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Integrated Effect of Slope Classes and Different Soil Depths on Soil Physico-chemical Properties of Watershed Ecosystem

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Abstract

Watershed come in many different shapes and sizes and can be affected by many different activities and events. The quality of change of the activities either bad or good has being found to be influenced by slope and depth variations. Thus a field study was conducted to evaluate the soil properties of two contrasting watershed management systems using slope classes (slope 1, 34.8% gradient; slope 2, 29.6% gradient; slope 3, 23.8% gradient; slope 4, 0.52% gradient) and three different soil depths (0-15cm, 15-30cm, and 30-45cm) as an index of the study. The study of the watershed was laid out in an experiment arranged in a randomised complete block design (RCBD) with three replicates data generated from the study were subjected to analysis of variance and significant means different were separated using least significant difference (LSD). The results of the study showed that slope classes and soil depths studied had significant ($P<0.05$) effect on the soil properties. The highest available P and TN were observed in slope 4 and 3 respectively. The variation in OC content show an order of slope 3 > slope 4 > slope 2 > slope 1. The lowest bulk density of 1.572gcm^{-3} was observed in slope 4 (plain). With regard to soil depth all the soil parameters showed decrease in value as soil depths increased, with the exception of clay, silt content and bulk density that increased with increasing soil depth. The highest recorded values for the chemical parameters tested were obtained from 0-15cm soil depth. The interaction effect of slope and soil depth result showed strong influence of the two indices on the soil properties. The slope gradient 4 (lower slope) with soil depth 0-15cm gave the highest value of OC (1.81gkg^{-1}) and available P (20.1mgkg^{-1}) as well as the lowest bulk density value (1.43gcm^{-3}). Top soil depth values were greater in slope 4 with 0-15cm soil depth. The present study findings is of evidence that slope classes and soil depths are indices to be considered in the effective management of watershed as their cumulative effects influenced the productivity of the watershed.

Keywords

Slope, Soil Depth, Soil Physico-chemical Properties, Watershed

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1. Introduction

Watershed which is a catchment area or drainage basin is an area of land that drains all rainfall to an out flow of a reservoir. The outflow point of a watershed determines its size and amount of outflow. For all of the land that drains water to the out flow point is the watershed for that outflow location. Hence [1] postulated that a watershed is a unique land area generally bordered by hills and ridges that ultimately drains to a common basin or out let such as stream, river, lake or wetland. While [2] noted that a watershed is an integration of ecosystems of flora and fauna, land and water and their mutually interacting elements. However, ecosystem approach in watershed as was explain in the work of [3] was based on the order that water, biodiversity, and environmental protection required

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establishing interdisciplinary, intersectional and inter-institutional initiatives. These initiatives according to them define strategies for actions and investment based on the needs and priorities of watershed inhabitants. The activities of man and his animals as an integral part of watershed affect the productive status of watersheds and vice-versa. Thus watersheds can as well be seen as multifunctional landscapes that are composed of diverse but interconnected agricultural and non-agricultural land units, drainage basins and streams. Another important interacting factor in watershed is the varied hydrologic processes which interact with the land use and soil types at different spatial (size, shape, position etc). Watershed is not merely hydrological unit as was noted by [4], but also socio-political-ecological entity which play crucial role in determining food, social, and economic security and provide life support services to rural people. Hydrological, watershed is an area from which the runoff flows to a common point on the drainage system. These hydrological cycles in tropical watersheds according to [5] are strongly affected by climate, geomorphology and soil types in the tropics, because rainfall intensities and amounts are commonly much higher in the tropical regions. These observations strongly influence rock weathering and the formation of deep soil profiles widely observed in the tropics. While the works of [6, 7] argued that soil physical properties, geological aspects and topographic conditions are key factors which control runoff response in tropical watersheds under extreme rainfall patterns.

