Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 20 Number 3 (July 2021) pp. 37 - 48
ISSN 1119-7455

INFLUENCE OF SLOPE ASPECT AND POSITION ON SOIL PHYSICAL QUALITY AND MANAGEMENT IMPLICATIONS AT UNIVERSITY OF UYO TEACHING AND RESEARCH FARM, AKWA IBOM STATE, NIGERIA

Ogban P.I.
Department of Soil Science, Faculty of Agriculture, Forestry & Wildlife Resources Management,
University of Calabar, Calabar, Cross River State, Nigeria

Corresponding author's email: peterogban@gmail.com; peterogban@unical.edu.ng

ABSTRACT

The effect of north and south aspects (NA and SA) and positions viz upper (US), middle (MS) and lower (LS) on soil physical quality from 2000 to 2020 was evaluated at the University of Uyo Teaching & Research Farm, to identify management factors at the Farm. Results showed that coarse sand increased while clay content decreased significantly ($p < 0.05$) and soil textural class was loamy sand on slope aspects and positions. Soil bulk density and total porosity were similar on the slope aspects and positions. Saturated hydraulic conductivity was significantly ($p < 0.05$) higher on SA (10.6 cm h^{-1}) than NA (3.1 cm h^{-1}) but declined by 93.03% and 52.47%, respectively in 20 years. Soil organic carbon, water-stable aggregates, mean-weight diameter of soil aggregates and structural index decreased by 14.81% and 38.33%, 60.53% and 55.53%, 31.26% and 21.71%, and 48.60% and 69.0%, respectively in NA and SA within the 20-year period. One minute infiltration rate was similar on NA and SA, while final infiltration rate, cumulative infiltration, sorptivity and transmissivity were significantly ($p < 0.05$) different; these soil hydraulic properties decreased in NA and SA by 83.0% and 86.43%, 52.63% and 14.29%, 81.53% and 63.9%, 95.0% and 85.63% and 90.42% and 96.11%, respectively on the aspects after the 20 years. Slope aspects and positions were generally similar in their effects on soil physical quality attributes, most of which were degraded after the 20 years. Principal component analysis (PCA) identified seven soil quality management factors namely (1) water intake, (2) soil texture, (3) soil pore space, (4) and (6) Fe and Al oxide, and (5) and (7) soil structural stability factors that could be used to improve and conserve the soil and water for increases in crop production on the farm.

Key words: crop residues, infiltration characteristics, soil functions, soil structural stability, soil quality

INTRODUCTION

Knowledge of soil physical quality (SPQ) attributes is important in developing stable and viable soil management practices that will conserve the soil resource base and its properties and processes and functions. Soil quality generally can be defined as the degree of fitness of a soil for a specific use (Carter *et al.*, 1997). Soil quality also implies other concepts such as the sustained capability of a soil to accept, store, and recycle water, nutrients and energy. It is a unique balance and interaction of its physical, chemical and biological components (Karlin *et al.*, 1997; Herrick *et al.*, 2002; Aparicio and Costa, 2007). Soil quality is dynamic and often assessed based on soil function (Doran and Parkin, 1996), to ascertain whether it is improving, stable or declining with soil use. This is because it is deemed important for the assessment of the extent of land degradation or amelioration, and for identifying management practices for sustainable land use. Consequently, good SPQ occurs when soils exhibit the absence of degradative symptoms such as poor water infiltration, which reflect poor soil structure.

Soil physical properties profoundly influence how soils function in an ecosystem and how they can best be managed (Weil and Brady, 2017). Soil physical quality, also termed *soil physical fertility*, is the component contribution of the soil physical properties and processes to the ability of the soil to perform its functions and support ecosystem services (Scott, 2000; Yaalon and Arnold, 2000). Shukla (2014) stated that the quality of land is dependent on its physical properties. Lal (1999) and Lal and Shukla (2005) reported that high SPQ plays an important role in enhancing soil chemical and biological qualities and hence in defining the overall productivity of the soil, as well as in sustainable management of natural resources.

The soil physical properties that profoundly influence soil's static and transmission properties are soil texture and the more dynamic soil structure (Pierce *et al.*, 1983; Rawls *et al.*, 1998; Zimmermann *et al.*, 2013) and can be used as indicators of soil quality (Arshad *et al.*, 1996), and to determine the ability of the soil to function. Larson and Pierce (1991) suggested three principal

Please cite as: Ogban P.I. (2021). Influence of slope aspect and position on soil physical quality and management implications at University of Uyo Teaching and Research Farm, Akwa Ibom State, Nigeria. *Agro-Science*, **20 (3),** 37-48.
DOI: https://dx.doi.org/10.4314/as.v20i3.6

functions that a soil must perform; (1) provide a medium for plant growth, (2) regulate and partition water flow in the environment, and (3) serve as an environmental filter. To perform these functions, however, a soil must resist erosion and runoff, and accept and transmit water. Soil quality assessment is thus purpose- and site-specific, and is a tool focused on dynamic soil properties and processes, while not ignoring the inherent soil properties (Karlen *et al.*, 2003), that are useful for assessing the ability of a soil to sustain crop production and the sustainability of soil management practices.

Soil quality cannot be measured directly but inferred by measuring soil attributes or properties that are sensitive to changes in soil functions (Doran and Jones, 1996; Aparicio and Costa, 2007; Dexter and Czyz, 2007). It is thus important to build a simple, sensitive, and workable indicator method for soil quality evaluation (Dumanski and Pieri, 2000). For this reason, soil quality is evaluated by use of a minimum data set (MDS) of indicators (Karlen and Stott, 1994; Doran and Parkin, 1996; Karlen *et al.*, 1997), measurable against some definable standards and sensitive to soil management (Doran and Parkin, 1996; Larson and Pierce, 1994; Karlen *et al.*, 1997, 1998; Andrews *et al.*, 2002). For instance, Tisdall and Oades (1982), Churchman and Tate (1987) and Pajasok and Kay (1990) suggested soil organic carbon (SOC) content as a soil quality indicator because decreases in this parameter can be related to decreased water stability of macroaggregates and microaggregates and soil's resistance to erosion and runoff, as well as water infiltration, storage and transmission (Miller and Baharuddin, 1986; Stern *et al.*, 1991).

