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Soil Management Systems Based on Soil Quality at Three Different Toposequences in Cross River State, South-Eastern Nigeria

Ogban*, P. I., Abang, P. O. Achi, E. A. and Nweke, C.

Department of Soil Science and Land Resources Management, University of Uyo, Uyo, Nigeria

ABSTRACT

The morphological, physical and chemical characteristics of three toposequences were studied in order to offer suggestions on soil management systems that would increase crop production in South-eastern Nigeria. The study was conducted at the upper slope, middle/lower slope, and valley bottom on three parent materials, namely, basement complex (BC), sandstone and sandstone/shale. The Ap horizon was generally shallow. A hue of 7.5YR typified the landscapes, and colour value ranged from light-brown to brown. Low chroma in the matrix and high value mottles were common in the valley bottom. The soil profiles were similar in soil structure and consistency, generally weak, medium sub-angular blocky and friable topsoil to very sticky and very plastic subsoil. Sand was the dominant particle-size fraction. Soil texture was either sandy loam or loamy sand overlying sandy clay or sandy clay loam. Soil density varied with the soil profiles. Macropores were generally greater than 50% of total pore space. Saturated hydraulic conductivity (Ksat) was 2.16, 1.50 and 1.28 cm h^{-1} in the respective toposequences. Water stable aggregates > 2.0 mm averaged 28.8%, 26.5% and 33.5%, while >0.5mm averaged 52.1%, 60.1% and 51.5%, respectively in the topographic positions of the toposequences. The soil profiles were slightly acidic. Soil organic C, averaged over all toposequences was 11.6, 12.5 and 10.5 g kg^{-1}, while available phosphorus was 9.32, 6.77 and 20.04 m kg^{-1}, respectively. Similarly, CEC averaged 7.21, 10.61 and 12.48cmolkg-2, while base saturation was 45.4%, 67.8% and 78.6%, respectively. Based on the soil characteristics, three soil management units (SMU) were identified as SMU A (Upper slope), SMU B (Middle/lower slope) and SMU C (Valley bottom). The corresponding soil management systems (SMS) are dry land farming with agroforestry and planted fallow in SMU A, wetland and dry land farming in SMU B, and wetland, and wetland/dry land farming in SMU C. These SMUs and SMS will facilitate the use of the soils on the slopes and lead to an increase in crop production and farmers' income in the study area and other areas with similar soil and ecological conditions. These SMS are being recommended for use by agricultural extension agents to assist farmers cultivate their sloping lands in a more efficient and productive manner.

Keywords: Soil characteristics, topographic position, soil management unit, soil management system

*Corresponding author : *cgulser@omu.edu.tr*

INTRODUCTION

Soils and their properties are known to be determined by the configuration of the state factors, the clorpt (climate, organisms, parent material, topography, and time) at a given location (Jenny 1980; Jungerius 1985). Beckett and Webster (1971) associated soil variation with landscape position, the clorpt, and/or soil use and management. Olatunji *et al*. (2007) observed a strong association between topographic position and soil properties rather than parent material. This is because topography through its slope element drives geomorphic processes (Evans 1972) through its influence on the speed of water flow, velocity of colluvial material and infiltration into soil. Topography significantly affects earth's surface water characteristics, endogenic and exogenic soil forming factors, and plays a crucial role in the spatial distribution of soils and their properties (Moore and Hutchinson 1991; Schaetzl and Anderson 2005; Seibert *et al.* 2007; Behrens *et al*., 2010). Consequently, in an undulating landscape, the influence of topography on soil characteristics and hence the potential for crop production can be substantial.

Soils frequently occur in well defined and regular sequences related to relief or topography (Ahn1970; Okusami *et al.* 1985). Moormann (1981) defined a toposequence as a succession of sites from the summit to the valley bottom. Some soils on the toposequence (e.g., crest – upper and middle slope) may be sedentary, while others (e.g., lower slope and valley bottom) may have developed from transported materials derived from the underlying geology of the area (Smyth and Montgomery 1962) Similarly, differences in parent material may occur on a toposequence even though the underlying geology may be uniform.

