



Comparative topsoil characterization of Selected cropping systems and slopes in inland valleys ecosystem around Ishiagu, southeastern Nigeria: Textural and selected soil chemical properties

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ABSTRACT

Cropping systems in Southeastern Nigeria is characterized with sole cropping, intercropping and mixed cropping patterns with no consideration of their effect on soil properties. A study was conducted in 2018 at Ishiagu, Ebonyi State, to evaluate the effect of different cropping systems on selected soil chemical properties in lowland areas of Southeastern Nigeria. The cropping systems were built into a split plot in randomized complete block design (RCBD). Eight different cropping systems (sole okro, sole maize, sole rice, sole cassava, maize + cassava, maize + okro, yam /cassava /cocoyam /maize /okra /castor oil bean, and fallow land), constituted the subplots, while the slope positions (upper, middle and lower slopes) represent the whole plots. Random and systematic methods of sampling were used to collect soil samples from the studied cropping system sites. In each of the cropping system site, soil samples were collected from upper, middle and lower slopes at 0 to 30 cm soil depth. Soil chemical properties evaluated were soil pH, organic carbon and total nitrogen. Results revealed that maize + okro intercrop significantly ($P < 0.05$) improved soil organic carbon (2.34%), while the least value was obtained from the intercrop of maize + cassava (0.86%). The results also indicated that the highest soil pH of 6.6 was obtained from the field with intercrop of maize + okro. Results generally indicated that all the intercropped fields including the fallow field significantly improved the soil pH higher than the sole cropped fields, except on the okro sole field. However, there was no significant ($P < 0.05$) difference among the different cropping systems on soil total nitrogen improvement. Generally, results noted the superiority of intercropping/mixed cropping over sole cropping in the improvement of soil chemical properties in the study area.

Keywords: cropping systems, fallow land, intercropping, lowland, mixed cropping, sole cropping, toposequences.

1. Introduction

One of the most important strategies to increase crop production among smallholder farmers in the Southeastern Nigeria is development of improved cropping system that intensifies land use efficiency and can make effective use of growth resources (water, nutrient, light, etc.) (Abuhay and Mohammed, 2016).

Cropping system refers to a pattern of crops taken up for a given piece of land, or sequence in which the crops are cultivated on piece of land over a fixed period and their interaction with farm resources and other farm enterprises (Karlen *et al.*, 1997). In agriculture systems, soil with its toposequences and cropping system affect soil quality, soil nutrients dynamics, and soil chemical properties. These cropping system include sole cropping, inter- cropping and mixed cropping (Bowman *et al.*, 1999). In Southeastern part of Nigeria, traditional farmers practice inter- cropping (a form of

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intensive cropping) with a wide range of crops consisting usually of a major crop and other crops. Crops like cassava, maize, cowpea and vegetables are minor crops in various parts of the region. The judicious management and conservation of the soil to guide against decreased crop yields under intensive cropping have become major areas of agronomics (Costa *et al.*, 1991).

Cropping systems with high biomass input to maintain the soil permanently covered imitate the conditions found with natural vegetation and develop the stratification of the soil organic carbon (SOC) pools similar to the natural vegetation (Carlos de Moraes Sá and Lal, 2009). They provide a continuous mass and an energy flow that release organic compounds to stimulate the soil biota biodiversity and the soil organic matter (SOM) changes (Séguy *et al.*, 2006; Six *et al.*, 2006; Uphoff *et al.*, 2006). This concept is based on the multifunctional action of each species in the cropping system interacting with the soil attributes and stimulating the biological activity in a systemic interdependence of the soil structure and the soil organic matter pools (Séguy *et al.*, 2006; Uphoff *et al.*, 2006).

Intercropping is defined as an environmental friendly method (Agegnehu *et al.*, 2008; Maffei and Mucciarelli, 2003). Nowadays, this method has become one of the popular methods in agricultural system due to the more efficient use of resources and its role in reduction of weeds interference and other pests (Chen *et al.*, 2012; Lithourgidis *et al.*, 2011). It should be kept in mind that intercropping has a long history in food production in the world.