Notably, soil quality can be evaluated at several different scales (Karlen *et al.*, 1997). For instance, Karlen *et al.* (1999), Liebig and Doran (1999), and Brejda *et al.* (2000) evaluated soil quality indicators from point to regional scales. Cambardella *et al.* (2004) assessed soil quality on a watershed scale by sampling along transects along topographic gradients, and then used terrain analysis to group the data into landform classes. This allowed them to evaluate the effect of topographic position on soil quality. They documented soil quality differences by (i) quantifying soil indicator variables, (ii) calculating soil quality indices, and (iii) comparing indicator variable and index results with independent assessment of soil function endpoints such as sediment loss, water partitioning at the soil surface, and crop yield. Some have suggested indicators that reflect changes over various spatial and temporal scales (Arshad and Coen, 1992), including long-term field studies (Karlen *et al.*, 1994). Karlen *et al.* (1994) developed a soil quality index based on four soil functions: (i) infiltration; (ii) water holding capacity and transmission; (i) degradation resistance; and (iv) supporting plant growth.

Dexter (2004), based on the observations of Dexter and Czyz (2000), proposed a SPQ index, *S*, that enables different soils and the effects of different management treatments and conditions to be compared directly. Pulido Moncada *et al.* (2015) reported that the use of *S* as an indicator to be considered as part of a MDS of indicators of SPQ assessment is less viable when other indicators such as bulk density, porosity, and visual examination are much more easily determined and more consistent than *S*. They concluded therefore, that it is too ambitious to consider that a unique indicator such as the *S* index could be used to evaluate SPQ as such. Although much has been achieved in the evaluation of soil quality, there is yet no universally agree on its evaluation; therefore, a wide variety of methods using vastly different indicators and indexes are used to evaluate soil quality (Qi *et al.*, 2009; Mukherjee and Lal, 2014).

Many of the soil attributes that contribute to soil quality are highly correlated; functioning in concert with other soil attributes (Larson and Pierce, 1991; Seybold *et al.*, 1997). Consequently, soil quality or SPQ may be assessed by evaluating several soil attributes simultaneously using statistical procedures that account for correlations among soil attributes (Brejda *et al.*, 2000). Multivariate statistical analyses provide techniques for simultaneously analyzing correlated variables. Factor analysis is a multivariate procedure used to describe the interrelationships among many correlated variables in terms of a few underlying factors (Johnson and Wichern, 1992). With factor analysis, a large number (*p*) of correlated variables are reduced to $m<p$ uncorrelated factors that are linear functions of the original variables. Each factor is responsible for the correlation among the group of correlated attributes that comprise it (Johnson and Wichern, 1992). If these factors can be related to soil functions, they could represent soil quality factors. Changes in the soil attributes that comprise each soil quality factor could be used to assess soil stability to use and management.

Land use and soil management primarily affect the dynamic properties of soil by changing soil structure and affecting SPQ (Lal and Shukla, 2005). On the other hand, Jenny (1941) had observed that soils and soil properties are known to be configurations of environmental or state factors at a given location. It is common knowledge that topography significantly affects soil characteristics (Ollinger *et al.*, 2002; Yimer *et al.*, 2006) because its slope element drives geomorphic processes (Evans, 1972), retard or accelerate (Weil and Brady, 2017) and cause the convergence or divergence of fluxes of materials on the landscape. Therefore, soils differ in their characteristics primarily because of topography (Aduloju and Tetengi, 2011), and because topography modifies the climate elements (Weil and Brady, 2017).

One reason for variation in soil properties with topographic settings is the orientation of the slopes on which soils develop, and the micro-climate (Iqbal *et al.,* 2004). Geroy *et al.* (2011) observed that soil water retention properties are primarily controlled by soil texture, which in turn varies spatially in response to microclimate-induced differences in isolation, wetness and temperature, all of which can be strongly differentiated by slope aspect. Geroy *et al.* (2011) also reported that soil porosity, soil organic matter and silt content were greater and more water stored on the north aspect than south aspect. Weil and Brady (2017) observed that south-facing slopes are more perpendicular to the sun's rays and are generally warmer and thereby commonly lower in moisture than their north-facing counterparts. Consequently, soils on the south slopes tend to be lower in organic matter and are not so deeply weathered. Ogban and Okon (2020) reported that infiltration characteristics were generally higher on north than south aspects.

Soil quality is a subject that is receiving increasing attention (e.g., Wilson and Maliszewska-Kordybach, 2000). However, research in soil quality is scarce in southern Nigeria. And, although much data on inherent soil properties have been generated over the years, no attempt has been made to integrate them into management categories based on their correlation structures on the Farm of the University of Uyo. The objectives of this study were to (i) evaluate the effects of slope aspect and position on SPQ attributes after 20 years of cultivation and (ii) identify quality soil management attribute-factors that could be used to enhance perceived soil functions for sustainable increases in crop production on this University Farm, relying on Enwezor *et al.* (1990), Ogban *et al.* (2000), Mukherjee and Lal (2014) and Pulido Moncada *et al.* (2015), adopting the broad categories of 'more is better,' 'less is better,' or 'optimum range' approach (Sojka and Upchurch, 1999).

MATERIALS AND METHODS

Study Area

The study which evaluated the status of SPQ between the years 2000 (Ogban *et al.*, 2000) and 2020, was conducted in the University of Uyo Teaching & Research Farm at Use Offot, in Akwa Ibom State. The Farm is 136-ha and has been cultivated for over 30 years. The Farm is located between latitudes 5° 00′ and 5°10′ and longitudes 7°50′ and 8° 00′. It is bisected by a dry valley with two opposing moderate slopes averaging 12% and 10% on the north aspect (NA) and the south aspect (SA), respectively.

The climate of the area is generally hot humid tropical characterized by distinct wet and dry seasons (Inyang, 1975). On the average, the wet or rainy season lasts from April to October and the dry season lasts from November to March, with variations in some years, and recently due to climate change. Generally, the rainfall regime is characterized by heavy storms of high erosion potential and the annual average rainfall may be over 2,500 mm. The average annual temperature is about 26^0C and the relative humidity is about 70% (Petters *et al.,* 1989; Udosen, 2017).

The study area is mostly flat-lying to gently undulating relief. However, slopes ranging from 5% to > 20% occur in some places. It is underlain by the Coastal Plain Sands consisting of tertiary unconsolidated sands deposits known as the Benin formation (Ojanuga *et al.*, 1981). The soils are classified as Ultisols (Keys to Soil Taxonomy, 2020) or Acrisol (FAO, 2014), and are characterized by sandy texture and low fertility due to dominance of kaolinitic, low-activity clays and low contents of organic matter (Ofomata, 1981; Ojanuga *et al.*, 1981; Enwezor *et al.*, 1990; Ogban and Ekerette, 2001; Chikezie *et al.*, 2010; Akamigbo and Nnaji, 2011). The soils are deeply weathered and poorly structured; hence they are permeable and droughty. A variety of bad soil-use practices, including bare cultivation, are common in the area. Also, rapid loss of surface coverage and over dependence on low-input farming are among the drivers of land degradation here. The poor soil conditions coupled with rainstorms and degradative soil-use practices often reduce the soils' capacity to function optimally (Petters *et al.,* 1989; Ogban and Ekerette, 2001; Udosen, 2017).