Differences among soils on a toposequence are also related to differences in drainage which are related to relief (Ahn 1970). Well-drained, imperfectly drained, and poorly drained soils are often found closely associated along a toposequence. Colour differences have also been used to separate soils on toposequences in West Africa. Gerrard (1981)reported that upland, well-drained soils are usually reddish brown or brownish red, middle and lower slope soils are brown or brownish yellow due to slower drainage, while poorly drained valley bottom soils are bluish grey, etc., and may be mottled (Brady and Weil 2002) because of fluctuating water tables. Generally, their colours range from reddish hues upslope to yellowish hues in the valley bottom (Fagbami and Udo1982).

Smyth and Montgomery (1962), Gerrad (1981)and Carsky (1992) observed that soils formed along a slope often varied greatly in pedological, chemical and mineralogical characteristics. De Souza *et al.* (2009) reported that variations in landscape shape promoted differentiated variability of the physical and mineralogical soil properties. Walker *et al*. (1968), Ahn (1970) and Stoop (1987) found that soil fertility and organic matter content were mostly low in the upper and middle slopes and soil degradation could be rapid when cultivation is intensified, compared to the higher organic matter content and fertility status, low erosion hazard and adequate soil water availability in the valley bottom.

Odemerho (1980) stated that the distribution of individual soils on a toposequence as well as the spatial distribution of toposequences have considerable

influence on land use utilisation, pattern, and soil management. Conversely, management practices affect significantly soil variability (Castringano *et al.* 2000), especially successive agricultural activities and erosion. Eshett (1985), van Stavern and Stoop (1985) and Carsky and Masajo (1992) reported that the local farmers often cleverly utilise the spatially variable conditions along the toposequence to diversify their crops. Consequently, because of the diversity of soil types and ecological conditions, a range of technological options may be required on a toposequence (Stoop *et al*. 1982; van Staveren and Stoop, 1985).

The toposequence concept has been studied intensively in Nigeria (Smyth and Montgomery, 1962; Juo, 1980; Juo and Moormann, 1980). Ogunwale *et al.* (1986) found soils on the upper and middle slope to be sandy to sandy clay loam, and sandy in all horizons in the lower slope and valley bottoms on coastal plain sands in South-western Nigeria. Fagbami and Udo (1980) reported that soils on the upper and middle slopes were coarse-textured while they were fine-textured in the lower slope and valley bottom on the basement complex in the Abuja area, Nigeria.

Juo and Moormann (1980) and Eshett (1985) identified three topographic positions/land types along toposequences in South-eastern Nigeria, namely, the upper and middle slope land, the lower slope land, and the valley bottom land. However, while Juo and Moormann (1980) considered the land types unsuitable for extensive food crop production on account of their shallow soil depth, sandy texture and erosion, Eshett (1985) reported that the upper, middle and lower slope and valley bottom soils of basaltic parent material are extensively used for yam-based cropping, and wetland rice cultivation, respectively. All this indicate that the soil-landscape relationship could be used in assessing potential land uses (Carsky and Masajo 1992). As yet, specific and suitable land and soil and crop management systems have not been developed for the sloping lands in the area of the current study and similar places elsewhere. The objectives of this study were (i) to characterise the soils occurring on physiographic positions along toposequences, and (ii) to propose appropriate management systems for the land types in Cross River State to improve agricultural production.

MATERIALS AND METHODS

Description of Study Area

The study was conducted in Assiga in central, and Adim and Odukpani in southern Cross River State, South-eastern Nigeria. The areas lie between latitudes 5° 30′ and 6° 00′ N and longitudes 8° 00′ and 8° 45′ E. The climate of the area is tropical, hot and humid with high temperatures and pronounced wet and dry seasons. Mean annual temperature is near uniform, varying between 26°C and 28°C, while mean annual rainfall varies from 2500 to 3000 mm. High relative humidity is common, averaging about 80%.