Intercropping is one of the cropping systems practiced in Southeastern Nigeria for higher crop production advantages per unit area. The vital features of intercropping systems are that they exhibit intensification in space and time, competition between and among the system components for light, water and nutrients and the proper management of these interactions. In light of these the system is considered among the agricultural practices associated with sustainable crop production in the tropics (Tolera, 2003).

Increased crop production (over-yielding) often observed in intercrops compared to sole crops has been attributed to enhanced resource use (Szumigalski and Van-Acker, 2008). For intercropping to be more productive it is recommended that component crops differ greatly in growth duration so that their resource requirement for growth resources occurred at different times (Hailu, 2015).

The long-term effects of intercropping on the soil carbon and nitrogen levels are key quality parameters for agricultural soils because they are positively linked to the supply of nutrients to the crop, water holding capacity, workability, and resistance to soil compaction, erosion and surface crusting (Weil and Magdoff, 2004). Because of greater productivity per unit land, it is expected that intercropping can enhance litter input into the soil, and hence promote the build-up of organic matter and sequestration of carbon indeed. Recent studies suggest greater input of carbon into the soil through root residues in intercropping systems as compared to sole crops (Campbell *et al.*, 2007; Six *et al.*, 2002). Li *et al.* (2001) found that legume-based intercrops have a lower environmental impact compared to sole crops. Regehr *et al.* (2015) found that intercrops were a more sustainable land management option compared to sole cropping since intercrops contributed to the long-term immobilization of nitrogen (N), with the potential to reduce nitrification and nitrate leaching. Reduced soil nitrification rates also moderate nitrous oxide losses, causing intercrops to abate the overall contribution of this greenhouse gas to global climate change (Regehr *et al.*, 2015). Dyer *et al.* (2012) noted that intercrops are more resilient to climate change due to a greater structural complexity, where a higher landscape-level complexity plays an important ecological role in maintaining microbial activity and diversity. In high-input intercrops, the quantity of nitrogen (N) fertilizer is reduced because of dynamic soil-plant interactions, where crops use N in a complementary way (Pelzer *et al.*, 2012). The mixed crop arrangement captures resources from different parts of the soil and/or uses resources at different times and/or in different forms (Echarte *et al.*, 2011). Input from mixed residue sources also create complex interactions that influence the magnitude of C and N cycled through the intercrop compared to the sole crop (Flavel and Murphy, 2006). Therefore, the various effects caused by crops on soil chemical properties and soil quality under continuous mono-cropping should be considered to step up restoration measures especially if the soil is degraded (Aweto, 1981).

Under the mixed cropping system of farming, man's activities have a large influence on soil properties since different kinds of crop are planted. It has effects on nutrient cycling, soil organic matter content, soil fertility and soil physical and chemical properties (Francis and Kemp 1990). Soil chemical properties and enzyme activities under continuous cropping may have greater crop N removal resulting

from higher yields from soil by inter-cropping systems compared with monocultures over a time scale of cropping season (Brady and Weil 2002).

In agricultural lands, tillage, fertility, crop rotations, and cropping intensity influence the rate at which carbon is added to or removed from soil (Franzluubbers, 2004). Machado *et al.* (2006) reported that growing one crop every 2 years adds less soil organic carbon (SOC) than annual cropping.

Soil landscape relationships due to anthropogenic and natural activities can influence the properties of soils through the summits to the foot slopes, and in most cases soil organic matter (SOM) and nutrient reserves are affected. Thus, soil properties (morphological, physical and chemical) and potentials for crop production often vary among landscape position and with depth which potentially limit crop production (Mbagwu, 1995). AungZaw *et al.* (2012), in a study on effect of toposequence position on soil properties and crop yield of paddy rice, reported that slope position influence the quantity of soil organic carbon input in an area. They further submitted that total nitrogen and carbon contents were significantly higher in middle field than in other slope positions. Toposequences as reported by findings are heterogeneous in morphology (physiography), soil type, vegetation, hydrology and agronomic practices. Nejad and Nejad (1997) reported the effect of topography on soil genesis and development of soils and observed that slope gradient and slope length had direct and indirect effect on calcification Nutrient removal, resulting in decline of soil fertility when replenishment with inorganic or organic nutrient inputs is inadequate. Silver *et al.* (2000) also found lower nitrogen transformation in sandy soils along sand to clay gradient. It is likely that variability in carbon uptake, biomass and diversity are related to soil properties associated with topography.