A watershed can be affected by many interacting factors of human activities and national events, [8]. The problems associated with watershed range from flooding resulting from unstable slopes, erosion from exposed land due to deforestation, shortage of food due to crop failures and water supply etc. Soil erosion is a major factor in the management of the watershed since it affects many critical properties of the soil. Eroded soils decreased plant yield through increased bulk density, poor tilt and reduced organic matter content, nutrient availability and water holding capacity. Top soil thickness is a major indicator of soil quality and productivity. The physical, chemical and biological properties of the surface horizon govern the reception, storage and the transfer of water and energy. Top soil stores most of the available nutrients present in the soil profile. So once it is attacked by the agents of erosion the productivity the soil declines rapidly. Therefore soil erosion remains one of the most important processes potentially affecting the productivity of agricultural lands especially the watersheds.

Slope is the gradient of the land or a measure of change in elevation. It can as well be explained as the rise and fall of the land surface. While depth is a dimension, usually downward from an upper surface, horizontally inward from an outer surface or from top to bottom of something regarded as one of several layers. These parameters have strong influence on the conservation and utilization of watershed. The slope nature of watershed creates impact on runoff, because it gives an additional power to runoff to flow the land surface with its attendant havocs. Schaetzl and Anderson [9] observed systematic down slope variation in soil texture of which they noted to have occurred as a result of decreasing slope and this slowed the rates of water movement from ridge to the slope positions. In such situation there is likely hood that soil texture and hill slope position will become the core centre that will influence the particle size and soil thickness, while low slope gradients combing their influences to encourage soil moisture retention. On the contrary the steep upper slopes are likely to be characterized by coarser soil texture less developed and thinner soils that will transmit water more rapidly. Soil hydrology as observed by [10] is strongly affected by spatial variability of soil moisture, which may be predominantly controlled by surface and/or subsurface topography. Sloppy land has been noted to be vulnerable to erosion and degradation of watershed function, hence it influenced its capacity to provide vital economic benefits and ecological services.

Therefore watershed development requires multiple interventions that will enhance the resource base and livelihoods of the rural people. This according to [4] can be tailored down to strengthening the abilities of the people to make efficient and effective use of resources in order to achieve their own goal on a sustained basis. While Joshi et al., [11] noted that ignorance and unawareness by the people about the objectives approaches and activities are the reasons that affect the performance of the watersheds. To reduce poverty and malnutrition there is need to focus on conservation methods that will increase agricultural productivity from sloping land and protect the watershed where the changes occur, bearing in mind that to succeed in agricultural intensification and diversification in sloping lands has to be done through carefully matching land use to land suitability as soil properties greatly influence crop production. Thus the objective of the present study was to show how slope and depth interact to influence the properties of soil in watershed ecosystem, that will invariable affect crop production and other activities of the watershed.

2. Materials and Methods

Experimental Site

The study was conducted in Anambra State Market Garden, Amawbia. Amawbia is a sub-urban community within Awka Capital Territory, Anambra State, Nigeria. The area is a watershed, which lies between latitude 06°18[1] north and longitude 070°4[1] east. The temperature of the area is uniformly high with mean monthly minimum average of 26°C, maximum temperature of 30°C - 35°C ± 1°C is obtained in March but temperature may reduce to 24°C - 27°C in October [12]. Amawbia receives an annual rainfall which range between 1500mm to 2500mm with its peak in the months of July and September. Parts of this watershed in recent past have come under some kind of management programme initiated by Anambra State Government leaving the adjacent watershed area unmanaged. Hence, the watershed areas can be clearly categorised into managed and non-managed watershed systems. This study was carried out under these two management systems (i.e. management and non-management).

The managed system was characterised with terraces separated by earth bunds and stabilised by permanent trees forming hedge rows. This plot was established in June, 1995, and has been under management for over 20 years. The non-managed system is neither terraced nor ridged for erosion control. The two management systems were subdivided in different slope gradients (slope 1, 34.8% gradient; slope 2, 29.6% gradient; slope 3, 23.8% gradient; slope 4 or plain, 0.52% gradient).