The area is situated over several geological formations, the predominant being the Quaternary coastal plain sands, the Cretaceous Cross River sandstone

group, and the Pre-Cambrian Basement complex. The most extensive formation is the Cretaceous Cross River sandstone group. Assiga is located on the Cretaceous sandstone plains; Adim is on the crystalline basement complex, while Odukpani is on the Cretaceous sandstone/shale (Odukpani Formation) parent materials. The soils show very strong influence of the underlying lithology. The depth of the soils varies considerably from shallow, due to underlying concretionary materials, to deep on well-developed soil profiles. Soil texture varies from loamy sand and sandy loam in the surface to sandy clay and clay in the subsurface layers. The soils are structurally unstable, generally low in inherent physical and chemical fertility, and susceptible to high erosion rates.

The vegetation in the area comprises the southern Guinea Savanna, the rain forest, and the mangrove and freshwater swamp forest. Much of the area has been farmed and the secondary forest that is now common is a degradation of the original natural rain forest vegetation. A variety of agricultural and non-agricultural activities contribute to modifying the native vegetation. A wide variety and diversity of tress, shrubs and grasses are common in the landscape. The area, as in other parts of the State, supports a wide range of agricultural crops, both for food and raw materials. The major food crops include yams, maize, plantains and bananas, rice and a variety of vegetables. The major plantation crops are oil palm, cocoa and rubber. The land use systems are upland/dry land or wetland uses, and based on traditional shifting cultivation with the associated bush or natural fallow rotation. But the fallow period has become shortened to about 4 years from 7-15 years (Ogban *et al.* 2004: 2005) and this has left the vegetation immature and unable to restore soil quality attributes (Areola 1990). Continuous cultivation has therefore become common in most places in the low external inputs production systems.

Fields Methods

The study was conducted at three topographic positions, namely upper slope, middle/lower slope and valley on three toposequences. At each site, and at each topographic position, soil profile pits were dug, described and sampled according to FAO/WSRI (2006). In the valley bottom, soil samples were collected with an auger according to designated depths of 0-15, 15-30, 30-50, 50-75 and 75-100cm because the soils were wet (at the time of study).

Bulk soil samples were collected from the depth zones for physical and chemical analyses. Undisturbed soil samples were also collected with metal cylinders measuring 7.2 cm long and 6.8 cm internal diameter for the determination of hydraulic conductivity and bulk density as described in Dane and Topp (2002). Another set of disturbed samples was collected from the top two soil depths for the determination of wet aggregate stability (Dane and Topp 2002).

Laboratory Methods

The samples were processed and used in the following analyses. Mechanical analysis, bulk density and hydraulic conductivity were determined as described

in Dane and Topp (2002). Soil texture was designated according to Soil Survey Staff (1999). Total porosity was calculated from soil bulk density and an assumed particle density of 2.65 Mg m^{-3}, and macroporosity was computed from total porosity and field capacity water content (at 50 cm tension). Percent sand-free water stable aggregates (WSA) >0.25 mm were determined by the wet sieving method of Yoder (1936) as also described in Dane and Topp (2002). Soil pH was measured in a 1:2.5 soil:water suspension using a pH meter. Organic carbon (SOC) was determined by the dichromate wet oxidation method of Walkley and Black (1934). Total N was determined by the Kjedahl digestion method. Available P was estimated by the Bray-1 method. The exchangeable bases, Ca, Mg, K and Na, were determined according to the methods described in IITA (1979) and Sparks (1996). Exchangeable acidity was also determined using routine procedures. The effective cation exchange capacity (ECEC) was obtained from the summation of exchangeable bases and exchangeable acidity. Base saturation was calculated from total exchangeable bases and ECEC (IITA 1979).

RESULTS AND DISCUSSION

Effect of Physiographic Position on Soil Morphological and Physical Characteristics

The Ap horizon was about 10cm thick at the upper and middle slope positions, and 15cm thick in the bottom land (Tables 1-3). The depth in the valley bottom was rather contrary to the findings of Philips (2007) who reported that erosional and depositional processes favour the accumulation of colluvial materials at the lowest members of the toposequence. The average soil depth in all slope positions was less than the 30 cm effective rooting depth of common cultivated crops. The shallow depth of the Ap horizon on the upper physiographic positions could be attributed to the interaction between topographic attributes and soil erosion. Erosional processes could inhibit the accumulation and formation of soil.

