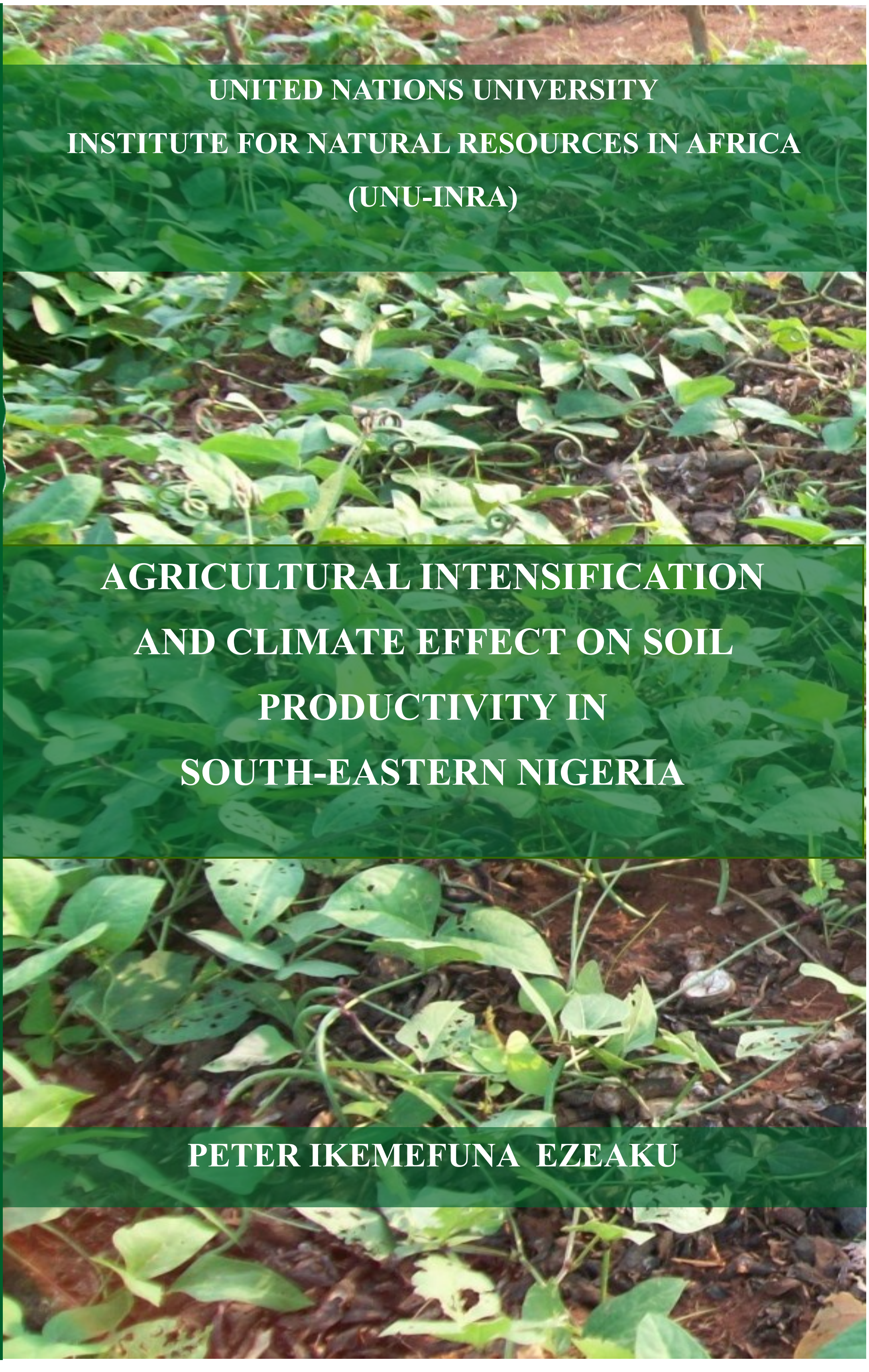
UNU-INRA WORKING PAPER NO. 8



UNITED NATIONS UNIVERSITY

INSTITUTE FOR NATURAL RESOURCES IN AFRICA

(UNU-INRA)

AGRICULTURAL INTENSIFICATION AND CLIMATE EFFECT ON SOIL PRODUCTIVITY IN SOUTH-EASTERN NIGERIA

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BY

PETER IKEMEFUNA EZEAKU

UNU-INRA Visiting Scholars Programme

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ISBN: 978-9988-633-49-3

Editorial Team: Kwabena O. Asubonteng, Praise Nutakor and Karamzo Saccoh, UNU-INRA, Accra, Ghana

Published By: United Nations University Institute for Natural Resources in Africa, Accra, Ghana

ABSTRACT

Agricultural intensification and climate variability will affect future food security. Improved soil, land and water management strategies are desired to enable science-based land management interventions for improved soil productivity to achieve food security. Quantitative analyses of soil and 12 years (2000-2011) of rainfall/temperature data were analysed using standard schemes. The soils were variously classified: *Typic Paleustults* in Nsukka, *Typic Haplustalfs* in Umuahia South and *Oxic Dystrusteps* in Ikot Abasi. Soil degradation effects were most significant in Nsukka (SDR= 3.4; $P<0.01$) cultivated soils than those of Ikot Abasi (SDR= 2.6) and Umuahia South (SDR= 2.5; $P<0.05$). Anomalies and variations in rainfall and temperature over the 12 year period revealed rainfall decreases and temperature increases into the future, hence susceptibility of crop yields. Temperature changes had a much stronger impact on crop yields than rainfall changes. Rainfall decreased cassava (0.5139 $kgha^{-1}$, $P<0.05$) and maize (0.1371 $kgha^{-1}$, $P<0.05$) yields, while temperature decreased all crop yields: cassava (14.4556 $kgha^{-1}$, $P<0.001$), maize (11.1758 $kgha^{-1}$), cowpea (0.0538 $kgha^{-1}$) and rice (8.1310 $kgha^{-1}$) and accounted for 66 and 58 % significant ($P<0.05$) variation in cassava and maize yield, respectively. Land degradation also decreased cassava (6.6739 $kgha^{-1}$) and cowpea (0.0359 $kgha^{-1}$) yields. Continuous decrease of crop yields by unit (1^oC) temperature increase and rainfall decrease negatively implicate food security in the future. Farmers ranked importance of soil properties to soil productivity. Combined green soil conservation measures: cover crops/live mulch; establishment of Vetiver system and early planting of diversified improved crop varieties are adaptation strategies recommended for action.

Keywords: *Land use, Soil degradation, Climate parameters, Crop response, Conservation, management, South-eastern Nigeria.*

ACKNOWLEDGEMENTS

This study was completed during my visit as a Visiting Scholar to the United Nations University Institute for Natural Resources in Africa (UNU-INRA), Accra, Ghana, in 2013. I am very grateful to Dr. Elias T. Ayuk, the Director of UNU-INRA for his hospitality. I appreciate UNU-INRA's Management Team for providing the funds that made my visit possible. UNU-INRA Staff are appreciated for their great supports.

