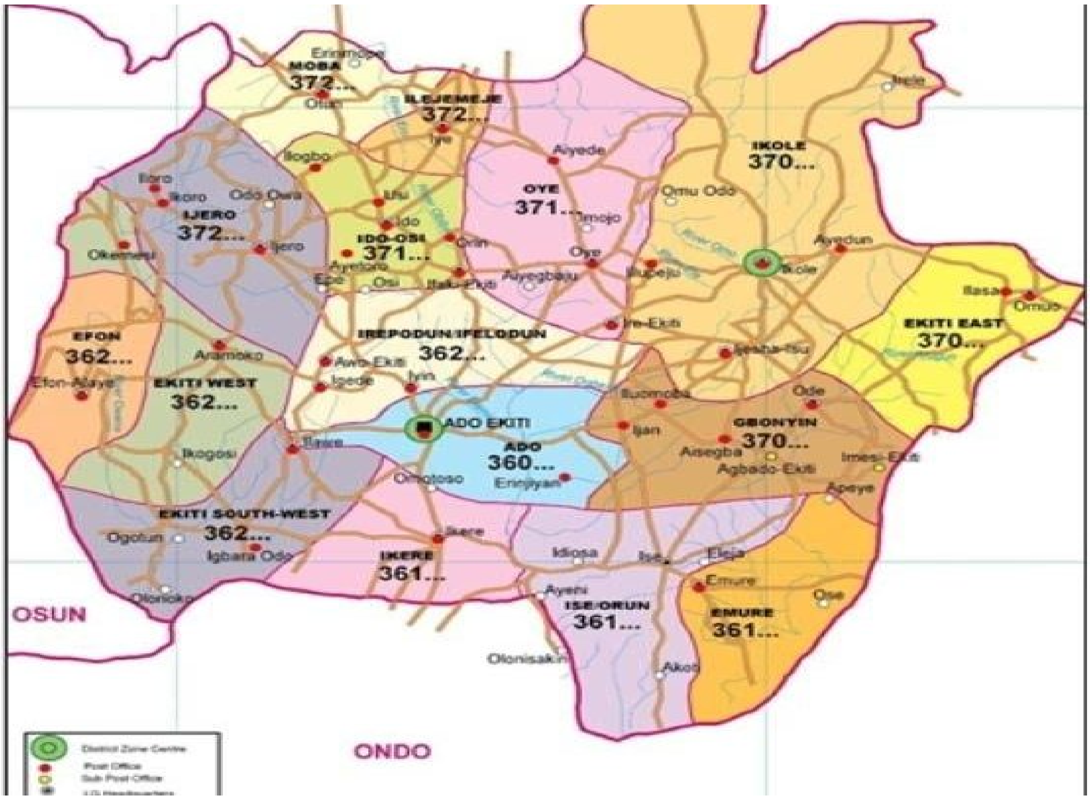

Fig. 1. Map of Ekiti State showing study location

Table 1. Selected Physical and Chemical Properties along the Toposequence

Soil Properties	Min	Max	Mean	Std	CV (%)	Skewness	Kurtosis
			UPPER SLOPE				
Sand (%)	75.6	86.6	81.33	2.86	3.51	0.01	-0.09
Clay (%)	7.3	13.4	10.9	1.77	17.36	-0.007	-0.74
Silt (%)	6	10	7.8	1.28	16.36	-0.009	-1.34
Particle Density (g/cm^3)	2.06	2.5	2.295	0.12	9.15	-0.045	-0.82
Bulk Density (g/cm^3)	1.62	1.81	1.72	0.06	3.72	-0.056	-1.42
Total Porosity (%)	13.11	32.4	24.82	5.21	20.99	-0.61	0.13
GMC (%)	7.8	0.7	9.59	0.77	8.07	-0.79	0.27
Ksat (cm/hr)	15.98	70.05	45.67	15.04	32.94	-0.42	-0.36
pH	5.4	5.9	5.67	0.12	1.79	-0.36	0.33
Organic carbon (%)	0.46	3.38	1.88	0.85	45.21	-0.02	-0.98
Sand (%)	68.6	81.6	73.4	4.72	6.43	0.68	-1.28
Clay (%)	10.4	18.4	15.13	2.49	16.44	-0.5	-1.01
Silt (%)	7	15	11.26	2.59	23.02	-0.53	-1.23
Particle Density (g/cm^3)	2.17	2.42	2.29	0.07	3.05	0.39	-0.91
Bulk Density (g/cm^3)	1.51	1.86	1.64	0.08	5.13	0.89	1.60
Total Porosity (%)	16.96	34.19	28.14	4.44	15.79	-0.83	1.00
GMC (%)	7.6	13.7	10.51	1.46	13.84	0.32	0.59
Ksat (cm/hr)	17.8	40.1	30.33	6.66	21.97	-0.55	-0.68
pH	5.6	5.8	5.72	0.07	1.04	-0.55	-1.13
Organic carbon (%)	0.49	2.43	1.36	0.69	50.73	0.35	-1.76
Sand (%)	68.6	75.6	72.33	2.01	2.79	-0.13	-1.01
Clay (%)	12.4	18.4	15.73	1.62	10.29	-0.14	-0.47
Silt (%)	9	15	11.87	1.4	11.86	0.42	0.89
Particle Density (g/cm^3)	2.23	2.5	2.33	0.07	3.00	0.78	0.27
Bulk Density (g/cm^3)	1.5	1.73	1.61	0.07	4.75	0.06	-1.401
Total Porosity (%)	24.11	38.4	30.5	3.71	12.17	0.35	-0.32