Slope is an important element of topography (Schaetzl, and Anderson 2005; Seibert *et al*. 2007) because it drives geomorphic processes (Evans, 1972) through its influence on soil water infiltration, flow rate of water and colluvial materials, and by controlling the rate of expenditure of energy or the stream power available to drive the flow. It influences the amount of sediment that moves down slope and also the amount of water that is available for eluviation and illuviation, and leaching in the soil profile. Consequently, it influences the process of soil formation both laterally and vertically, and has a significant influence on a wide range of soil physical and chemical properties (Garrard 1981).

Surface water flow or stream power directly relates to soil erosion, in terms of its detachment and transportation power. In other words, the stream power on these generally <5% slopes may be such that could have inhibited soil formation, but soil destruction on the slopes in this study environment where soil erodibility (susceptibility of soil to erosion) and rainfall erosivity (potential of rainwater to cause erosion) were high. The shallow depth of the Ap horizons of

the physiographic positions may therefore be attributed to erosional processes in the study area, and therefore require specific best management practices for soil and water conservation and increases in agricultural production.

The soil in the upper and middle slope positions was dominated by a hue of 7.5YR, while the valley bottom soil had a hue of 10YR, generally (Tables 1-3). Similarly, the soil in the upper and middle slope had high chroma of $>$ 4 while the soil in the valley bottom had a chroma ≤ 2. The upper and middle slope positions had little or no mottles while the soil in the valley bottom had mottles with high value and chroma. The observed colour patterns and prevalence of mottles from the upper slope to the valley bottom were attributed to the parent materials and episodic drainage condition. Presence of mottles in the soil profiles of the upper and/or middle slope positions are characteristic in some basement complex materials. These imply that while soils on the upper and middle slope may usually be well-drained and somewhat well-drained or imperfectly drained respectively, and oxidising and therefore exhibit a lower hue and high chroma, soils in the valley bottom are under the influence of a perennially high or seasonal fluctuating water table, poorly drained and reducing and therefore have a higher hue and lower chroma in the matrix as observed in this study. The cyclical nature of the ground water table directly influences the dynamics of iron in soil water or the oxidising and reducing conditions and prevalence of mottles in valley bottom soils, and could be capitalised in managing the soils for crop production by adapting the uses of the soils to their wet conditions.

Soil structure was weak and medium sub-angular blocky. Soil consistency ranged from moist and friable in the surface horizons to very sticky and very plastic at lower depths of all topographic positions and landscapes (Tables 1-3). The weak structure of the soil indicated poor state of aggregation, fragility and susceptibility to erosion. Although erosion hazards were low or could be non-existent in the bottom land, the soil may remain slaked, dispersive and easily sorted, and this could explain the coarse-texture of the soil. Weak soil structure can be an erosion-susceptibility factor at the upper and middle slopes where the stream power index could be high, aggravating the severity of soil erosion and degradation.

Particle-size distribution differed both within and among the toposequences (Tables 1-3). Percent sand separate was generally higher in the surface soil depth and decreased down the soil profiles and from the upper to the bottomland, and was apparently similar among the toposequences/parent materials. The underlying lithology was sandstone, which may be responsible for the similarity in the magnitude of the sand fraction. The respective contents of silt and clay fractions generally increased with depth and from the upper to the bottom land. The particle-size fractions varied irregularly with depth at all physiographic positions. But, while the sand fraction generally decreased with depth, the silt and clay separates increased with depth in all soil profiles and parent materials. At the upper and middle slopes of the basement complex, clay content was highest at about 30-40cm depth. Particle-size distribution among the topographic positions

and parent materials was similar, indicating that the parent materials/geomorphic units were essentially similar or have a common lithology.

Soil texture was therefore either sandy loam or loamy overlying sandy clay loam, or coarse-textured overlying medium-textured soil. The bottomland was generally more coarse-textured than soil at the other toposequence positions, probably due to sorting and deposition of colluvial materials from the upper slope positions. The soil profiles were different in texture and suggest that each toposequence comprises a group of soils that occur in a catenary sequence. The topographic positions could therefore form soil management units on each toposequence.