Additionally, I gratefully thank Dr. Fonta Williams (Department of Economics, University of Nigeria, Nsukka), Dr. Effiom Oku, Stephen Frimpong (UNU-INRA), Dr. Aquinas Thomas Adjadeh and Wisdom Sabastian Brahene (Department of Soil Science, University of Ghana, Accra) for their assistance with resource materials and statistical analysis.

The reviewers of this work are well acknowledged.

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1.0 INTRODUCTION

Land shortage for agriculture is an outstanding feature of many localities in South-eastern Nigeria. The shortage, occasioned by population pressure and other competing land use such as urban, industrial and commercial development, has led to land fragmentation. This has also led to the reduction of fallow period or absence in some cases indicating that soil fertility is not naturally restored (Asadu et al., 2004), and more particularly limiting the capability of natural restoration of these resources (Ezeaku & Alaci, 2008). Agricultural intensification, in order to increase productivity per available unit area of land, has become the coping strategy by smallholder farmers.

Agricultural intensification is defined as ‘increased average use of modern agricultural inputs on a smallholding, either cultivated land alone, or on cultivated and grazing land, for the purpose of increasing the value of output per hectare (Nani et al., 2010). They also described it as an increased frequency of cultivation (fixed unit of land) for higher value added output. Agricultural intensification achieves soil productivity improvement through increased use of natural or artificial fertiliser, improved seeds and mechanisation, multi-cropping/relay-cropping with subsequent changes to the landscape that leads to soil degradation. The system of agricultural land use is dynamic in nature and so it has been changed and is still changing in response to the changing physical, human and economic circumstances of the areas.

The drivers of agricultural intensification include an improved economy, which result from increase in income through yield increase. Nani et al. (2010) reported 61% yield and net income from vegetable based cropping pattern relative to 41% in cereal cropping pattern. Food security is a social determinant of livelihood as agricultural intensification leads to increase food production (Westarp et al., 2004) and the creation of employment opportunities in the marketing of agro-chemicals and other inputs such as, fertilisers, pesticides etc. (Nani et al., 2010). The need to sustain agricultural intensification has also given rise to local institutions and leadership indicators for livelihood improvement as evidenced in the emergence of different focus groups, such as Conservation Development Group; Community Forest User Group; and Women Group. These groups serve as social capital for sustainable livelihood system.

Despite the above advantages of agricultural intensification, the fundamental question is whether it can save land. Okafor (1991) and Okigbo (2001) report that the changing population and land relationship and the associated agricultural land use change have implications not only for the socio-economic conditions of the population but also for the environment. In South-eastern Nigeria, a major environmental consequence of agricultural land use intensification is land degradation. Environmental degradation is defined as the reduction of the capacity of the environment to meet social and ecological objectives and needs, hence leads to soil productivity decline and food insecurity (FAO, 2008). Another consequence of land use intensification is involution, which occurs when increasing demand is met by output intensification but at the costs of decreasing or small marginal and average returns to outputs (Nani et al., 2010).

Soil degradation is caused by a number of factors such as nutrient output exceeding input; when soil is acidified; when there is physical deterioration of soil structure e.g. surface sealing and crusting; when there is increase in bulk density, reduction in porosity and aggregate stability, when soil is water-logged and salinised, where there is sediment deposition on valley bottoms and wherever there are barriers on sloping land. In addition to these are nutrient mining, use of inappropriate farming practices and frequent changes in land use (over-cultivation) (Thomas et al., 2006; Islam & Weil, 2000; Ezeaku, 2011a).

Land degradation occurs through three processes (physical, chemical and biological). The physical is in terms of soil erosion, compaction, crusting, and reduction in aggregate stability due to fire and burning of vegetation as well as tillage related problems. Chemical degradation involves nutrient output exceeding input; leaching, and acidification. Depletion of soil organic matter and reduction in soil biodiversity are signatures of biological degradation. Literatures exist on effect of land use change on productivity of soils (McConkey et al., 1997; Eswaran et al., 1997; Deborah et al., 2001). Existing information on the extent of degradation (vulnerability) of soil properties and influences on crop cultivation in South-eastern Nigeria remain scanty.

Studies have shown evidence of climate effects on environment (NRC, 1993; Malla, 2008; Sivakumar & Ndiagui, 2007; Wolfram & Lobell, 2010). These studies showed that rainfall pattern experienced inconsistency with higher intensities of rain and less number of rainy days, resulting to increases in sheet, rill and gully erosion. Ofomata (1981) notes that soil erosion is, however, the most obvious significant evidence of land degradation. In the southern region, as over 70% of the land, is affected by one form of soil erosion or another.

Decline in soil productivity due to erosion, especially in cultivated soils; lead to decline in crop yields. Amana et al. (2012) have shown that reduction of crop yields is a major concern in those regions where the attainment of food security is closely related with soil degradation due to nutrient mining. Obi & Nnabude (1988) showed declines in productivity of soils under intensive and continuous cultivation, even when supplementary fertilisers are in use.

Despite soil degradation caused by climate in terms of water, there has been widespread interest in the relationship between climate and agriculture (Wolfram & Lobell, 2010). Thus, given the central role of agriculture in any regional economy such as Southern Nigeria and the unprecedented changes in climate, there is a need to understand possible responses of crops to climate phenomena. Determining the effect of climate variability on crop yields would enable application of mitigation and adaptation strategies that would at short- and long-term obviate its negative impacts on agriculture and environment. It is quite obvious that the yield performance of crops is fundamental to the success of farmers growing them and to the intensive livestock sector within the region relying on the yield output for feed.

The net consequence of land degradation caused by climate variability and anthropogenic activities diminishes capacity of the land to provide benefits in terms of yield and productivity (FAO, 2002). This deepens food insecurity (a widening “food gap”- the difference between what is to be produced and what is needed to maintain minimal food nutrition) and health degeneration (Ezeaku et al., 2008). Inadvertently, this affects individuals and national economies, which also retard national development. This situation traps the population in a vicious cycle between land degradation and poverty (UNU-INRA, 1997). The linkage between agricultural intensification, climate change and poverty is aptly captured by Nani et al. (2010) and re-modified as in Figure 1.