Therefore, the study aimed at evaluating the effects of different cropping systems at different slope positions in lowland areas on the improvement of selected soil physical and chemical properties.

2. Materials and Methods

2.1 Description of the Study Site

The study was conducted in eight different cropping systems in Ishiagu, Ivo Local Government Area of Ebonyi State, Southeastern Nigeria. Farmers with these fields where the study took place were interviewed on the agronomic practices usually adopted in their various fields. The results of the interview indicated that farmers in the area do not usually use fertilizer or any manure source for their crop production. The only agronomic practice common among the farmers in the study area is the use of selective and non-selective herbicide for weeds control in their farmers. The interview became necessary as to identify any other source(s) of variability in relation to the physical and chemical properties of the studied soil other than the cropping systems studied. Ishiagu is located between latitude 5° 55' N and 6° 00' N and longitudes 7° 30' E and 7° 35' E. The relief of the study area is lowland and undulating (Eze and Chukwu, 2011).

The geology of the area comprises sequences of sandy shales, with fine grained micaceous sandstones and mudstones that is Albian in age and belongs to the Asu River Group. The dark coloured shales are believed to have formed in stagnant marine basins and are dark coloured because they contain sulphide minerals and large quantities of organic matter (Eze and Chukwu, 2011).

Soils in the area comprise reddish brown gravely and pale clayey soils derived from shales and shallow pale brown soils derived from sandy shales. The red yellow soils are derived from the red and reddish-yellow earth formed by the weathering and subsequent ferruginisation of underlying sandstone units, the shales and igneous rocks which form the bedrock (Ezeh and Chukwu, 2011). The soil classification is Ultisol, which is hydromorphic, of shale parent material with underlying impervious layer at about 40 cm depth. It is characterized by rampant flooding and water logging which is a precipitate of poor drainage resulting from the impervious layer, high soil bulk density and crusting (FDALR 1985). The flooding is experienced at about the peaks of the rainy season (July and September) and covers the basins and floodplains around the middle and lower courses of the river and the streams (Nwite *et al.*, 2014).

2.2 Field study

Eight different cropping systems including fallow land was marked in different lowlands of Ishiagu, Southeastern Nigeria for the study in 2018. The cropping systems include; Sole rice, Sole

cassava, Sole maize, Sole okra, Intercrop of maize and yam, Intercrop of maize and cassava, Mixed cropping of yam/cassava/cocoyam/maize/okra/castor oil bean and Fallow land system.

2.2.1 Collection of Soil Samples

Random and systematic methods of sampling were used to collect soil samples from the eight (8) different cropping systems. In each study cropping system site, soil samples were collected at three different sampling points from three toposesquences or slope positions (upper, middle and bottom slopes) at 0-30 cm depths. The experiment was built into a split-plot in a randomized complete block design where the three toposesquences constituted the main plots, while the eight (8) cropping systems constituted the subplots (treatments). Three sampling points in each cropping system were used as the blocks/replicates. This gave rise to seventy-two (72) auger samples collection used for the study. The soil samples were stored in labeled soil bags.

They were air-dried, crushed, sieved with a 2.00 mm sieve and taken to the laboratory for the determination of the particle size distribution and some selected soil chemical properties.

2.2.2 Laboratory Methods

Soil fractions less than 2 mm from individual samples were then analyzed using the following methods; Particle size distribution of less than 2 mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder (1986). Soil pH was measured in a 1:2.5 soil:0.1 M KCl suspensions (McLean, 1982). The soil OC was determined by the Walkley and Black method as described by Nelson and Sommers (1982). Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and CuSO_4 and Na_2SO_4 catalyst mixture (Bremner and Mulvaney, 1982).