Bulk density was moderately high, ranging from 1.42 to 1.59 Mg m^{-3}, and varied irregularly with depth at all topographic positions in the landscapes (Tables 1-3). Also, average soil density was generally higher at the upper slope than in the middle slope of the parent materials/toposequences. Bulk density is an index of soil compaction, resistance to root growth and penetration, and water infiltration (Hillel 1998). The observed soil density may not adversely affect plant root growth and development since the soils were generally friable and could easily be penetrated by plant roots, and infiltrated by rain water (the latter) depending on the position of the soil on the landscape. The pattern of differences in total and macro-porosity was similar to bulk density. Total pore space averaged 40% of the soil volume while water-free pore space averaged 50% of total pore space. The high total and air-filled porosities reflect the medium to coarse textures of the soils and may favour a high rate of water transmission or internal drainage in the soils, but may be diminished by the effect of slope on water infiltration and overland flow. The apparently high micro-porosity may, however, favour water retention in the soils. Management practices such as mulching may be adopted to enhance rainwater infiltration and conserve soil water against evaporative losses.

Hydraulic conductivity (Ksat) was higher in the surface horizons and decreased with depth in all soil profiles (Table 1-3). In each location, average values were higher at the upper than at the middle slope positions. The values obtained varied from rapid in the top soil layers to moderate at lower depths in all topographic positions. Although there was no significant relationship between Ksat and other soil properties, the observed Ksat may be associated with the pattern of increases in clay distribution with depth in the soils (organic carbon vs Ksat, $r = 0.31$, $p<0.05$, clay vs Ksat, $r = 0.77$, $p< 0.05$). Hydraulic conductivity is an index of soil resistance to fluid flow and a characteristic of soil for drainage. The Ksat determined in this study indicates that the soil could be well drained except where the water table is high and perennial.

The data in Tables 1-3 show that percent water stable aggregates (WSA) in the top 30cm soil depth was greater in the 2.0 - 0.5 mm diameter range than in the >2.0 mm range, within and across the toposequences/landscapes. That is, aggregate stability in the size range >2.0 mm was less than in the size range <0.5 mm. Overall, however, there was a preponderance of aggregates >0.5 mm (2.0 + 0.5 mm), averaging more than 70%, in all landscapes. This indicates that the soils

could be less readily disposed to splashing and structural damage, for according to Bryan (1969), soils with a greater proportion of aggregates <0.5mm are easily erodible. There is however no guarantee that the aggregates would not disintegrate and erosion accentuated when the lands are intensively cultivated, as soil organic matter (SOM) decomposition rate would also increase. Although the stability of the aggregates could not be attributed to soil organic carbon (SOC) (Org. C vs. WSA (2.0 to 0.5mm) was not significant), even as organic matter is reputed to be the main agent of aggregate stabilisation in soils of the humid tropics. The lack of a significant SOC vs. WSA relationship may be attributed to the interacting effect of other aggregation and stabilisation agents (mainly inorganic substances not determined in this study), which may have obscured the importance of SOC in the soil. It could also be attributed to the constantly changing content of organic matter and its derivatives that are important as stabilising agents, due to the favourable decomposition environment (high moisture and elevated temperatures). Bronick and Lal (2005) reported that the effectiveness of SOC in forming stable aggregates is related to its decomposition rate. Niklaus *et al.* (2001) stated that increased decomposition rates due to increased temperatures, moisture and microbial activities may have a greater influence on rapid turnover of SOC pool and further losses as radiative gas, and may be deleterious to aggregate stability. Consequently, the structural stability and shear strength of the soil may be low, under the prevailing high intensity rainfall and rainfall erosivity in the area.

Effect of Physiographic Position on Soil Chemical Properties

The data in Tables 4-6 show that soil pH was slightly acidic and with very low variability both within and across the toposequences. This is attributed to the acidic parent material of the soils, leaching losses of basic cations, and to the shortened fallow which reduces the effectiveness of nutrient cycling between plant and soil, depressing the soil pH.