Field Study

The study was conducted on 12% NA and 10% SA. At the time of the study, the middle slope of NA and crest of SA were under cassava/ pumpkin intercrop and garden egg, respectively. Other slope positions on NA and SA were under a two-year natural fallow. A transect was taken from the crest to the valley bottom of each slope aspect. Each of the two slope aspects was then categorized into three slope positions namely upper (US), middle (MS) and lower (LS) slope positions. At each position, two sampling points 5 m apart were taken on either side of the transect. At each point, three random samples were collected from the top-(30 cm) soil layer using a spade and bulked to give a total of 24 (4 × 3 × 2) samples for the determination of particle-size fractions, aggregate-size distribution, and contents of SOC and amorphous and crystalline oxides iron and aluminum. A set of two undisturbed core samples was also collected with metal cylinders of 7.20 cm height and 6.80 cm internal diameter at each slope position and on either side of the transect, giving 12 (2 × 3 × 2) for the determination of soil bulk density and saturated hydraulic conductivity, K_s. Four infiltration runs were carried out with the double ring infiltrometer (Reynolds *et al.*, 2002) for a duration of 3 h at each slope position, and at 5 m intervals on either side of the transect. Measured cumulative infiltration was used to compute the infiltration rate (i_o), steady-state infiltration (i_c), and the curve-fitting procedure was used to obtain the soil sorptivity (S), and soil transmissivity (A).

Soil Physical Quality (SPQ) Assessment

The bulk soil samples were analyzed for some SPQ properties. Particle-size was analysis was done as described in Gee and Or (2002). Structural stability of the soil was inferred by water-stable aggregates (WSA) ≥ 0.25 mm, and by mean-weight diameter (MWD) of WSA ≤ 4.75 mm (Nimmo and Perkins, 2002). To compute these indices, the aggregates were first physically separated in five size fractions; > 2000, 1000-2000, 250-1000, and 50-250 µm, including the mineral fraction (silt + clay) < 50 µm in diameter. The %WSA > 0.25 mm for the *i*th fraction was computed according to Hillel (1980) thus:

$$WSA_i = \left[\frac{M_{soil.i} - M_{sand.i}}{M_{soil.t} - M_{sand.t}}\right] \quad (1)$$

where *Msoil,i* is the mass of oven-dry soil sample after wet-sieving for the *i*th fraction, *Msand,i* is the oven-dry mass of sand for the *i*th fraction, *Msoil,t* is the mass of the whole sample, and *Msand,t* is the mass of sand in the whole sample. Correction for sand was done to take care of differences in contents of total sand. The MWD was calculated as follows:

$$MWD\ (mm) = \sum_{i=1}^{n} w_i m_i \quad (2)$$

where w_i is the mean diameter of a given size class (mm), m_i is the fractional mass of a given size class (g g^{-1}), and *n* is the number of sieves used. The soil structural stability index, which expressed the risk of soil structural degradation associated with SOC depletion (Pieri, 1992), was calculated thus:

$$SI = \left[\frac{1.72xSOC}{Si + Cl}\right] 100 \quad (3)$$

where *SI* is structural stability index of the soils (%), *Si* is total silt (%), and *Cl* is total clay (%) in the soils. As did Obalum *et al.* (2011, 2013) and Obalum and Obi (2013, 2014), the index was used to group the soils according to their stability.

The higher the value of the above indices, the more stable the soil is. The K_s was determined as described by Reynolds and Elrick (2002). Thereafter, soil bulk density determined by the procedure of Grossman and Reinsch (2002) and total pore space computed (Flint and Flint, 2002). Soil water sorptivity and transmissivity were estimated from the Philip's (1957) two-term algebraic equation:

$$I = S\sqrt{t} + At \quad (4)$$

where *I* is cumulative infiltration (cm), *t* is elapsed time (h), *S* is the soil water sorptivity (cm $t^{-1/2}$), and *A* is the soil water transmissivity (cm h^{-1}). The SOC was determined by the modified Walkley-Black method of Nelson and Sommers (1996). Crystalline and non-crystalline (amorphous) oxides of Fe and Al were extracted by the dithionite-citrate-bicarbonate (Fe_{di} and Al_{di}) solution (DCB) and 0.2 *M* ammonium oxalate (Fe_{ox} and Al_{ox}) solution (Ox) at pH 3.0. Dissolved Fe and Al were measured using Atomic Absorption Spectrophotometer (McKeague and Day, 1966).

Statistical Analysis

Data were subjected to two-way analysis of variance (ANOVA) at the 5% probability level for differences in SPQ among the slope aspects and positions. The data were also subjected to Pearson's correlations and standardized principal component analysis (PCA) to identify best management practices for the sustainable uses of soil of the Farm. The PCA was performed on all untransformed data that showed significant differences between the slope aspects and positions based on the ANOVA to select a minimum dataset (MDS) of best indicators of soil functions at the Farm. Principal components (PCs) for a dataset are defined as linear combinations of the variables such that the strategy described here is similar to that described by Dunteman (1989). We assume that PCs with high values best represent system attributes. Therefore, we examined only the PCs with eigen values ≥ 1 (Brejda *et al.*, 2000).

RESULTS AND DISCUSSION

Effects of Slope Aspect on Soil Properties

Particle-size distribution

The results show that particle-size fractions were similar on NA and SA but dominated by total sand > 85% and > 75%, respectively in the year 2020 (Table 1). Also, total sand was about 13% (NA) and 8% (SA) higher in Table 1 than in the year 2000 (Table 2). Similarly, coarse sand was about 70% and 11% higher than fine sand in 2020 than 2000, respectively, implying that over a 20-year period, about 59% of fine sand was lost on both aspects. Also, both aspects lost respectively 45% and 29% fine sand over the period. During the period too, NA and SA lost, respectively, 49% and 45% of their clay content. Thus, the increased content of total sand and/or coarse sand and decreased contents of fine sand and clay in the surface (30 cm) layer either by infiltrating water and/or surface wash, indicated severe erosion in this layer; the losses, though similar, appeared to be higher on NA than SA. The loss of colloidal materials in a soil negates aggregation because it disrupts the electrostatic bonding of the primary particles in the early stages of formation and stabilization of microstructure. Consequently, bare cultivation encouraged soil erosion, requiring the adoption of appropriate soil management practices in the study area.