Soil samples were collected from the two different plots with the aid of auger at the depths of 0 – 15cm, 15 – 30 cm and 30 – 45 cm and each was replicated three times. The soil samples were air dried and passed through 2mm sieve and stored in sample bags for physical and chemical analysis. Particle size analysis was determined by the hydrometer method of [13]. Soil pH in 1:1 water was determined with pyeunicam meter; organic carbon was determined by the dichromate wet oxidation method as described by [14] while K was measured using flame photometer.

Data collected from the study was tested on analysis of variance based on randomised complete block design (RCBD) according to [15] while least significant difference (LSD) at 5% was used to compare treatment means.

3. Results

3.1. Main Effects of Slope on Soil Properties in the Watershed

The result presented in Table 1 indicated significant (P<0.05) differences among the slopes studied and parameters assessed, except for pH and TN. The value recorded for pH showed that slope 1, 3 and 4 gave the same value of 5.4 and the highest value of TN was recorded in slope 3 (0.260gkg^{-1}), of which is 2.69% higher than values obtained from slope 1. The variations in OC content with regard to the slope gradients show an order of slope 3> slope 4> Slope 2> slope 1. The result of K, P, fine and coarse sand in Table 1 showed that the values of these parameters decreased as the slope gradient increased, while the values of clay, silt and bulk density increased with increase in the slope gradient with attendant decrease in top soil depth. Slope 1 and 2 recorded the same value in silt content with slope 1 recording the highest value in bulk density (1.616gcm^{-3}). Generally these tested parameters were found to be slope dependent; hence they were significantly influenced by the slope.

Table 1. Main effect of slope on soil properties.

Slope	pH H_2O	OCg/kg	TNg/kg	Kcmol/kg	Avail Pmg/kg	Clay%	Silt%	F/sand%	C/sand%	BDgcm^{-3}	Top soil depthcm	Textural class
1 (34.8%)	5.47	0.847	0.253	0.050	2.488	39.0	14.0	21.0	26.0	1.616	5.83	CL
2 (29.6%)	5.35	0.957	0.255	0.047	4.043	38.20	14.0	24.8	29.0	1.607	4.81	SC
3 (23.8%)	5.47	1.083	0.260	0.043	3.422	26.70	12.3	31.0	30.0	1.566	5.30	SC;
4 (0.52%)	5.47	1.082	0.258	0.090	9.638	16.70	9.24	35.0	38.16	1.572	8.28	SCL
LSD (P<0.05)	NS	0.125	NS	0.043	0.933	12.30	0.20	4.20	1.333	0.036	0.490	

NS = Not significant; F/Sand = Fine Sand; C/Sand = Coarse Sand; BD = Bulk Density

3.2. Main Effect of Soil Depth

The effect of soil depth recorded in Table 2, indicated significant (P<0.05) differences among the parameters tested, showing strong influence of soil depth on the tested parameters. All the parameters showed decrease in value as soil depth increased, though with exception of clay content, silt content and soil bulk density that increased with the increase in soil depth. Highest value recorded for these parameters were mostly obtained from 0-15cm soil depth. The values of pH, OC, TN, K and P obtained from 0-15 cm soil depth were 8.27%, 52.44%, 91.53%, 55.56% and 59.13% respectively higher than their respective values recorded in soil depth of 30-45 cm which showed an increase in value order of TN > available P> Exchangeable K> Organic carbon content in top soils of 0-15cm compared to the subsoil of 30-45cmdepth. The values of coarse sand and available K of 15 – 30cm and 30 – 45 depths were relatively the same, but significantly different from their values recorded in 0- 15cm soil depth.

Table 2. Main effect of soil depth on the soil properties in the watershed.