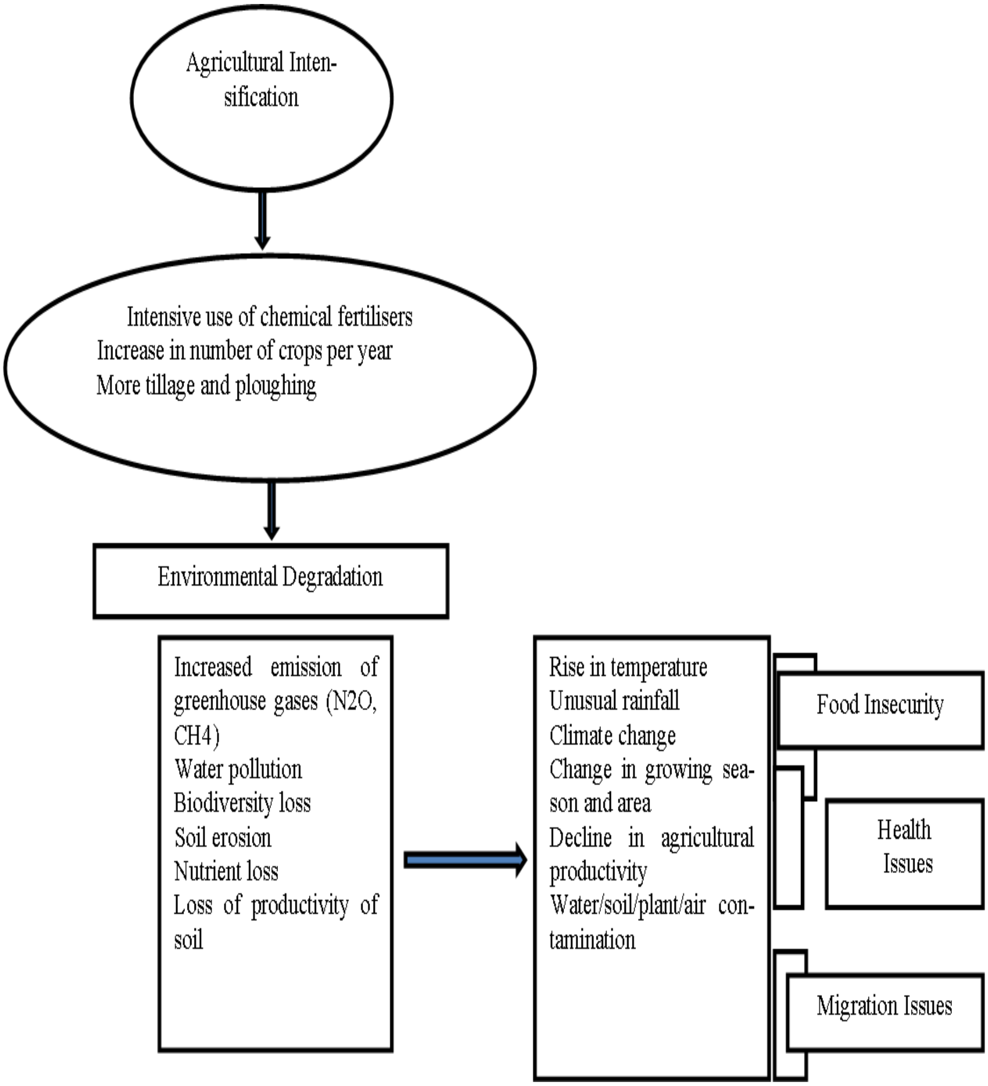


Figure 1: Linkage between agricultural intensification, climate change and poverty

Source: Modified from Nani *et al*. (2010)

The above scenario is a demonstration that land degradation will remain a major issue for the 21st century because of its adverse impact on agronomic productivity, the environment and its major effect on food security and the quality of life. The rate of degradation necessitated the “Earth Summit Conference” held in Brazil in 1992 by the United Nations. Protocols have been developed, ratified and implemented by National governments. They concern particularly areas like the southern region of Nigeria, where in-spite of several attempts at controlling erosion in the region (Ofomata, 1981; Okigbo, 2001), the problem of land degradation has continued unabated due to the fact that majority of the population depend on land for sustenance. This creates the need, in this study, for evaluation of changes in the quality of land resources in Southern Nigeria.

The overall objective of the study is to determine the effect of agricultural intensification and climate effect on soil properties and productivity in some locations in Southern Nigeria. The specific objectives are to:

i) Determine impact of rainfall, temperature and soil parameters on average crop yields;
ii) Assess soil fertility degradation rates of the soils;

iii) Examine and classify the soils along a *toposequence* of the study locations.

The research output is expected to provide green management solutions that would reduce diminution of fertile soils for normal crop growth; restore, sustain and enhance the productive and protective functions of the ecosystems, improve food and fibre production for poverty reduction and social equity, while preserving unique landscape and important soil biodiversity.

2.0 MATERIALS AND METHOD

2.1 Study location

Enugu State is situated in inland South-eastern Nigeria, lying partly within the semi-tropical rain forest belt of the south. The State lies 6°30’ north and longitude 7°30' east and spreads towards the north through a land area of approximately 7,161 sq. km (Figure. 2). Its physical features changes gradually from tropical rain forest to open wood-land and then to Savannah. Apart from a chain of low hills, running through Abakaliki, Ebonyi State in the east to Nsukka in the north-west, and southwards through Enugu and Agwu, the rest of the State is made up of low land separated by numerous streams and rivulets, the major ones being the Adada and the Oji Rivers. It has a population of 3,267,837 (2006 census figures) and a population density of 460 people per square kilometre. Nsukka LGA is one of the 17 local government areas (LGAs) in Enugu State (www.onlinenigeria.com).

Abia State covers an area of 4,902.3 square kilometres. It lies at latitude 5°25’ north and longitude 7°30' east. It has a population of 2,845,380 (2006 census figures) and a population density of 578 people per square kilometre. The state shares common boundaries to the north with Ebonyi State; to the south and southwest with Rivers State; and to the east and southeast with Cross River and Akwa lbom States respectively. To the west is Imo State, and to the northwest is Anambra State (Figure 2).The state has seventeen LGAs with Umuahia South inclusive (http://www.abiastateonline.com). Akwa Ibom is a State in Nigeria named after the Qua Iboe River. It is located in the coastal South-Southern part of the country, lying between latitudes 4°321 and 5°331 North, and longitudes 7°251 and 8°251 East (Figure. 2), with total land area of 7,081 square kilometre. The State is bordered on the east by Cross River State, on the west by Rivers State and Abia State, and on the south by the Atlantic Ocean and the southernmost tip of Cross River State. The State has a population of 2,359,736 (1991 Census) and population density of 330 km-2 (860/sq. mi). Thirty-one LGAs make up the State with Ikot Abasi LGA being one of them (http://www.akwaibomstateonline.com).