Soil texture on both aspects was generally loamy sand (≥ 85%) (Babalola and Obi, 1981). The similarity in texture is ascribed to the parent material and soil erosion processes on the Farm over the years. The sandy texture of the soils on both slopes implies that textural pores may have been skewed toward macropores that facilitate the entry of water and high internal drainage, negating its ability to hold and supply water for crop production. This is so because soil texture affects soil pore geometry, pore-size distribution and the absorptive and capillary potentials (Warrick and Nielsen, 1980), and thus water economy of crop rooting zone.

Soil bulk density and total porosity

Soil bulk density showed marginal changes, being 3.85% higher in NA and 4.97% lower in SA during the 20-year period (Tables 1 and 2). Similarly, soil total porosity increased by 1.18% in NA and 7.93% in SA. These marginal changes imply that the loss of fine sand and clay and the abundance of coarse sand did not influence the preponderance of pores in the soils. However, compared with 1.33 Mg m^{-3} lower and 1.48 Mg m^{-3} upper critical limits for medium-textured soils (Mukherjee and Lal, 2014; Pulido Moncada *et al.*, 2015), the values in Tables 1 and 2 were fairly high and the soil on both aspects deemed compacted and hence degraded in the 30 cm depth, despite the continual tillage operation. The observed soil density values are attributed to the dominance of quartz in the soils. Bulk density and porosity are indexes of soil texture and structure, or the geometric arrangements of the particles and their dynamics (Lal and van Doren, 1990; Franzluebbers, 2002). They are an indicator of soil quality (Lal *et al.*, 1998), influencing soil hydraulic and water transmission properties (Rawls *et al.,* 1998). Dexter (2004) related their SPQ index, *S*, to soil porosity, noting that a combination of textural and structural pores is necessary for good SPQ. However, the observed soil density and porosity values may not limit water transmission and uptake, or hinder root penetration since the loamy sand-textured soils are permeable and uniformly deep (Babalola and Obi, 1981).

Saturated hydraulic conductivity, K_s

Saturated hydraulic conductivity, K_s, the index of soil resistance to flow, averaged 3.10 and 10.6 cm h^{-1} on NA and SA, respectively (Table 1), representing 70.75% significantly ($p < 0.05$) lower on the former than the latter. It appeared to reflect the trend in particle-size fractions and soil bulk density. In 2000, K_s was 49.85% higher on NA than SA (Table 2). During the 20-year period, K_s declined by 93.03% on NA and 52.47% on SA (Tables 1 and 2), indicating severe reductions in water transmission rate in the soils, which might be due to the marginal increases in total pores since small changes in soil porosity/pore-size distribution result in orders of magnitude of change in hydraulic conductivity. Compared to < 1.8 cm h^{-1} critical value for *very low* water movement and 1.8-18.0 cm h^{-1} *optimal range* for water movement (Pulido Moncada *et al.*, 2015), the ranges of values in Tables 1 and 2 show that the soils were disposed to water entry and movement.

The K_s is an important soil hydrological property influencing water movement/retention in saturated and unsaturated soils. It integrates the effects of soil texture and structure and management on soil water (Anderson and Bouma, 1973; Bouma, 1981). It exerts a dominating influence on the partitioning of rainfall into vertical and lateral flow paths (Zimmermann *et al.*, 2013), and influences the flow regime of water in the soil profile.

An important soil function and an index of good SPQ is that the soil accepts, stores and transfers the water for crop uptake. The results of this study showed that the soils may be inhibited in this function, requiring soil management practices that would improve infiltration and plant available water capacity (PAWC) on NA and SA.

Table 1: Effect of slope aspect on soil properties averaged over slope position

Soil property	Aspect		$LSD_{5\%}$
	North	South	
Coarse sand (g kg^{-1})	663.00	677.00	43.40
Fine sand (g kg^{-1})	198.00	198.00	24.00
Total sand (g kg^{-1})	862.00	884.00	25.10
Total silt (g kg^{-1})	46.00	39.00	8.40
Total clay (g kg^{-1})	92.00	77.00	16.70
Bulk density (Mg m^{-3})	1.56	1.53	0.08
Total porosity (m^3 m^{-3})	0.425	0.429	0.03
Ks (cm h^{-1})	3.10	10.60	5.05*
Soil organic carbon (g kg^{-1})	13.80	14.00	3.20
WSA (%)	66.20	61.30	6.70
MWD (mm)	8.38	7.37	3.09
Structural index (%)	17.20	20.80	
Fe_{ox} (mg g^{-1})	1245.00	1235.00	181.00
Al_{ox} (mg g^{-1})	341.20	335.90	30.90
Fe_{di} (mg g^{-1})	1409.00	1340.00	183.30
Al_{di} (mg g^{-1})	192.60	201.10	16.70
IR-i (cm h^{-1})	0.51	0.57	0.12
IR-f (cm h^{-1})	0.19	0.12	0.06**
Cum-I (cm)	34.00	21.0	9.95*
Sorptivity (cm $h^{-1/2}$)	0.51	0.69	0.18*
Transmissivity (cm h^{-1})	0.23	0.14	0.05**

*significant at $p < 5\%$; ** significant at $p < 1\%$;
Ks - saturated hydraulic conductivity;
IR-i initial infiltration rate; IR-f - final infiltration rate;
Cum-I - cumulative infiltration;
WSA - water stable aggregates; MWD - mean weight diameter;
Fe_{ox} - oxalate Fe; Al_{ox} - oxalate Al; Fe_{di} - DCB Fe; Al_{di} - DCB Al

Table 2: Effect of slope aspect on soil physical properties averaged over slope position*

Soil property	Slope Aspect		Std. dev.±
	North	South	
Coarse sand (g kg^{-1})	393.00	536.00	10.18
Fine sand (g kg^{-1})	359.00	279.00	8.38
Total sand (g kg^{-1})	751.00	815.00	2.10
Total silt (g kg^{-1})	65.00	44.00	1.40
Total clay (g kg^{-1})	183.00	141.00	2.10
Bulk density (Mg m^{-3})	1.50	1.61	0.14
Total porosity (m^3 m^{-3})	0.42	0.395	4.82
Ks (cm h^{-1})	44.47	22.30	13.53
Soil organic carbon (g kg^{-1})	16.20	22.70	0.28
WSA (%)	49.60	50.00	6.97
MWD (mm)	1.67	1.77	0.13
Structural index (%)	33.50	67.20	
Fe_{ox} (mg g^{-1})	739.50	850.70	69.84
Al_{ox} (mg g^{-1})	103.00	97.10	5.03
Fe_{di} (mg g^{-1})	741.60	866.20	74.88
Al_{di} (mg g^{-1})	110.00	98.10	5.44
IR-i (cm h^{-1})	3.00	4.20	0.98
IR-f (cm h^{-1})	0.09	0.14	0.03
Cum-I (cm)	6.28	7.58	0.92
Sorptivity (cm $h^{-1/2}$)	10.20	4.80	3.12
Transmissivity (cm h^{-1})	2.40	3.60	1.33