Soil Deptcm	pH H_2O	OCg/kg	TNg/kg	Kcmol/kg	Avail Pmg/kg	Clay%	Silt%	F/sand%	C/sand%	BDg/cm^3	Textured class
0-15	5.68	1.43	0.59	0.09	8.27	27.30	10.0	29.2	33.50	1.467	SCL
15-30	5.41	0.86	0.12	0.04	3.03	31.0	11.0	28.0	30.00	1.628	SCL
30-45	5.21	0.68	0.05	0.04	3.38	32.0	12.0	26.0	30.0	1.675	SCL
LSD (P<0.05)	0.275	0.564	0.475	0.049	5.245	4.750	1.40	2.90	2.375	0.208	

BD = Bulk density

3.3. Combined Effect of Slope and Depth

The interaction effect of slope and depth recorded in Table 3, show strong influence of the two indices on the soil properties of the watersheds. Significant (P<0.05) differences were observed on the values of the tested soil properties, except for soil pH and total nitrogen. The soil depth of 0-15 cm of slope 1 gave the highest value of soil pH (5.75) with the least value (5.10) recorded in 30-45 cm depth of slope 2. While for TN, the highest value 0.605gkg^{-1} was observed in 0-15 cm depth of slope 3 and the least 0.042gkg^{-1} obtain from 30-45cm depth of slope 2. The organic carbon (OC) content result show that the value obtained increased with the decrease in soil depth from 30-45cm to 0-15cm soil depth, while its value decreased with increase in slope gradients. The slope gradient 4 which is plain gave the highest OC content value of 1.18gkg^{-1} with soil depth 0-15cm. The value of exchangeable K showed significant difference among the slopes but not with the soil depths studied. The result of the available P in Table 3, indicated that the value of P decreased with an increase in the slope gradient, while the value increased with a decrease in soil depth from 30-45 to 0-15cm depth. However, values of P obtained from most of the soil depths were statistically similar. The clay and silt content were observed to increase as the soil depth increased to 30-45 while the bulk density decreased with increased soil depth. The top soil depth was observed not have been affected by the slope gradients of the watersheds however the plain watershed showed higher top soil depth value of 8.282 cm

Table 3. Combined effect of slope and depth on the soil properties in the watershed.

Slope	Soil depth (cm)	pH H_2O	OCg/kg	TNg/kg	Kcmol/kg	Avail Pmg/kg	Clay%	Silt%	F/sand%	C/sand%	BDgcm^{-3}	Top soil depthcm
Slope 1 (34.8%)	0-15	5.75	1.26	0.597	0.075	3.73	36.0	9.70	24.30	30.0	1.48	
	15-30	5.45	0.755	0.113	0.035	1.87	42.0	9.70	19.0	30.0	1.67	5.833
	30-45	5.20	0.525	0.049	0.040	1.87	39.0	8.50	20.50	32.0	1.70	
Slope 2 (29.6%)	0-15	5.70	1.335	0.603	0.065	3.74	37.0	9.0	23.50	30.50	1.50	
	15-30	5.25	0.90	0.12	0.035	2.34	38.0	11.0	24.50	26.50	1.65	4.812
	30-45	5.10	0.635	0.042	0.040	6.06	40.0	11.0	23.0	26.0	1.68	
Slope 3 (23.8%)	0-15	5.70	1.315	0.605	0.04	5.60	23.0	13.0	33.0	31.0	1.46	
	15-30	5.35	1.09	0.113	0.04	2.34	27.0	14.0	29.0	30.0	1.56	5.30
	30-45	5.35	0.845	0.063	0.05	2.34	30.0	16.0	26.0	28.0	1.67	
Slope 4 (0.52%)	0-15	5.60	1.810	0.577	0.018	20.1	13.0	10.0	35.0	42.0	1.43	
	15-30	5.60	0.720	0.134	0.055	5.06	18.0	10.0	37.0	35.0	1.63	8.282
	30-45	5.20	0.715	0.063	0.035	3.27	19.0	11.0	34.0	36.0	1.66	
LSD (P<0.05)		NS	0.564	NS	049	5.250	4.80	0.90	1.333	2.375	0.050	NS