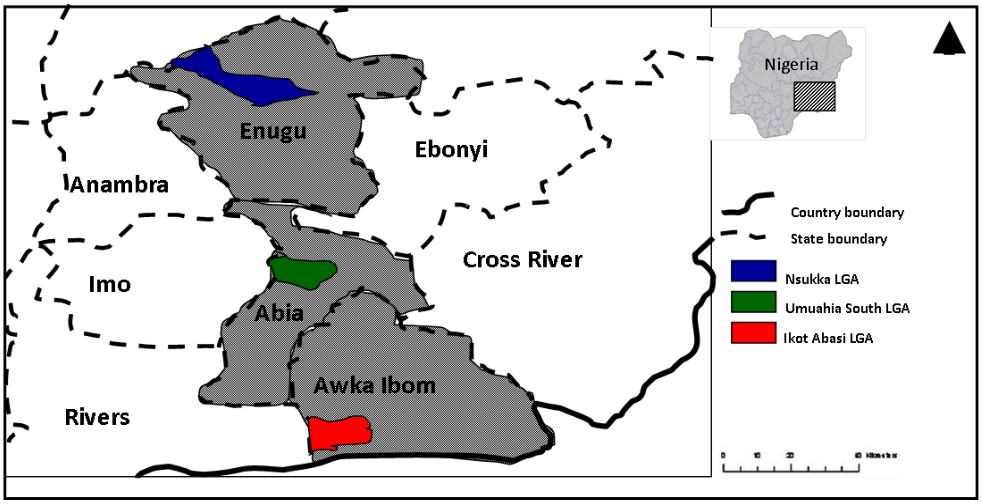


Figure 2: Map of Nigeria showing the study locations

2.1.1 Site selection and procedure

Multistage random sampling technique was employed in the selection of the study locations. This involved selection of three agro-ecological zones (AEZs), namely; derived savannah in Nsukka local government area (LGA), Enugu State; low land rainforest in Umuahia South LGA, Abia State, and fresh water swamps in Ikot Abasi LGA, Akwa Ibom State. These zones were selected based on differences in physical environments, particularly the climate, landforms and soil. In each zone a state was chosen. In addition, a random selection of three communities out of the list of five communities provided by the community leaders was done for each LGA, making a total of nine communities. Communities selected in Nsukka LGA are Ehalumonah, Ede-Obala and Opi. Ibeku, Ubakala and Umuokereke communities in Umuahia South, while Ikot Akpan, Ikwa Eta and Ikot Ekara are communities in Ikot Abasi LGA.

2.2 Farmer interviews (Household survey)

The fourth stage involved the selection of individual respondents. Ten farmers who were involved in crop production were purposely selected from each of the nine communities and interviewed. Thus, a total of 90 farmers (30 in each state) constituted the population size for the study. The farmers, who were interviewed and administered with a structured open-ended questionnaire, were heads of households, who have had at least 20 years' experience in crop production. Household heads were selected and interviewed because they were the persons responsible in making key decisions regarding farming practices.

The questionnaire was developed based on the soil quality survey proposed by USDA Soil Quality Institute (Romig et al., 1995). The questions were used as an interview guide and contain important information on the following aspects: criteria used in assessing land degradation; as it impacts soil productivity and farm crop yields, and soil conservation practices. The survey was conducted at the same time and the same place where soil samples were taken.

2.3 Soil sampling

In each village, a farm land (50m x 100m = 500m^2) was mapped and sampled at grid size of 250m^2. Soils were sampled and composited within each farm at two repeated measures (2010 and 2011) with auger (internal diameter of 86mm) at 0-30cm soil depth. Soil samples were also collected at similar depth in adjacent fallow soils for standardisation. The depth was chosen because most arable and vegetable crops are surface feeders. A total of 90 auger and 36 core soil samples were collected from a total of 0.006 km^2 (1500m^2) grid size for the states. One profile pit was dug in each of the three studied locations at the upper slope, mid slope and lower slope positions and soils sampled from the horizons, giving a total of twelve profile soil samples.

2.4 Laboratory analyses

Soil samples collected from the field were removed from the steel collection augers and were air-dried in the laboratory. The dried samples were gently disaggregated and mixed with a mortar and pestle. The sample was then passed through a 2mm screen.

The analytical characteristics of the soil horizon samples were determined in the following manner: Gee & Bauder’s (1986) pipette method was used to determine particle-size distributions, soil bulk density as described by Blake & Hartge (1986), while porosity was calculated using the relationship in equation (1) (Dannielson & Sutherland, 1986).

$$Tp = 1 - \frac{Bd}{Pd} \; x \; 100\,\% \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where Tp = total porosity (%), Bd = bulk density (gcm-3), Pd = particle density assumed (2.65 gcm-3)

Soil saturated hydraulic conductivity (Ks) was determined based on Klute &

Dirksen (1986) method and calculated by using the transposed Darcy's equation for vertical flows of liquids:

$$Ks = \left(\frac{Q}{At}\right)/\left(\frac{L}{DH}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

Where, Ks = saturated hydraulic conductivity (cm hr^{-1}), Q = steady-state volume of water outflow from the entire soil column (cm3), A = the cross-sectional area (cm^2), t = the time interval (hr), L = length of the sample (cm), and DH = change in the hydraulic head (cm).

Soil pH was determined using 1:2.5 soil water suspension (adequate to wet the glass electrode) and read using the pH metre (Mclean, 1982). Organic carbon was obtained by the wet dichromate acid oxidation method (Nelson & Sommers, 1982). Total nitrogen was determined using the Micro-kjeldhal method (Bremmer & Mulvaney, 1982), while available phosphorus was assayed by Bray P-2 bicarbonate extraction method (Olsen and Sommers, 1982). Exchangeable bases (Ca, Mg, Na and K) were extracted in 1 N NH4OA buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity (EA) was determined by titration with 0.05 N NaOH, while ECEC was determined titrimetically using 0.01 N NaOH (McLean, 1982). Effective cation exchange capacity (ECEC) was obtained as a summation of exchangeable bases and the exchange acidity (Rhoades, 1982). Base saturation was computed as the percentage ratios of exchangeable bases.

Data from the pedagogical studies was used to classify the soils according to USDA Soil Taxonomy (2003) edition.

2.5. Analytical approach

2.5.1 Quantitative statistics

In this study, only two climate variables (rainfall and temperature) were used. Rainfall and temperature measurements (data) for 2000–2011 were obtained from the Meteorological stations in the study areas and arranged according to Mitchell & Jones (2005) method. Cassava, rice, maize and cowpea are the major crops grown by the farmers. Their average yields over the 12 year period were obtained.

All data (rainfall/temperature, soil, and crop) were statistically analysed using STATA Version 12, and Genstat 9.2 Edition. The Coefficient of Variability (CV %) was used to assess the variation in climate parameters over the 12 year period. Anomaly was calculated as the departure of rainfall and temperature annual values from the normal annual Mean for each location. Rainfall and temperature effects on crop yields were obtained through regression analysis.

2.6 Assessment of soil degradation rate (SDR)

The degradation status of the soils in the three locations were assessed by field observation and using criteria for land degradation assessment (FAO, 1979; Landon, 1984; Lal, 1994).