Ks - saturated hydraulic conductivity;
IR-i initial infiltration rate; IR-f - final infiltration rate;
Cum-I - cumulative infiltration;
WSA - water stable aggregates; MWD - mean weight diameter;
Fe_{ox} - oxalate Fe; Al_{ox} - oxalate Al; Fe_{di} - DCB Fe; Al_{di} - DCB Al
*Ogban *et al.* (2000).

Soil organic carbon, SOC

The SOC content was similar on NA and SA, averaging 13.8 and 14.0 g kg^{-1}, respectively in 2020 (Table 1), and 16.2 and 22.7 g kg^{-1} in 2000 (Table 2). It was 1.45% and 40.12% lower in NA than SA in 2020 than 2000, respectively. Similarly, the decline in SOC over the 20-year period was lower (14.81%) in NA than SA (38.33%). These losses represent an average of 26.57% carbon flight from the slopes, a significant degradation of the soil. Compared to the rating by Enwezor *et al.* (1990); < 11.6 g kg^{-1} as low, 11.6-17.4 g kg^{-1} as medium, and > 17.4 g kg^{-1} as high for southeastern Nigeria soils, SOC content was in the medium range in 2020, and high in 2000, further indicating the sustained loss over the period. Also, compared to Pulido Moncada *et al.*'s (2015) rating; < 11.6 g kg^{-1} as low, 11.6-23.2 g kg^{-1} as medium, and > 23.2 g kg^{-1} as high; the soils were medium in SOC concentration in Tables 1 and 2.

Generally, SOC plays vital roles in the maintenance and improvement of soil properties and functions, e.g., soil water retention and transmission, aggregate formation and stabilization against erosion and other degradative processes (Agbim and Adeoye, 1991; Lal and Shukla, 2005). Enwezor *et al.* (1990) described the soils in the area as low in SOC content. Enwezor *et al.* (1981) attributed the low content of SOC to favourable high moisture and temperature conditions that favour soil organic matter decomposition in south-eastern Nigeria. Jenkins and Ayanaba (1977) noted that decline in SOC content of cultivated soils is a direct effect of high temperatures throughout the year that enhance the mineralization of organic matter, and preferential removal of soil colloids, including the humified organic matter fraction by water erosion down slope (Lal, 1976), adversely affecting soil structural stability, infiltrability, and plant-available water reserves. It was probable that years of exposure to degradative cultivation practices (plough-bare soil surface management) had favoured SOC sequestration in the atmosphere, contributing to atmospheric radiative gases. The SOC is dynamic and sensitive to management practices and therefore can be used as an indicator of degradation of SPQ and diminishing agronomic function (Larson and Pierce, 1994; Doran and Parkin, 1996; Karlen *et al.,* 1997; 1998; Obalum *et al*., 2017), requiring the use of plant residues, manures and rotational fallow to improve SOC storage.

Effect of Slope Aspect on Aggregate Stability

Water-stable aggregates & mean-weight diameter

The indices of soil structural stability, %WSA and MWD averaged respectively 66.2% and 61.3% and 8.38 mm and 7.37 mm, and were not significantly different in NA and SA (Table 1). The respective average values in Table 2 are 49.6% and 50.0%, and 1.67 mm and 1.77 mm. The results showed that WSA was 4.90% higher in NA than SA (Table 1). Over the evaluation period, WSA in the respective aspects was significantly higher in 2020 (60.53%) than 2000 (55.53%). Compared with Mukherjee and Lal (2014) and Pulido Moncada *et al.* (2015); < 50.0% as low, 50-70% as medium, and > 70.0% as high aggregate stability, the soils on NA and SA were categorized as very low in macrostructural stability (Table 1) and medium aggregate stability (Table 2). Similarly, MWD was not significantly different between NA and SA at each sampling period, but increased remarkably by 31.26% in NA and 21.71% in SA (Table 2 to Table 1).

The increases in WSA and MWD were against the trend in SOC and its depletion in the soils. The percentage WSA (> 60.0%) on the slopes indicated that macro aggregates dominated the aggregate hierarchy. And since the formation and stabilization of macrostructure is in the domain of organic matter, the residual organic matter, despite being depleted, may have caused the increases in macrostructural stability in the soils. The results of WSA and MWD were corroborated by the soil structural index, SI, whose values were on NA and SA, respectively 17.2% and 20.8% in 2020 and 33.5% and 67.2% in 2000 (Tables 1 & 2). The results also indicated that SI declined by 48.6% on NA and 69.0% on SA; the decreases in SI following the pattern of SOC depletion. However, compared to Mukherjee and Lal (2014) and Pulido Moncad *et al.* (2015) or Pieri (1992); < 5% as structurally degraded soil, 5-7% as soil with high risk of degradation, and > 9% as soil with sufficient C; the soils whose data are in Tables 1 and 2 would be highly structurally stable against disruption due to tillage and raindrop impact.

With the observed values of WSA and MWD, cultivation that fragments soil structure through degradation of soil organic matter (Six *et al.*, 1998) may not have adversely affected the soils. Indeed, the results indicated a high degree of structural stability on NA and SA, irrespective of the contrary trend in SOC content which was higher on SA where WSA and MWD were lower. The higher WSA and MWD on NA may also be attributed to less disruption of soil aggregates by raindrops (Webster and Wilson, 1980). Soil aggregate stability relates to soil resistance to raindrop impact, erosion and runoff, as well as its ability to accept, store and transmit water for crop growth. The results obtained indicated that the soil physical conditions in terms of structural porosity and stability were optimum for soil-water relations function but that quality soil management methods must be adopted to sustain the amount of SOC and stability of the soils.