SOC content differed widely in its distribution from the upper slope to the valley bottom, average profile values being generally higher in the valley bottom and lower in the middle slope positions of the toposequences (Tables 4-6). Similarly, its variability ranged from low in the basement complex to very high in the sandstone parent material. The data show that percent organic C was higher in the topsoil layers, and decreased to lower values with depth in all topographic positions. The higher values in the surface layers were attributed to supplies of organic matter from the above and below ground plant biomass. However, the observed SOC contents, which were generally below 20 g kg^{-1}, the critical value for the area (FMANR 1990), was attributed to favourable decomposition processes. Besides, the length of the bush fallow period has been drastically reduced (Ogban *et al* 2004; 2005), the vegetation is immature (Areola 1990), and therefore evergreen. The vegetation may therefore be acting as an effective C sink. Also, the slash-and burn plant residue management destroys organic matter in the soil and may have contributed to the low SOC content. The low SOC

storage has important environmental effects. First, the atmosphere may become a sink for organic C. Second, degraded SOC contributes significantly to increasing the tropospheric concentration of one of the radiatively active greenhouse gasses, carbon dioxide (CO_2). This is accentuated by the slash-and-burn system of plant residue management common in the area, and in all traditional farming systems. The overall effect is the trapping of earth radiation and increasing the scourge of climate change and environmental degradation.

The trend in percent total N was similar to that of SOC. Thus recapitalising SOC will increase the soil N content. Similarly, it will reduce the C/N ratio which varies from very low to very high among the topographic positions and locations, as can be inferred from Tables 4-6. The values of soil N in this study were low and lower than 2.0g kg^{-1}, the critical N value for the area (FMANR, 1990). The deficiency of soil N is one of the factors constraining agricultural production in the area. Therefore, agronomic or soil management practices that increase soil N levels will improve the productive capacity of the soil, crop performance and farmers' income.

Available P varied irregularly with depth, ranging from about 8 to 57 mg kg^{-1} at all physiographic positions (Tables 4-6). Average profile values were generally low except at the upper and middle slope of the sandstone with 21.55 mg kg^{-1} and 28.86mg kg^{-1}, respectively. Available P content was less than 15.0 mg kg^{-1}, the critical value for southeastern Nigerian soils (FMANR, 1990). Also, there was no definite pattern of differences in P content among the parent materials. The high values at the two topographic positions of the sandstone parent material could be attributed to fertilisation. However, the generally low P content was probably due to low inorganic P content of the parent materials, weathering and erosion losses, the low SOC content, and the slash-and-burn system of plant residue management or post-clearing soil management, as well as insufficient fertiliser application which is associated with a high cost and often, non-availability.

Exchangeable Ca and Mg increased from the upper slope to the valley bottom in all parent materials (Tables 4-6). Also, the variability in the profile distribution of the exchangeable bases increased down the slope, generally ranging from low to very high. The higher values down slope, especially in the valley bottom, indicates the erosion of the exchangeable bases from the upper members to the lower members of the toposequence on all parent materials, since the basic cations are easily mobilised in soil water or runoff. Therefore, agronomic practices to be adopted in intensive cultivation, should include mulching, routine fertilisation and hedge row planting to minimise nutrient runoff. The trend in the distribution of exchangeable K and Na was almost similar to exchangeable Ca and Mg (Tables 4-6). While exchangeable K may be said to be fairly adequate in the soil, but not the case with exchangeable Na. However, both basic cations will need supplementation when the soils are intensively cultivated.

The profile distribution of exchangeable acidity and Al varied among the parent materials, especially in the sandstone where variability was as high as 60%, but differed from the pattern of distribution of exchangeable Ca and Mg (Tables

4-6). However, the toxicity of Al in particular is generally not feasible because of the high rainfall which will always flush the rooting zone, and mitigate its influence on the availability of other plant nutrients. Effective cation exchange capacity (CEC) varied irregularly with depth, and profile variability range from low (15.9%) to very high (42.7%). Effective cation exchange capacity (CEC) varied among the parent materials, and was generally low in status. It is probable that the parent materials were poor in nutrient status or it could be the result of cycles of weathering or erosion and/or cultivation. The pattern of base saturation was similar to the effective CEC. The results also indicate that the exchange complex in the sandstone parent material was dominated by non-basic cations compared to the basement complex and shale.