GMC (%)	10.4	15.5	13.33	1.75	13.16	-0.36	-1.56
Ksat (cm/hr)	10.67	28.57	20.59	5.04	24.57	-0.25	-0.43
pH	5.7	5.9	5.8	0.07	1.03	-0.12	-1.34
Organic Carbon (%)	0.59	2.93	1.5	0.79	52.66	0.25	-1.45

Table 2. Differences in soil physical, hydraulic, and chemical properties along the to posequence

	Sand (%)	Silt (%)	Clay (%)	Particle density (g/cm3)	Bulk density (g/cm3)	Total porosity (%)	GWC (%)	Ksat (cm/hr)	pH	OC (%)
Upper Slope	81.33	10.9	7.8	2.29	1.72	24.82	9.59	45.67	5.67	1.88
Middle Slope	73.4	15.13	11.26	2.29	1.64	28.14	10.51	30.33	5.72	1.36
Lower Slope	72.33	15.73	11.87	2.33	1.61	30.5	13.33	20.59	5.8	1..5
LSD (0.05)	0.20	0.21	0.86	0.0001	0.51	0.81	0.46	0.76	0.75	0.50

The mean Ksat was less than half of the one at the upper slope for the lower slope (20.59 cm/hr) while it was 30.33 cm/hr at the middle slope. The Ksat along this to posequence decreased as one moved down the slope.

Selected Soil Chemical Properties

Soil pH: The pH of each slope along the toposequence ranged from 5.4 to 5.9 with the mean value of 5.67 at the upper slope. At the middle slope the pH ranged from 5.6 to 5.8 with the mean value of 5.72 while at the lower slope the pH ranged from 5.7 to 5.9 with the mean value of 5.8.

Soil Organic Carbon: The organic carbon of each slope position along the toposequence ranged from 0.46% to 3.38 % with mean value of 1.8 8% at the upper slope. At the middle slope the organic carbon ranged from 0.49 % to 2.43 % with the mean value of 1.36 % while at the lower slope the organic carbon ranged from 0.59 % to 2.93 % with the mean value of 1.5 %.