Fe and Al oxides

The Ox and DCB extractable Fe and Al showed similar values but generally tended to be higher on NA than SA in 2020; Fe was higher than Al on NA and vice versa on SA in 2000 (Tables 1 and 2). Both forms of oxides were significantly higher in 2020 than 2000. For instance, Ox extractable Fe and Al increased by 40.6% and 69.8% on NA, and by 31.0% and 71.1% on SA. Also, the more reactive Fe and Al (amorphous) oxides were less abundant than the crystalline oxides in the soils. However, Fe and Al oxides are part of the organo-mineral complexes that contribute to good soil structure by cementation of clay and stability of micro aggregates against colloidal dispersion and soil erodibility. Since the oxides are micro aggregants, it appeared that they were active in the about 40% micro structural stability in the soils. Igwe and Obalum (2013) indicated that Fe and Al oxyhydroxides play an important role in the colloidal stability of tropical soils though these oxidic substances are not easily manipulated in regular soil management practices. As indices of macroaggregate stability of soils, WSA and MWD depend not only on total amount of organic matter but more importantly on its chemical composition (Barthes *et al.*, 2008). Hence, soil management must emphasize organic matter and its composition as a means of protecting macro aggregates against breakdown to micro aggregates, erosion and deterioration of SPQ on the Farm.

Effect of Slope Aspect on Water Infiltration

Water intake

Initial infiltration rate (IR-i) being water intake in the first 1 min. averaged 0.51 and 0.57 cm h^{-1} in 2020 (Table 1) and 3.0 and 4.2 cm h^{-1} in 2000 (Table 2) on NA and SA, respectively. The effect of aspect on IR-i was similar. Notably, its pattern of differences resembled that of particle-size fractions, indicating that textural pores may have controlled the simulated acceptance of rainwater. However, final infiltration rate (IR-f) and cumulative infiltration (Cum-I) were significantly higher on NA than SA in 2020 and vice versa in 2000 (Tables 1 and 2). Over the 20-year period, IR-i declined by 83.0% on NA and 86.43% on SA; IR-f increased by 52.63% on NA and decreased by 14.29% on SA; and Cum-I increased by 81.53% on NA and 63.9% on SA.

Infiltration is one of the rapidly changing, highly dynamic characteristics of the soil (Sparling, 2008). Thus, since IR-i decreased by > 80% over the period, soil texture did not influence it in the 30-cm depth. This was probably because the rains occurred in storms and ponded rapidly to the detriment of infiltration. It was also probable that the soil pores below the 30-cm depth had been clogged by the finer particle-size fractions depleted from the topsoil layers affecting K_s and downward flow. Consequently, the low infiltration rate generally and the decreases within 20 years were attributed largely to rainfall characteristics. However, it also appeared that Cum-I increased as reflected in the > 80% on NA compared to > 60% on SA, which would be good for the water economy of the rooting zone especially in NA, provided that it would not be lost to deep percolation.

Compared to the average monthly rainfall depth of about 200 cm in the area (Udosen, 2017), the Cum-I indicated that much of rainwater was lost in runoff, but more on SA than NA. Also, the IR-f, an index of the maximum flux of water into the soil, was low on NA and SA. Since IR-f varies with soil texture and structure, and indirectly with Ks, IR-1 and Cum-I would increase with suitable tillage and residue management on the Farm, as surface residue helps to conserve soil moisture (Ogban, 2017).

Sorptivity and transmissivity

Soil water sorptivity, S, was significantly ($p < 0.05$) higher on SA than NA in 2020 but on NA than SA in 2000; the reverse was the situation for soil water transmissivity, A (Tables 1 and 2). Over the 20 years, S decreased by 95.0% in NA and 85.63% in SA, while A decreased by 90.42% in NA and 96.11% in SA. These results imply serious deterioration of SPQ and the soils' ability to perform soil-water relations function, and explain the low values of Cum-I recorded on both aspects of the Farm.

Soil sorptivity, S, reflects the cumulative amount of water infiltrated into the soil at the early stages of infiltration. It depends on initial moisture content, time and the absorptive forces that usually govern the early stages of infiltration. These forces being functions of pore-size distribution in the soils are more effective in fine-textured soils with dominance of capillary pores than in coarse-textured soils dominated by drainage pores. Results have shown that the 30-cm soil depth was coarse-textured and characterised by drainage pores with low capillarity, and this could explain the values observed of S and A. However, to regenerate the soils and improve their water retention capacity, suitable soil management practices such as rotational fallows and the use of manures and crop residues are needed so that the organic matter will bond the primary particles, form and stabilize soil aggregates, maintain infiltration at high rates and increase the magnitude of S and A and soil moisture storage in the root zone depth.

Effect of Slope Position on Basic Soil Properties

The effect of slope position on soil properties showed that the particle-size fractions, bulk density and total pore space were not significantly different among the three slope positions (Table 3). However, there was a general trend of decreases in the values of the mechanical separates from US to MS, followed by an increase in the LS. For instance, while total sand was lowest at US and highest at MS, clay fraction and soil bulk density were highest at US and lowest at MS on both aspects. Similarly, there were no differences in K_s among the slope positions, but K_s increased from US (4.7 cm h^{-1}) to MS (9.1 cm h^{-1}) and decreased down the slope (6.8 cm h^{-1}). With Table 2 as baseline, the results (Table 3) indicated the effect of erosion on the mechanical properties in the 30-cm soil depth.

Table 3: Effect of slope position on soil properties averaged over slope aspect

	Slope position			
Soil property	Upper	Middle	Lower	LSD$_{5\%}$
Coarse sand (g kg^{-1})	659.00	690.00	661.00	53.20
Fine sand (g kg^{-1})	205.00	280.00	210.00	29.60
Total sand (g kg^{-1})	864.00	883.00	871.00	30.70
Total silt (g kg^{-1})	45.00	39.00	43.00	10.20
Total clay (g kg^{-1})	91.00	78.00	86.00	20.50
Bulk density (Mg m^{-3})	1.58	1.51	1.54	0.098
Total porosity (m^3 m^{-3})	0.407	0.447	0.427	0.042
Ks (cm h^{-1})	4.70	9.10	6.80	6.18
Soil organic carbon (g kg^{-1})	13.80	15.10	12.80	3.97
WSA (%)	62.50	67.70	61.00	8.30
MWD (mm)	6.71	5.88	11.04	3.78*
Fe$_{ox}$ (mg g^{-1})	1141.00	1261.00	1317.00	221.70
Al$_{ox}$ (mg g^{-1})	327.10	330.50	358.10	37.80
Fe$_{di}$ (mg g^{-1})	1487.00	1362.00	1275.00	224.50
Al$_{di}$ (mg g^{-1})	193.10	201.50	195.90	20.50
IR-i (cm h^{-1})	0.63	0.54	0.46	0.15
IR-f (cm h^{-1})	0.22	0.13	0.11	0.07**
Cum-I (cm)	39.7	23.3	19.50	12.20*
Sorptivity (cm h$^{-1/2}$)	0.67	0.62	0.51	0.22
Transmissivity (cm h^{-1})	0.27	0.14	0.15	0.06**