2.4. Data Analysis

Data analysis was performed using GENSTAT 3 7.2 edition. Treatment means was separated and compared using least significant difference (LSD) and all inferences was made at 5% level of probability.

3. Results and Discussion

3.1 Textural Characteristics/Physical Properties of Studied soils

The results of the physical properties of the studied soils are presented on Table 1. The textural classes of the soils differ from cropping system to cropping system with clay and clay loam soils dominating most of the lowland toposesquences used by the farmers for their cropping. Generally, the results indicated that most of the cropping systems have much of clay materials in all the slope positions making the soils to be poorly drained in all the depths. This could be attributed to the influence of the parent materials of the soils of the study areas, which is clayey in texture (Nwite *et al.*, 2014). The clay content of most of the soils in the lowlands was generally medium to high, while few areas were low in clay content. The area of medium to high clay content ranged from 20 – 57% in all the slope positions, whereas the low clay contents in few lowland slope positions varied from 9% to 11% in all the slope positions.

The high clay content in most of the lowlands toposesquences studied could be attributed to the submissions of Nwite *et al.* (2014) that geological fertilization occur in the inland valleys (the transportation of clay and other finer materials on the upland soils by serious sheet erosion down the lowland) of the studied areas.

The silt content also is very high in most of the lowland slope position, ranging between 22 and 43% which also agrees with Nwite *et al.* (2014) on the effect of geological fertilization of inland valleys in the study area. In few cases the values did not follow a definite trend, showing little fluctuations within the slope positions.

The sand content of the soils were generally low to high, especially where higher clay and silt contents were recorded in the slope positions, ranging between 4 and 76% in the different toposesquences. This could be attributed to the parent materials which are poorly leached followed by the continuous accumulation of clay and silt contents of the soil thereby increasing the aggregate stability of the soil (Nwite *et al.*, 2014).

Table 1: Textural Characteristics/Physical Properties of Studied soils

Cropping system/pattern	Slope position	Depth (cm)	Sand%	Silt %	Clay%	Textural Class
Sole Okro	Upper	0 – 30	34	33	33	CL
Sole Okro	Middle	0 – 30	44	25	31	CL
Sole Okro	Bottom	0 – 30	38	33	29	CL
Sole Maize	Upper	0 – 30	68	23	9	SL
Sole Maize	Middle	0 – 30	57	23	20	SCL
Sole Maize	Bottom	0 – 30	64	25	11	SL
Sole Rice	Upper	0 – 30	18	33	49	C
Sole Rice	Middle	0 – 30	18	29	53	C
Sole Rice	Bottom	0 – 30	4	39	57	C
Sole cassava	Upper	0 – 30	40	32	28	CL
Sole cassava	Middle	0 – 30	42	29	29	CL
Sole cassava	Bottom	0 – 30	44	25	31	CL
Intercropping maize/cassava	Upper	0 – 30	4	43	53	SC
Intercropping maize/cassava	Middle	0 – 30	4	41	55	SC
Intercropping maize/cassava	Bottom	0 – 30	58	22	20	SCL
Intercropping maize/okra	Upper	0 – 30	55	25	20	SCL
Intercropping maize/okra	Middle	0 – 30	57	23	20	SCL
Intercropping maize/okra	Bottom	0 – 30	56	23	21	SCL
Mixed cropping y/c/cy/m/o/cob	Upper	0 – 30	24	33	43	C
Mixed cropping y/c/cy/m/o/cob	Middle	0 – 30	20	35	45	C
Mixed cropping y/c/cy/m/o/cob	Bottom	0 – 30	18	29	53	C
Fallow land	Upper	0 – 30	72	19	9	SL
Fallow land	Middle	0 – 30	76	15	9	SL
Fallow land	Bottom	0 – 30	64	25	11	SL

y/c/cy/m/o/cob = y = yam, c = cassava, cy = cocoyam, m = maize, o = okra, cob = castor oil bean.