PROPOSED SOIL MANAGEMENT SYSTEMS

Lack of suitable cultivable land is one reason resource-poor farmers cultivate intensively and dig deep into their agricultural capital, the soil quality or its physical and chemical fertility, to produce more food (IITA 1989/90). The quality of vast areas of the uplands has substantially declined in the attempts to increase food production due partly to the shortening of the soil-restoring fallow period between crops (Areola 1990; Ogban *et al.* 2004). Loss of soil quality is accentuated by soil erosion and degradation or loss of soil capacity to function, limiting land use to extensive crop production. There is also a dearth of information on the properties of the soils and how these properties change under cultivation. In addition, regenerating and productive soil management/conservation technologies are not components of the agricultural systems. For this reason, soil use does not include management based on soil's inherent properties and characteristics, and their specific needs.

A *soil-scape* is the catena or gradient of soils along a toposequence or across the landscape, that is, from valley bottoms, slopes and fringe, to the uplands (IITA 1989/90). It is farming by soil, which is, matching management practices or technological options to specific soil and landscape characteristics (Pierce and Lal 1991).

The study demonstrated that the topographic positions of the landscapes were different in morphological, physical, hydrological, and chemical characteristics. The Ap horizon, soil zone of intense plant root activities and soil process interactions, was shallow in all topographic units. Soil texture was sandy or loamy sand or medium, to coarse, and generally permeable. The upper slope is most likely to be droughty and the agricultural potential will depend on the soil depth in relation to water availability and susceptibility to erosion and degradation. On the other hand, the middle slope and valley bottom may be droughty during the dry season, due to low water table, inducing soil water stress, or poorly drained during the wet or rain season and likely to impair cultivation. The soils were generally low in physical and chemical quality attributes, and may easily be degraded when cultivation is intensified without best management practices suitable to the soils. Management systems must aim at manipulating

the soils' properties and characteristics to increase their productivity. One such practice is increasing soil organic carbon stock which will invariably improve the C/N ratio in each soil management unit (SMU), because of its relation to soil physical quality through soil structure stability and chemical quality through its nutrient holding capacity.

In a similar study, Juo and Moormann (1980) considered the catena in the area unsuitable for extensive food production. They also found valley bottoms in the area poor in soil quality attributes for lowland rice production. Although the soils in this study were equally of low physical and chemical quality, their use can be adapted to their conditions by adopting the soil management unit and systems proposed here. The soil management units are the physiographic positions, that is, the upper slope, middle slope and valley bottom. Basically, it is farming by soil-scape or soil ecosystem or soil condition, and adapting soil management systems to the prevailing conditions as outlined hereunder.

Soil Management Unit (SMU) A

Upper slope: This soil management unit occurs on rolling topography with the slope varying from 0 to 5% in all landscapes. Top soil is shallow with sandy surface and sandy clay loam and concretionary subsoil especially in the basement complex and sandstones parent materials (Fagbami 1981; Obi and Akinbola 2010). The soils have weak structural properties, low inherent fertility and acidity problems. Present land use is crop production under shifting cultivation. Common food crops are cassava, yams and maize. Slash-and-burn practice is common even as the fallow vegetation is immature.

The soil is susceptible to erosion and degradation, and its position on the landscape and shallow soil depth may limit available soil water, especially as soil conservation measures such as residue mulching and fertiliser application are not commonly practised in the low input-output production systems in the area. Dependence on the natural fallow to restore soil quality and resilience is the rule.

Dryland farming in the rain season is an appropriate soil management system (SMS) and the common practice in the area. But continuous and intensive food crop production requires the adoption of modified agro-forestry, the planting of acid-tolerant leguminous tree species and encouragement of growth of adapted shrubs and tree species. This will also provide adequate stakes for yam culture, common in the area. Intensifying mixed-cropping by widespread use of melon and related crops, and including leguminous crops such as cowpea, will greatly improve soil quality attributes by recycling nutrient elements and improving soil fertility properties such as soil organic matter content, bulk density, aggregation and soil structural stability, soil water infiltration and plant available water. These measures will at the same time reduce soil erosion. These practices will increase the residence time of soil water and the wetness index, allowing the water to percolate through and influence soil formation processes down the profile, and ultimately increase the crop rooting depth.

Soil Management Unit (SMU) B

Middle slope: The soils are sandy over sandy clay loam subsoil and could be imperfectly drained. The physical and analytical data in this management unit are similar to those of SMU A, and although on a different topographic position, somewhat similar management practices may be adopted.