*significant at $p < 5\%$; ** significant at $p < 1\%$; *Ks* - saturated hydraulic conductivity; IR-i initial infiltration rate; IR-f - final infiltration rate; Cum-I - cumulative infiltration; WSA - water stable aggregates; MWD - mean weight diameter;
Fe$_{ox}$ - oxalate Fe; Al$_{ox}$ – oxalate Al; Fe$_{di}$ - DCB Fe; Al$_{di}$ - DCB Al

The SOC concentration was similar among the slope positions (Table 3), and the pattern of variation was similar to the mechanical properties; results supporting Lal (1976) on the preferential removal of soil colloids (including humified organic matter) by water erosion down sloping lands. It could be inferred from the data that since SOC content was medium (Enwezor *et al.*, 1990; Pulido Moncada *et al.*, 2015), the many years of cultivation sustained low levels of SOC in the soil, contrary to Enwezor *et al.* (1981) that intensive cultivation depletes SOC. However, there was a decline in SOC here, and viable soil management practices, e.g., rotational fallowing, are needed to store SOC in the soils.

Effect of Slope Position on Aggregate Stability and Infiltration Characteristics

The data in Table 3 show that over 60.0% of the sand-free aggregates estimated by WSA were stable and similar on US, MS and LS of NA and SA. It appeared that the decreases in SOC did not affect the status of WSA in the soils over the 20-year period. This was corroborated by the increases in MWD at all slope positions over their average values in Table 2. Since SOC enhances macro-structural stability (Tisdall and Oades, 1982), it is probable that the available organic matter was effective in the aggregation process. Consequently, the use of crop residues and manures would improve SOC content and sustain aggregate stability in the soils.

The IR-i and *S* were not significantly different, while IR-f, Cum-I and *A* differed ($p < 0.05$) among the slope positions (Table 3). The IR-i decreased down the slope, while IR-f was significantly higher at US than MS and LS. Compared to the average values in Table 2, the infiltration characteristics decreased significantly at the slope positions during the 20-year period, indicating loss in the fitness of the soil to accept water, i.e., that a great proportion of rainwater was lost as runoff on the farm. With the observed degradation in mechanical, aggregate and hydrological properties, portray by the data in Tables 1-3, there is the need for quality soil surface management techniques on the slopes for erosion control and moisture conservation. Soil management practices as incorporation of residues and manures and ploughing across the slopes would form the basis for enhancing structural stability, cumulative depth of infiltrated water, and soil moisture storage.

Identification of Management Factors for the Teaching and Research Farm

Pearson's correlation coefficients among the soil properties showed significant ($p < 0.05$) correlations in 28 out of 190 soil property pairs (Table 4). Although the frequency of correlation was low, it still indicated that the soil attributes could be grouped into factors based on their correlation patterns. Positive significant correlations existed between IR-f and Cum-I and *A*, total silt and total clay, Cum-I and *A*, Fe$_{ox}$ and Fe$_{di}$, IR-i and *S*, and coarse sand and total sand. The strongest negative correlations were between total sand and total silt and total clay, coarse sand and total silt, coarse sand and total clay, coarse sand and fine sand, and soil bulk density and total porosity. The significant correlations mostly involved particle-size fractions, bulk density, total porosity and water intake rate. The positive significant correlations between total porosity and K_s and between K_s and IR-I min and *S* indicated the influence of pore space on water intake rate and post-intake soil water distribution.

The PCA was used to group the soil attributes into seven soil management factors (Table 5), and each of the selected factors had eigen values > 1 (Table 6). The essence of these factors was to identify

Table 4: Correlations matrix of soil properties on the University of Uyo Teaching and Research Farm

Soil prop.	CS	FS	TS	TSilt	TClay	BD	TP	K_s	IR-i	IR-f	Cum-I	S	A	WSA	MWD	SOC	Fe_{ox}	Al_{ox}	Fe_{di}
FSand	$-.733^{**}$	1																	
TSand	$.755^{**}$	-.286	1																
TSilt	$-.755^{**}$	.286	-1.0^{**}	1															
TClay	$-.755^{**}$	.286	-1.0^{**}	1.0^{**}	1														
BD	-.123	.224	-.133	.133	.133	1													
TP	.313	$-.425^{*}$	.230	-.230	-.230	$-.739^{**}$	1												
K_s	.287	-.244	.349	-.349	-.349	$-.586^{**}$	$.637^{**}$	1											
IR-i	.113	-.182	.113	-.113	-.113	-.276	.313	$.442^{*}$	1										
IR-f	.001	-.164	-.197	.197	.197	-.105	.080	.071	$.600^{**}$	1									
Cum-I	-.001	-.162	-.196	.196	.196	-.102	.080	.073	$.605^{**}$	1.0^{**}	1								
S	.050	-.080	.169	-.169	-.169	-.301	.259	$.494^{*}$	$.777^{**}$	.179	.185	1							
A	-.046	-.096	-.229	.229	.229	-.113	.000	.027	$.614^{**}$	$.981^{**}$	$.981^{**}$	.222	1						
WSA	.137	$-.519^{**}$	-.184	.184	.184	.087	.108	-.193	.001	.377	.375	-.338	.282	1					
MWD	-.090	.057	-.208	.208	.208	.016	-.080	-.218	-.152	.029	.021	-.234	.073	-.036	1				
SOC	.239	-.292	-.138	.138	.138	-.090	.212	.051	-.077	.014	.008	-.176	-.054	.151	.166	1			
Fe_{ox}	.154	$-.443^{*}$	-.141	.141	.141	.171	.051	-.103	.234	.306	.303	.070	.259	$.531^{**}$	.117	.231	1		
Al_{ox}	.251	-.132	.080	-.080	-.080	.262	.154	.052	-.074	-.296	-.296	-.052	-.286	-.012	.062	.248	.125	1	
Fe_{di}	.119	-.279	-.191	.191	.191	.294	-.026	-.072	.140	$.440^{*}$	.434	-.025	.382	.322	.157	.247	$.805^{**}$	.058	1
Al_{di}	-.009	-.004	.003	-.003	-.003	.175	.041	.061	-.368	-.369	-.371	$-.412^{*}$	$-.441^{*}$	.035	.109	.147	.258	.035	.322

*significant at $p < 5\%$; ** significant at $p < 1\%$; BD - bulk density; TP - total porosity; other abbreviations as explained in the previous tables

some viable soil and water management techniques for improving and sustaining the soil functions for crop production on the Farm. The seven factors explained 87.7% of the variability in soil properties. The first factor was termed *water intake factor* because it had high positive loadings (> 0.90) on A, IR-f and Cum-I, moderate positive loading (> 0.70) on IR-i and moderate negative loading (> 0.60) on Al_{di}, and explained 23.5% of the total variance. The ability of a soil to accept and store water is a key soil function for agricultural productivity. This first factor thus demonstrated the need water conservation in the root zone for sustainable crop production in the coarse-textured soil on NA and SA.