3.2. Effect of different cropping systems and slope positions on the selected chemical properties of the studied soils

3.2.1 Soil pH

Table 2 presents the effect of different toposequences and cropping systems in lowland areas on soil pH. The results showed that there was very high significant ($p < 0.05$) improvement on the soil pH due to different cropping systems, while the different toposequence did not significantly changed the soil pH within the period of study. It was observed that the highest significant ($p < 0.05$) improvement on the soil pH was obtained from the intercrop of maize and okra in the cropping system. Generally, all the intercropping patterns among the studied cropping systems significantly increased the soil pH higher than the sole cropping patterns, as the lowest soil pH was obtained from sole cassava.

Table 2: Effect of different slope positions or top sequences and cropping systems in lowland areas on soil pH (0-30cm) soil depth

Cropping Systems Studied	Slope Positions			Mean
	Upper slope	Middle slope	Bottom slope	
Sole Okro	5.500	5.533	5.700	5.578
Sole Maize	5.000	4.800	5.400	5.067
Sole Rice	5.500	5.433	5.167	5.367
Sole cassava	5.000	5.000	4.867	4.956
Intercropping maize/cassava	5.333	5.733	5.600	5.556
Intercropping maize/okra	6.400	6.533	6.600	6.511
Mixed cropping y/c/cy/m/o/cob	6.233	6.200	5.467	5.967
Fallow land	5.100	4.900	5.30	5.100
Mean	5.508	5.517	5.513	
LSD _{0.05} (Slopes)		NS	F – probability	0.977
LSD _{0.05} (Cropping System)		0.2248	F – probability	<.001
LSD _{0.05} (Slopes x Cropping System)		0.3718	F – probability	0.002

y/c/cy/m/o/cob = y = yam, c = cassava, cy = cocoyam, m = maize, o = okra, cob = castor oil bean; NS = non-significant

The higher significant improvement on the soil pH in the intercropped systems higher than the sole cropping can be attributed to higher litter fall from the intercropped systems which were assumed to have decomposed within the period to act as buffer materials in the soils. The litter decomposition might have improved the base saturation of the studied soils and other soil basic cations, hence increased pH in such soils.

Table 2 also revealed that the interaction of different cropping systems and slope positions in the studied lowlands significantly ($p < 0.05$) increased the soil pH. It was shown that the highest significant improvement on soil pH was recorded in the bottom slope position of maize and okro intercrop, while the least pH value was obtained from middle slope position of sole maize.

3.2.2 Soil organic carbon

The effect of different slope positions and cropping systems in lowland areas on soil organic carbon (0 – 30cm soil depth) showed that there were significant differences ($p < 0.05$) among the slope positions in each of the cropping system. It was obtained that bottom slope position generally increased the soil organic carbon (SOC) significantly higher in all the respective cropping systems studied, followed by the upper slope position, while the middle slope position recorded the least value of soil organic carbon. The mean organic carbon values ranged from 14.24 g/kg to 16.54 g/kg. The results (Table 3) indicated that the effect of cropping systems did significantly ($p < 0.05$) increased the soil organic carbon in the lowland valleys studied. It was recorded that among the cropping systems studied, maize/okro intercrop significantly ($p < 0.05$) increased the soil organic carbon higher among the cropping systems. This was followed by mixed cropping of yam/cassava/cocoyam/maize/okra/castor oil bean, while the least SOC value was obtained from cassava/maize intercrop. The results revealed that fallow system did significantly ($p < 0.05$) improved the soil organic carbon higher than all the sole cropping except the sole okro system.

Table 3: Effect of different cropping systems in lowland areas on soil organic carbon (0-30cm) soil depth (g/kg)

Cropping Systems Studied	Slope Positions			Mean
	Upper slope	Middle slope	Bottom slope	
Sole Okro	14.50	14.33	18.73	15.86
Sole Maize	13.30	11.47	12.93	12.57
Sole Rice	12.50	11.90	16.13	13.51
Sole cassava	11.33	13.13	16.60	13.69
Intercropping maize/cassava	11.07	10.27	8.77	10.03
Intercropping maize/okro	21.37	19.33	27.33	22.68
Mixed cropping y/c/cy/m/o/cob	20.27	16.93	18.60	18.60
Fallow land	19.30	16.53	13.23	16.36
Mean	15.45	14.24	16.54	15.41
LSD _{0.05} (Slopes)		0.969	F – probability	0.007
LSD _{0.05} (Cropping System)		2.113	F – probability	<.001
LSD _{0.05} (Slopes x Cropping System)		3.489	F – probability	<.001

y/c/cy/m/o/cob = y = yam, c = cassava, cy = cocoyam, m = maize, o = okra, cob = castor oil bean; NS = non-significant