BD = Bulk density

4. Discussion

The present study has indicated that the slope and soil depth as well as their interaction have very much effect on the soil properties of the watersheds. Their influence on the watersheds resulted in decreased OC, TN, K and available P with increased slope gradients and decreased soil depths. Clay content and bulk density were also found to be increased with the slope, but decreased with the soil depth. The dominance of the sand fraction among the soils in the three (3) soils horizon depth and even in slopes, according to the work of Nweke and Nsoanya [16] indicated that the soils are well aerated and may not present problem with drainage and crop root penetration. The observed variations in clay content, silt and sand fraction with depths and slope, could be due to loss of clay from surface horizon by eluviations [17] and preferential removal of clay and silt by soil erosion [18]. This may have resulted to the predominance of sand in the soils. The observed differences in the ratio of sand to clay and silt were in line with the observations of [19, 16] who observed that the texture of most of the soils of humid tropics like Nigeria particularly in the surface horizon is predominantly sandy. Further the proportion of the clay in the soil is of utmost importance as it relate to the soil fertility, nutrient availability, retention and water holding capacity. In an unmanaged (unprotected) watershed, there may be selective removal of finer soil particles by erosion, thereby increasing the proportion of the coarser particles in the soil that eventually will leave more sand particles. Intensive farming practices and deforestation, leaving the soil bare without cover, change soil texture by aggravating soil erosion [20, 21]. Also under sparsely vegetation cover, the clay fractions are likely to be lost to processes of erosion and migration down the soil profile [22]. The bulk density result showed that generally, the value across the study areas, slope classes, soil depths and their interaction effects, were less than 1.68gcm^{-3}. The higher bulk density values observed could be attributed to the excessive wet season usually observed in a humid tropical environment like Nigeria, low organic matter content and to some extent continuous shallow depth cultivation. Yihenew and Getachew [23] observed higher bulk density values in grazing land and cultivated among the land use types and slope classes studied. Conversely the lowest bulk density values (<1.572gcm^{-3}) that indicates an ideal situation for root proliferation observed in lower soil depth (0-15cm) and lower slope (slope 4) position might be due to higher content of organic carbon in the soil and lesser clay content. Bulk density is a strong physical parameter index of the soil that influence root growth and penetration. As the bulk density increased crop production activities with regard to root penetration and proliferation may be hampered, because Evanylo and McGuinn [24] noted that soil density values of 1.55mgm^{-3} – 1.65 mgm^{-3} adversely affect or restrict root growth and development, though in silt loam soils. The decrease in values of the soil chemical parameters (pH, OC, TN, K, and P) assessed with increased slope and soil depth might be due to higher rainfalls usually observed in the study area which apparently lead to leaching of the basic cations at the expenses of H^+ and Al^{3+} leading to soil acidity. Mohammed [25] observed that the soil in high altitude and higher slopes had low pH values that suggest the washing away of solutes and basic cations from these parts. Constant land use depletes organic matter build up [26] and this has strong influence on the soil C, N and P [23, 27]. The low values of available P in the sub soils horizons and increased slope may as well suggest high fixation of P by sesquioxides. Nweke and Nsoanya [16] made similar observation in the physical and chemical characterization of Igbariam soils. The steepness of the topography and the kind of soil amendments used on the site by farmers are some of the other factors that might have influenced the nature of the results obtained in this study. Thus the conservation methods that should be applied at a specific slope and soil depth locations of the watersheds will depend very much on the soil characteristics and local circumstances.

5. Conclusion

The suitability of any watershed for crop production, animal and human activities, water quality etc can partly be inferred from its soil characteristics. A good knowledge of these characteristics is important for its effective management. The findings from the present study showed that slope gradients, soil depth and their interaction influenced the soil characteristics of the watersheds. Thus land capability within the watershed should be based on slope, soil depth and soil characteristics as they will form the basis for the assessment of the recommended land use and required soil conservation practices.

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