The second factor was termed *soil texture factor* because it had high positive loadings (> 0.90) for total silt and total clay and high negative loadings (> 0.80) for total sand and coarse sand and (Table 4), and explained 22.4% of the total variance (Table 5). Soil texture affects the physical and chemical fertility of the soil. It is a static soil property that could be managed through the application of organic inputs that would improve soil aggregation. The 1.1% difference in percentage variance between the *intake factor* and *soil texture factor* indicated that the proper management of the latter, being critical limiting factor for water intake and retention, is important in the water economy of the root zone.

The third factor was termed the *pore space factor* because it had high positive loadings (> 0.80) on total porosity and moderate positive loading (> 0.70) on K_s and high negative loading (> 0.80) on soil bulk density (Table 4), and explained 14.5% of the total variance (Table 5). Pore space geometry is an important hydraulic property. The texture of the soil indicated that its porosity was dominated by macro or drainage pores and that the soil was susceptible to moisture stress even in the rainy season. Pore space-induced moisture stress could be managed by the application of organic residues that could improve the moisture retention capacity of the soil.

Oxides characterised factors 4 and 6 and both were termed *Fe-Al oxide factor*. Factor 4 had positive loadings (> 0.80) on Fe_{ox} and Fe_{di}, and moderate positive loading (> 0.60) on Al_{di} and explained 9.6% of the total variance; factor 6 had high positive loading (> 0.80) on Al_{ox} and explained 5.7% of the total variance (Tables 4 and 5). Both crystalline (Fe_{di} and Al_{di}) and poorly crystalline (Fe_{ox} and Al_{ox}) oxyhydroxides are responsible for microaggregation in deeply weathered tropical soils, compensating for the low contents of organic matter in them (Igwe *et al.*, 1995; Igwe and Obalum, 2013). Again, the addition of organic residues would enhance the formation of stable macroaggregates and reduce the removal of finer particles and microaggregates.

Factors 5 and 7 were termed *WSA* and *MWD factor* or *soil structural stability factor* because of high positive loadings (> 0.80) on WSA and MWD (Table 4), and explained 6.7% and 5.3% of the total variance, respectively (Table 5). The WSA and MWD are indices of macroaggregate stability. Although the rankings showed that WSA was relatively more important than MWD, both are needed for enhanced moisture and nutrient conservation, carbon sequestration and checking of soil erosion to improve and sustain the productive capacity of the soils for increases in crop production on the Farm. Although the principal component factors are statistical constructs, they combine the inherent soil properties for focusing of quality soil management.

Table 5: Rotated component matrix

	Rotated Component Matrix						
	1	2	3	4	5	6	7
CSand	.059	-.843	.170	.111	.295	.289	.055
FSand	-.162	.392	-.344	-.277	-.576	-.302	.078
TSand	-.099	-.972	.101	-.071	-.086	-.032	-.087
TSilt	.099	.972	-.101	.071	.086	.032	.087
TClay	.099	.972	-.101	.071	.086	.032	.087
Bd	-.114	.038	-.878	.276	-.034	.175	-.079
Tp	.022	-.146	.882	.034	.136	.135	-.013
Ksat	.050	-.260	.785	.077	-.264	.012	-.162
IR-1	.716	-.106	.348	.142	-.344	.133	-.282
IR-f	.934	.094	.051	.166	.149	-.152	.050
Cum-I	.935	.094	.050	.164	.145	-.153	.040
S	.390	-.103	.369	.023	-.597	.208	-.418
A	.957	.123	.002	.095	.059	-.135	.069
WSA	.243	.099	-.038	.276	.829	.025	-.137
MWD	.050	.115	-.074	.083	-.099	.063	.874
SOC	-.063	.104	.262	.178	.296	.475	.412
Fe_{ox}	.231	.048	-.031	.834	.233	.203	-.042
Al_{ox}	-.238	-.084	-.067	.079	-.034	.842	.024
Fe_{di}	.294	.063	-.115	.871	.098	.073	.138
Al_{di}	-.614	.008	.069	.636	.044	-.270	.170

Table 6: Total variance explained by the factors

Components	Eigen values		
	Total	% of Variance	Cumulative %
1	4.693	23.467	23.467
2	4.481	22.405	45.871
3	2.909	14.547	60.418
4	1.928	9.639	70.057
5	1.338	6.692	76.749
6	1.134	5.672	82.421
7	1.051	5.256	87.677

CONCLUSION

The study evaluated the effect of slope aspects and positions on soil physical quality (SPQ) at the University of Uyo Teaching and Research Farm over a 20-year period and proffered management factors for sustainable crop production on the Farm. Virtually all indicators of SPQ namely particle-size fractions, bulk density and total porosity, K_s, SOC, infiltration characteristics (IR-i, IR-f, Cum-I, S and A), and oxides of Fe and Al declined remarkably, while WSA, MWD and SI remained relatively unchanged on NA and SA and slope positions over the 20-year period. The decreases in the SPQ attributes indicated serious soil degradation. The PCA identified seven factors that could guide quality soil management on the Farm namely (1) *water intake*, (2) *soil texture*, (3) *pore space*, (4) and (6) *Fe and Al oxide*, and (5) and (7) *structural stability.* The importance of water infiltration, storage and transfer function expressed by the status of particle-size fractions and infiltration characteristics was underscored by PCA *factors* 1, 2 and 3; *factors* 2 and 3 being the determinants of *factor* 1 and soil moisture retention and release capacity. The PCA factors could thus aid the selection of SPQ conservation and management techniques for sustainably improving the productive capacity of the soils on the slope aspects of the Farm. The recommended quality soil management practices include adoption of rotational fallows and application of crop residues, manures and organo-mineral fertilizers. Ploughing across the slope to incorporate the organic materials would generate organic matter for increased aggregation of the soils, translating into improved infiltration, water retention capacity and hence erosion resistance on the Farm.

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