However, the soils have a high wetness index, because of seasonal groundwater fluctuation which results in capillary infringement of the rooting depth and the soil being occasionally (seasonally or perennially) saturated, creating phreatic or hydromorphic upland conditions (Garity 1984). However, the shallow ground-water table makes the soil suitable for rice culture during the rainy season. Cultivating this soil unit with upland *dry food crops*, for example, yam, cassava and maize, during the rainy season (*dry land farming*) requires managing the groundwater table by using shallow drainage furrows constructed across the slope to intercept runoff; by not letting them become erosion channels, the groundwater does not inhibit root activity, that is, water and nutrient uptake functions of the plant. The use of moderate residue mulching will allow evaporation and reduce weed growth as well as improve soil physical and chemical quality attributes. Hydromorphic processes will also mobilise nutrients in the soil.

Therefore, the recommended SMS for this SMU is the *upland or dry land farming,* but which will require a greater mulch application rate, and only when soil strength or bearing capacity has improved, so that evaporative drying is not impeded and that crop roots follow the receding groundwater table (Cornish, 1987). This soil management unit is usually under-utilised because of the wetness condition of the rooting zone of the soil.

Soil Management Unit (SMU) C

Valley bottom: Soil in this SMU is either seasonal or perennially strongly hydromorphic (Andriesse 1986; Carsky and Masajo 1992; Ogban, 1999) with a high wetness index, which may impede cultivation during the rain season. Soil is sandy throughout the profile, low in plant nutrient supply and present land use is mainly rice cultivation (*wetland farming*). Hydromorphic processes are excellent for the nutrition of the rice crop, and the SMU is already being exploited in all three landscapes by adapting the farming of the land to the wet condition (Ogban and Babalola 2003). In spite of the low inherent chemical fertility, soils are more productive than adjacent upland soils due to adequate water supply, nutrient transformation under wet soil conditions, and low erosion hazard.

Soil in this topographic position has potential for wetland/dryland and dryland farming or SMS which can be utilised to maximise crop production. Wetland/dryland farming involves simultaneous cultivation to wetland and dryland crops. A system of mound-tillage will be required to grow a toposequence of water-tolerant crops (e.g., rice) at the base, progressing to crops with aerobic edaphic requirement (e.g., maize, yam etc) at the apex (Ogban and Babalola (2003 &2009). The mounds will be large, more than 1m height and diameter. Ponding or flooding is controlled by drainage through space among mounds, although, a

system of shallow ditch drainage to a 20cm depth will remove flood or overland flow without increasing production cost (Ogban and Babalola 2002). Dry land farming involves cultivating the land types with maize, cassava and vegetable crops in the dry season, similar to the practice in SMU B. The land will however be cultivated when soil strength or soil workability has been improved by natural drainage (internal drainage or evaporation). This approximates the second rate stage of evaporation. Plant residues collected at sites may be applied as mulch during the dry land cropping phase, to minimise evaporation, reduce weed growth, conserve soil water, improve SOC sequestration and chemical fertility as well as counteract radiative emission of methane (CH_4) when the soils are intensively used. Adopting these soil management practices or SMS will enhance intensive use of the land type and increase the productivity of the low resource farmers.

CONCLUSION

Three toposequences were investigated for their soil quality attributes to guide the design of soil management practices for increases in crop production in the study area. The three toposequences were generally low in soil physical and chemical fertility and therefore not suitable for intensive food cultivation without the adoption of appropriate quality soil (best) management practices. Based on the status of the soil characteristics, particularly, soil water availability, three suitable SMUs have been identified, corresponding to the topographic upper slope, middle slope and valley bottom, in the landscapes. Also, three SMS have been designed for the topographic positions in the agro-ecological zones, namely, dryland farming for the upper slope, and wetland, wetland and dryland farming for the middle slope and valley bottom SMUs. Maximising increases in food production necessitates adopting the recommended soil management systems to the SMUs. These SMS can also be adopted in other similar agro-ecological conditions. These SMS are being recommended for use by agricultural extension agents to assist farmers to cultivate their sloping lands more efficiently and productively.

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