Soil physico-chemical properties were weighted and applied to soil degradation rating (SDR) scheme that uses relative scale of 1 to 5, where 1 is none, 2 (slight), 3 (moderate), 4 (high) and 5 (severe). In this case, a weight of 1 was given when there was no limitation and 5 were given when the limitation was extreme/very high. Determining the relative weight scale of the soil parameters was based on the established critical levels of soil elements from various literatures (FAO, 1979; Akinrinade & Obigbesan, 2000; Landon, 1984; Enwezor et al., 1989; Aune & Lal, 1997).

3.0 RESULTS

3.1 Distribution of Mean annual rainfall and temperature parameters in the study sites

The Mean annual rainfall and air temperature values obtained from the locations over the 12 year period (2000 - 2011) indicate some degree of variations, due probably to the differences in *agroecology* (Figures 3-5).

Mean annual rainfall at Nsukka varies from 1154.3 to 1901 mm corresponding to lowest and highest rainfall amounts obtained in the year 2010 and 2005, respectively. At Umuahia South, highest rainfall of 2416.7 mm was obtained in 2010 and lowest amount (1739.4 mm) in 2000. Highest (2839.4 mm) rainfall was obtained in the year 2010, while lowest value (1729.1 mm) in 2011 in Ikot Akpan (Figure. 3).

The result in figure 4 shows that the highest and lowest rainfall did not coincide with the highest and lowest number of rainfall days in the locations. Highest number of rainfall days (131) is obtained in 2010 and the lowest (102 days) observed in 2008 at Nsukka. Rainfall days in Umuahia South ranges from 123 in the year 2005 to 147 in 2006 corresponding to lowest and highest periods. At Ikot Abasi, the year 2007 had highest rainfall days (139) and lowest (121 days) in 2009.

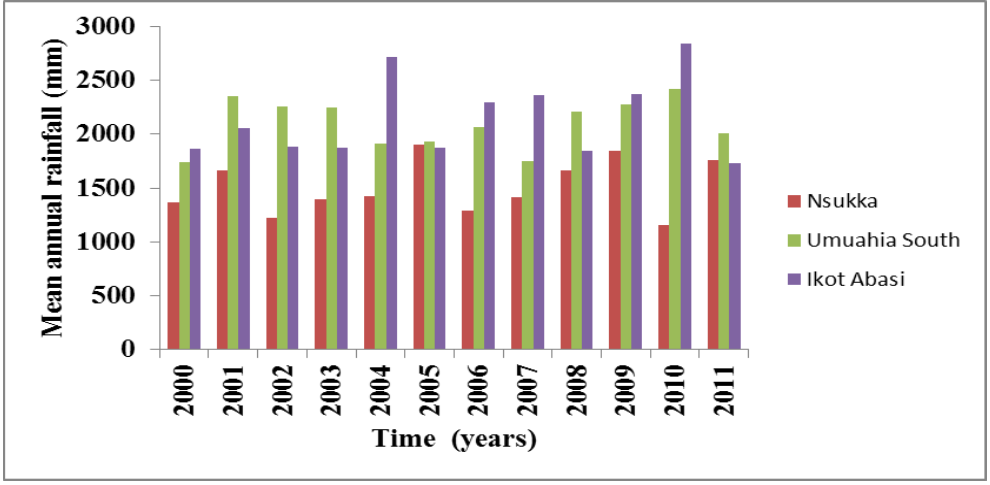


Figure 3: Mean annual rainfall (mm) distribution over a 12 year period in Nsukka, Umuahia South and Ikot Abasi locations (Computed from data source: Nsukka– Dept. of Crop Science, University of Nigeria, Nsukka; Ministry of Agriculture, Umuahia South; MOA, Ikot Abasi)

Over the 12 years, Mean annual minimum and maximum air temperatures at Nsukka is approximately 20.8 and 34.2 ^{o}C. The corresponding value at

Umuahia South for the same period is 22.3 and 32.0 °C and 20.0 and 34.0 °C for Ikot Abasi (Figure 4). Average minimum temperature ranges from 26.8 to 29.0 °C (Nsukka), 26.7 to 27.3 °C (Umuahia South), and 22.9 to 28.3 °C (Ikot Abasi). The minimum air temperature coincides with the period of cloud cover and heavy rains.

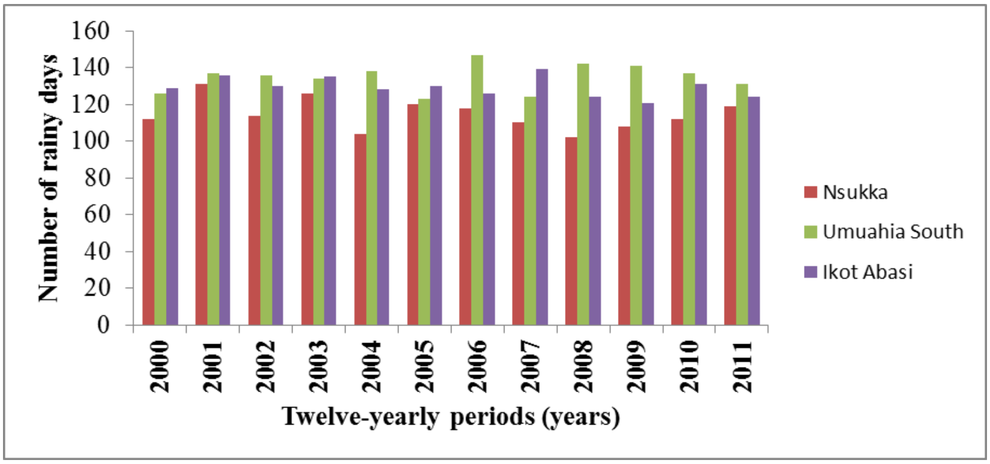


Figure 4: Number of rainy days over a 12 year period in Nsukka, Umuahia South and Ikot Abasi locations. (Computed from data source: Nsukka – Dept. of Crop Science, University of Nigeria, Nsukka; Ministry of Agriculture, Umuahia South; MOA, Ikot Abasi)

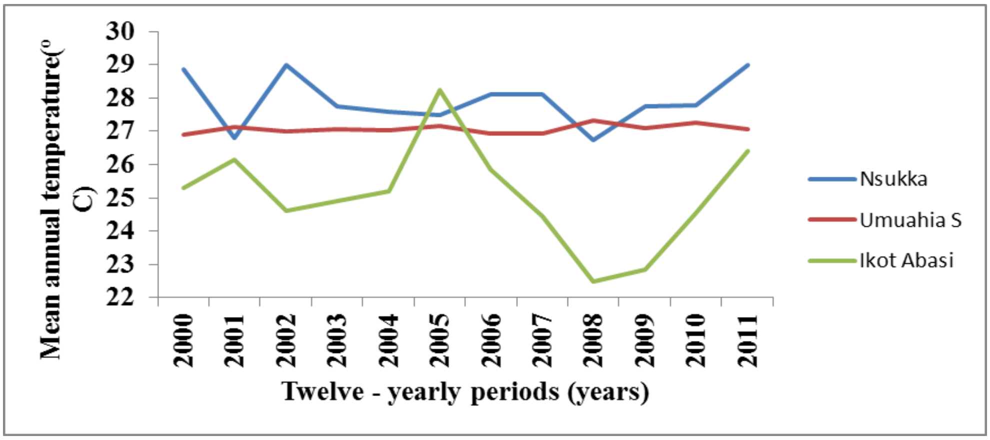


Figure 5: Mean annual temperature over a 12 year period in Nsukka, Umuahia south and Ikot Akpan locations (Computed from data source: Nsukka– Dept. of Crop Science, University of Nigeria, Nsukka; Ministry of Agriculture, Umuahia South; MOA, Ikot Abasi)