These results implied that the increased soil organic carbon pool obtained from most of the intercropping systems including the fallow, higher than the sole cropping system was as a result of increased plant biomass residues from these intercrops in the systems. This result conforms to the submission of Kuo and Jellum (2002) that the organic carbon concentration in the surface soil (0-15cm) largely depends on the total input of crop residues remaining on the surface or incorporated into the soil.

It was equally observed that the interaction of the slope positions and the cropping systems did significantly increased the soil organic carbon pool with the highest pool obtained from bottom slope position of maize/okro intercrop (Table 3). However, the least interacting improvement on the SOC was recorded in the cassava/maize intercrop within the study area.

3.2.3 Soil total nitrogen

The effect of different toposequences and cropping systems in lowland areas on soil total nitrogen at 0-30cm soil depth was presented in Table 4. The results indicated that there was no significant

difference ($P < 0.05$) on the soil total nitrogen concentration among the different slope positions in the respective cropping systems studied. This implies that all the slope positions in all cropping systems were statistically the same on their effect in soil total nitrogen concentration.

Table 4 showed that the different cropping systems studied significantly varied the soil total nitrogen concentration in various level. It was obtained that the highest significant ($p < 0.05$) increase in soil total nitrogen concentration (17.44 g/kg) was observed from fallow system. This was followed by intercrop of cassava and maize with 16.54 g/kg soil total nitrogen concentration, while the lowest concentration of the soil element (nitrogen) was recorded in sole rice field of the studied lowlands. The result implies that the highest consumption rate and loose of soil total nitrogen is usually on rice field. This means that rice crop exploits more of the soil total nitrogen; therefore need higher nitrogen fertilizer application to sustain its growth performance. This decrease in the soil total nitrogen in rice cropped field could be as a result of occasional flooding and drying of rice field in the studied area and understanding the fact that nitrogen element is highly mobile, therefore, might have been leached out of the soil, on this process of flooding and seasonal drying occasionally observed in lowland rice fields in the studied area.

Table 4: Effect of different cropping systems in lowland areas on soil total nitrogen (0-30cm) soil depth (g/kg)

Cropping Systems Studied	Slope Positions			Mean
	Upper slope	Middle slope	Bottom slope	
Sole Okro	2.99	7.84	12.57	7.80
Sole Maize	6.95	5.00	12.69	8.21
Sole Rice	2.55	2.78	3.69	3.01
Sole cassava	11.65	5.12	3.40	6.72
Intercropping maize/cassava	15.36	11.32	22.67	16.45
Intercropping maize/okro	2.25	2.83	22.72	9.27
Mixed cropping y/c/cy/m/o/cob	4.29	13.66	9.10	9.02
Fallow land	13.19	23.86	15.27	17.44
Mean	7.40	9.05	12.76	9.74
LSD _{0.05} (Slopes)		NS	F – probability	0.105
LSD _{0.05} (Cropping System)		6.364	F – probability	<.001
LSD _{0.05} (Slopes x Cropping System)		10.976	F – probability	0.031

y/c/cy/m/o/cob = y = yam, c = cassava, cy = cocoyam, m = maize, o = okra, cob = castor oil bean; NS = non-significant

4. Conclusion

The results indicated that maize + okro intercrop produced the highest organic carbon, followed by mixed cropping. The results also showed that maize + okro intercrop produced the highest soil pH, followed by mixed cropping. The results equally revealed that all the cropping systems were statistically the same on their effect in relation to soil total nitrogen. The general implication is that maize + okro intercrop followed by mixed cropping performed relatively better than other cropping systems on the effect of organic carbon and soil pH, thus enhance the performance of soil chemical properties.

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