DISCUSSION

Differences in soil physical, hydraulic, and chemical properties along the toposequence: Table 1 shows the differences in the soil physical and chemical properties along the toposequence. The highest sand content (81.3%) was obtained in the upper slope while the lowest (72.3%) was obtained in the lower slope with no significant difference ($P \geq 0.05$) in the sand content along the toposequence. The higher sand content at upper slope is in line with Prasetyo (2003) that as elevation decreases, sand content decreases. From the Table 1 also, the highest silt content (15.72%) was observed from the lower slope while the lowest silt content (10.9%) was obtained in the upper slope. The higher value of silt observed in lower slope is in conformity with Buol*et al*., (2003) that the transport of soil sediment occurs from the hillslope by erosion and get settled at the lower slope although there was also no significant difference ($P \geq 0.05$) in silt content along the toposequence. Also, the highest clay (15.73%) was obtained in the lower slope while the lowest was obtained at the upper slope this result is in line with the study of Buol*et al*., (2003) which stated that more fine soil particles are washed down by the erosion from the hill top to the lower bottom.

There was no significant difference ($P \geq 0.05$) in clay content along the toposequence. The textural class of the soil along the toposequence changed from sandy loam at the upper slope to loamy sand at both the middle and lower slope. This textural distribution might be as a result of washing down of soil particles from the upper slope to the lower slope. The particle density of the soil at the upper and middle slope was found to be lower than the lower slope. The higher particle density at the lower slope might be as a result irregular shape of various soil particles that has been washed down from the hill top to the bottom valley (Achalu *et al*., 2012). The bulk density decreased along the toposequence. The highest bulk density of $1.72g/cm^3$ was recorded at the upper slope and the lowest ($1.61g/cm^3$) was recorded at the lower slope. This result conformed to Dagnachew *et al.,* (2012) which states that as the slope decreases along the top sequence so is the run-off and erosion which leads to higher water content at the lower slope that causes low bulk density.

The total porosity increased along the toposequence, the highest total porosity was recorded at the lower slope (30.5%) while the lowest was recorded at the upper slope (24.8 %). The reason for the increment in bottom valley could be related to reduced organic matter, aggregation and root penetration compared to the upper slope (Pravin *et al*., 2013). The highest saturated hydraulic conductivity value (45.67 cm/hr.) was observed at the upper slope while the lowest value (20.59 cm/hr.) was observed at the lower slope in line with The pH increased along the toposequence, the highest pH was recorded at the middle slope while the lowest pH was recorded at the upper slope. The washing out of bases from higher part of the soil (clay) and subsequent deposited at the lower elevation (middle slope) which in agreement in the findings of (Shimeles *et al*., 2012). The highest organic carbon content (1.88 %) was observed at the upper slope while the lowest was observed at middle slope (1.36 %) and at the lower slope 1.5 % was recorded which indicate that organic carbon fluctuate along the toposequence. The highest value of organic carbon at the upper slope was in line with Abraham *et al.,* (2012) which indicated that the high accumulation of organic matter is due to increase in total input of organic material.

CONCLUSIONS AND RECOMMENDATION

The soils occupying different slope positions along the toposequence showed distinguishing characteristics. Soil textural class changed from sandy loam on the upper slope to loamy sand from middle to lower slope with clay content decreasing from about 10 % in the upper to over 15 % in the lower slope. However, sand content decreased significantly down the slope. Bulk density was high for the different soils at the three slope positions; generally, above 1.5 g/cm3. Particle density was generally below the assumed 2.65 g/cm3; varying from 2.29 to 2.55 g/cm3 while the total porosity thus follows similar trend, viz: 24 to 34 %, found to be considerably low too. The hydraulic conductivity and infiltration rates of the different soils were moderately adequate for crop water uptake and thus field moisture capacity obtained after rainfall was equally moderately adequate. Land use changes from long bush fallowing on the upper slope to cassava cultivation at middle to young teak plantation at the lower slope may have caused the significant variation in soil organic matter, cation exchange capacity and water retention capacity of the soils. The three soils occupying the three slope positions on this toposequence are suitable for cultivation of different arable crops. On this toposequence and such similar ones in this agro-ecological zone, bush fallowing and appropriate tillage practices would be necessary for the successful management of these soils for sustainable crop production.

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