The anomaly results in Table 1 indicates that 8 years for Nsukka (1508 mm), 5 years for Umuahia South (2175 mm) and 7 years Ikot Abasi (2167 mm) were below the normal values. The corresponding value above normal for each location is 4, 7 and 5 rainfall years. A percentage rainfall anomaly above the normal value shows 45.5%, 54.2% and 55.9% for Nsukka, Umuahia South and Ikot Abasi, respectively. Corresponding below the normal value is 54.6%, 45.8% and 44.0%.

Table 1: Mean, standard deviation, coefficient of variation and anomaly of rainfall and temperature (2000-2011)

Location	**Nsukka**	**Umuahia South**	**Ikot Abasi**	**Nsukka**	**Umuahia South**	**Ikot Abasi**
	Mean annual rainfall (mm)			**Mean annual temperature (^{o}C)**		
Mean	1507.9	2174.5	2167.0	27.9	27.1	25.1
	238.63	208.60	405.32	0.7181	0.1239	1.4819
SD±	15.8	9.6	18.7	2.57	0.46	5.0
CV (%)						
Year						
2000	140.4*	435.1*	309.8*	1.0	0.2*	0.2
2001	157.4	177.8	112.4*	1.1*	0.0	1.1
2002	283.9*	82.0	284.6*	1.1	0.1*	0.5*
2003	111.9*	74.9	298.4*	0.1*	0.0	0.8*
2004	87.0*	55.6	693.9	0.3*	0.1*	0.1
2005	393.9	244.1*	298.4*	0.4*	0.1	3.1
2006	221.8*	109.7*	121.4	0.2	0.2*	0.7
2007	93.5*	136.1*	192.1	0.2	0.2*	0.7*
2008	151.0	242.2	322.5*	1.1*	0.2	2.6*
2009	336.6	221.1	203.8	0.1*	0.0	2.3*
2010	353.6*	242.7	855.3	0.1*	0.2	0.7*
2011	252.9*	171.0*	439.9*	1.1	0.0	1.3
Change:						
Below	**0.5455**	**0.4576**	**0.4403**	**0.5614**	**0.6153**	**0.5937**
Above	**0.4545**	**0.5423**	**0.5594**	**0.4385**	**0.3846**	**0.4063**

*Values with rainfall below normal.

Computed from data source: Nsukka– Dept. of Crop Science, University of Nigeria, Nsukka; Ministry of Agriculture, Umuahia South; MOA, Ikot Abasi

Temperature analysis shows that 7 temperature years are below and 5 temperature years are above the normal (27.9 ^{0}C) for Nsukka. Also, 5 temperature years are below and 7 temperature years are above the normal (27.1^{0}C) for Umuahia South location. Ikot Abasi site had equal (6) temperature years below and above the normal (25.1 ^{0}C). Also, assessment of temperature change shows percentage changes in Nsukka to be 56.1%

below and 43.9% above the normal. Umuahia South had 61.5 below and 38.5 % above the normal, while 59.4 and 40.6 % is respectively below and above the normal temperature in Ikot Abasi.

3.2 Crop yields in the three locations studied

The report of the National Research Council (NRC 1999) shows that rainfall and temperature variables are important parts of the abiotic components of a site and are basic to an ecosystem because of their significance in both soil development and crop productivity. Jones & Thornton (2003) also noted that weather parameters play a vital role in the agricultural practices, crops grown and yields in a location. Thus, the extent of rainfall and temperature parameter influence on crop yield is ascertained and discussed as below.

Average crops yields (Figure 6 and not 4 in textbox) vary between the years and in the three locations. At Nsukka, highest yield (10.5 t ha^{-1}) of cassava was obtained in 2008 and the lowest (8.27 t ha^{-1}) in 2000. Highest and lowest average yield for other crops were: maize (2.31 & 1.28 t ha^{-1}) and cowpea (1.40 & 1.00 t ha^{-1}). Cassava's highest (12.3 t ha^{-1}) and lowest (9.62 t ha^{-1}) yield was obtained in 2000 and 2001, respectively in Umuahia South. Other crop yields include maize (2.38 & 1.55 t ha^{-1}), cowpea (1.62 & 1.20 t ha^{-1}) and rice (1.90 & 1.30 tha^{-1}). At Ikot Abasi, highest yield (13.4 tha^{-1}) was obtained in 2008 and the lowest (10.38 tha^{-1}) in 2005. Similar trends of other crop yields were observed as maize (3.0 to 2.1 tha^{-1}), cowpea (1.43 to 1.23 t ha^{-1}) and rice (1.93 to 1.53 t ha^{-1}). The overall trend shows higher crop yields obtained in Ikot Abasi and Umuahia South locations than in Nsukka.

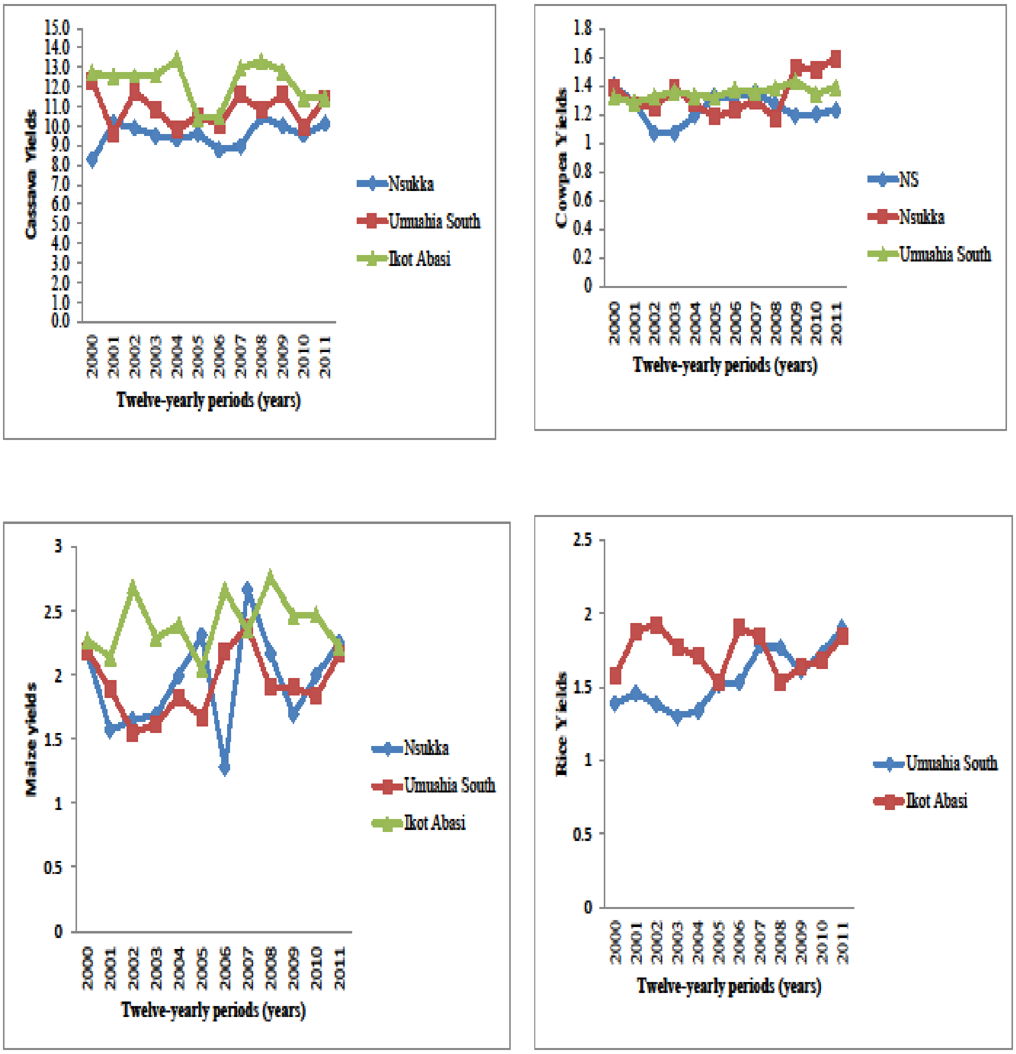


Figure 4: Crop yields over 12-years period of time in Nsukka, Umuahia South and Ikot Abasi locations

Figure 6: Note: this textbox is Figure 6: Crop yields over the 12 year period in Nsukka, Umuahia South and Ikot Abasi locations

3.3: Soil Fertility Parameters and Degradation Rates

3.3.1 Soil fertility parameters and their distributions in cultivated and fallow soils

The result of the textural classes showed differences among the locations (Tables 2-4). Textural class as a function of weathering in association with parent materials influenced by climate over time (Fitz-Patrick, 1986) varies from sandy loam in Nsukka to sandy clay loam in Umuahia South and Ikot Abasi. It was found that textural classes in cultivated soils did not vary with those of fallow soils but differed in terms of clay contents, which were higher in the latter.

Bulk density (Bd) Mean values in the study areas range from 1.51 gkg^{-1} (Nsukka) through 1.45 gkg^{-1} (Umuahia South) to 1.46 gkg^{-1} (Ikot Abasi), and are within the range (1.00 – 1.60 gkg^{-1}) reported as ideal for agronomic activities in most mineral soils (FAO, 1979; Aune and Lal, 1997). Cultivated soil had lower bulk density value (1.51 gkg^{-1}) relative to that of fallow soil (1.57 gkg^{-1}) in Nsukka (Table 2). Bulk density values obtained in Umuahia South (Table 3) and Ikot Abasi (Table 4) followed similar trend in cultivated and uncultivated soils as those obtained in Nsukka site. Soil bulk density in all the sites (Tables 3 & 4) were moderately degraded (SDR = 3).

The result of the chemical properties of the soils in the three locations as presented in Tables 2-4 shows that the pH of the soil in water is very highly acidic (pH = 4.93) in Ikot Abasi and Nsukka (pH = 5.01) and moderate (pH = 5.7) in Umuahia South. Mean soil organic carbon (SOC) obtained in cultivated Nsukka, Umuahia South and Ikot Abasi soils is 7.3, 9.6 and 10.7gkg^{-1}, respectively. Soil OC values in cultivated soils were consistently lower than those obtained in fallow soils (Tables 2-4).

Result of soil organic nitrogen (SON) showed a similar pattern to that of SOC, which is found highest (0.92 gkg-1) in Ikot Abasi, followed by Umuahia South (0.81 gkg^{-1}) and lowest (0.78 gkg^{-1}) in Nsukka (Tables 2-4).

The contents of exchangeable cations (Ca, Mg, Na and K) differ in the locations. In cultivated soils, Ca+2 ranges from 1.3 cmol kg^{-1} in Nsukka through 3.4 (Umuahia, South) to 3.0 cmol kg^{-1} in Ikot Akpan. This corresponds to their rating of moderate to slight degradation (Tables 2-4). Magnesium (Mg) content is higher (2.3 cmol kg^{-1}) in Ikot Abasi and Nsukka (1.8 cmol kg^{-1}) than in Umuahia South (1.13 cmol kg^{-1}).

Table 2: Mean soil properties of fallow and cultivated at 0-30cm soi and their degradations rates in Nsukka location within a grid of 250 cm^2

Soil property	**Ehalumonah**	**Ede-Obala**	**Opi**	**Mean**	**DR**	**Fallow**	**SDR**
Soil pH (H_2O)	4.91	5.02	5.1	5.01	4	5.20	4
OC (gkg^{-1})	7.2	7.8	6.9	7.3	4	11.2	3
TN (gkg^{-1})	0.80	0.92	0.62	0.78	4	0.94	3
TP (mgkg^{-1})	33	28	30	30.3	4	62	1
Ca (cmol kg^{-1})	1.3	1.2	1.4	1.3	3	1.6	2
Mg (,,)	1.6	2.0	1.8	1.8	2	2.3	1
Na (,,)	0.23	0.20	0.19	0.21	2	0.22	2
K (,,)	0.03	0.02	0.05	0.03	4	0.07	4
CEC (,,)	6.9	6.0	5.3	6.0	4	12.8	1
BS (%)	46	52	48	48.6	4	66	2
Texture	Scl	Sl	Sl	Sl	4	Sl	3
Bd (gkg^{-1})	1.44	1.56	1.53	1.51	3	1.57	2
Tp (%)	45.7	41.1	42.3	43.1	3	40.8	2
Ks (cmhr^{-1})	0.48	2.09	1.52	1.14	2	2.45	3
				Mean SDR = 3.36*			**=2.36**

Note: SDR = soil degradation rate* = highly significant at P<0.01
Source: Author's field data

Table 3: Mean soil properties of fallow and cultivated soils at 0 – 30 cm soi and their degradation rates in Umuahia South location within a gris size of 250 cm^2

Soil property	**Ibeku**	**Ubakala**	**Umuokereke**	**Mean**	**DR**	**Fallow**	**DR**
pH (H_2O)	5.4	6.2	5.5	5.7	**3**	6.3	**1**
OC (gkg^{-1})	8.2	9.6	11.1	9.6	**3**	12.32	**2**
TN (gkg^{-1})	0.62	0.84	0.97	0.81	**3**	1.07	**2**
TP (mgkg^{-1})	29.8	23.0	30.1	27.3	**4**	11.3	**2**
Ca (cmol kg^{-1})	3.0	3.1	4.0	3.36	**2**	3.6	**2**
Mg (,,)	0.82	1.21	1.35	1.13	**3**	1.54	**3**
Na (,,)	0.32	0.33	0.28	0.31	**1**	0.33	**1**
K (,,)	0.28	0.16	0.19	0.21	**2**	0.30	**2**
CEC (,,)	7.1	8.0	9.9	8.3	**3**	11.8	**3**
BS (%)	63	66	57	62	**3**	68	**2**
Texture	Scl	Scl	Sl	Scl	**3**	Scl	**3**
Bd (gkg^{-1})	1.40	1.47	1.49	1.45	**2**	1.49	**1**
Tp (%)	46.8	45.3	43.8	45.3	**2**	43.8	**2**
Ks (cmhr^{-1})	0.36	0.46	0.87	0.53	**1**	0.31	**1**
				Mean SDR = 2.50**			**= 1.93**

SDR = soil degradation rate,* *Significant at P<0.05
Source: Author's field data

The potassium (K+) values ranges from 0.03 cmolkg^{-1} in Nsukka, 0.08

cmolkg^{-1} in Ikot Abasi to 0.21 cmolkg^{-1} in Umuahia South. The value of Ca, Mg and K in the soils of the study areas is below critical limits of 2.0, 4.0 and 1.5 cmol kg^{-1}, respectively.

Soil cation exchange capacity (CEC) has been classified as low (< 6 cmol kg^{-1}), medium (6-12 cmol kg^{-1}) and high (> 12 cmol kg^{-1}) for some Nigerian soils (Enwezor et al., 1989). On the basis of this classification, mean CEC of Nsukka soils (7.2 cmol/kg), Umuahia South (8.3 cmol kg^{-1}) and Ikot Abasi soils (10.0 cmol kg^{-1}) fell within the medium class (Tables 2-4). The CEC of fallow soils are similar in class except that of Ikot Abasi (>12cmol/kg). Soil degradation assessment of CEC values shows moderate rate (SDR = 3) in all the sites studied.

Table 4: Mean soil properties of fallow and cultivated soils at 0–30cm soi and their degradation rates in Ikot Abasi location within a grid size of 250cm^2

Soil property	Ikot Akpan	Ikot Eta	Ikot Ekara	Mean	DR	Control	DR
pH (H_2O)	4.9	4.8	5.1	4.93	5	5.3	4
OC (gkg^{-1})	12.2	9.8	10.0	10.7	3	12.4	2
TN (gkg^{-1})	0.92	0.86	0.98	0.92	3	0.88	2
TP (mgkg^{-1})	33	48	39	40.0	3	52.0	1
Ca (cmol kg^{-1})	3.2	3.0	2.7	3.0	2	3.7	2
Mg (,,)	1.7	2.0	3.2	2.3	2	2.8	1
Na (,,)	0.21	0.24	0.30	0.25	2	0.28	3
K (,,)	0.07	0.09	0.08	0.08	4	0.09	4
CEC (,,)	10.2	8.5	11.1	10.0	3	12.4	2
BS (%)	79.0	70.0	74.0	74.0	2	82.0	1
Texture	Scl	Scl	Scl	Scl	2	Scl	2
Bd (gkg^{-1})	1.38	1.42	1.47	1.42	2	1.45	2
Tp (%)	48.0	46.5	44.6	46.5	2	43.1	2
Ks (cmhr^{-1})	0.24	0.31	0.58	0.35	2	0.53	1
				Mean SDR = 2.64			**=2.07**

SDR = soil degradation rate (Source: Author's field data)

Base saturation (Bs) degradation rating was high in cultivated soil of Nsukka, moderate in Umuahia South soil and slightly degraded in Ikot Abasi soil. The Bs value of fallow soil when compared with cultivated soil was higher.

3.3.2 Soil Degradation Rate (SDR) Assessment

Table 5 presents both the test of significance and overall degradation rates of cultivated and fallow soils in the three study locations. It was found that agricultural intensification significantly affected the cultivated soils of Nsukka (P < 0.01) and Umuahia South (P < 0.05) and did not have any significant effect on Ikot Abasi cultivated soils. But in terms of degree of deterioration and suitability for crop cultivation, Umuahia South had a better soil (SDR=2.50), followed by Ikot Abasi (SDR=2.64) and Nsukka the least (SDR=3.36).

Table 5: M Test of significance between the degradation rates of cultivated and fallow soils

Location	Land type	Mean Dr	Std. Error Mean	Mean Difference	t	Sig. (2-tailed)
Nsukka	Cultivated	3.36	0.225	1.000	2.849	0.008
	Fallow	2.36	0.269			
Umuahia South	Cultivated	2.5	0.228	0.571	1.902	0.068
	Fallow	1.93	0.195			
Ikot Abassi	Cultivated	2.64	0.248	0.571	1.569	0.129
	Fallow	2.07	0.267			

Source: Author's field data

3.4 Regression results between climate, soil and crop yield parameters

Contrast analysis shows significant ($P<0.001$, $P<0.01$ or $P<0.05$) variation in sensitivity of crop yields to rainfall, temperature and soil parameters. The soil properties in the tables are those that regressed with crop yields in each location. Yields of crops were affected either positively or negatively by rainfall, temperature and soil properties as indicated by their interaction coefficients.

Table 6: Model with average rainfall, temperature and soil properties showing regression coefficients for each crop response function at Nsukka location

Parameters	Cassava	Maize	Cowpea
Rainfall (r mm)	-0.0169	-0.0077	0.0038
Std Error (SE)	(0.0351)	(0.0257)	(0.0085)
Temperature (t ^{o}C)	-1.3197	-0.2783	0.2292
SE	(2.0683)	(1.5287)	(0.5310)
Rainfall x Temp (rt)	-0.0006	0.0002	0.0001
SE	(0.0012)	(0.0009)	(0.0003)
Base saturation (%)	-0.3015	0.0110	0.0358
SE	(0.1691)	(0.1691)	(0.0415)

Total porosity (%)	-0.4265	-0.0870	0.0378
SE	(0.2339)	(0.1758)	(0.0533)
R^2	**0.5833**	**0.3612**	**0.1364**

Note: Values in brackets are the standard error (SE)
Source: Computation from author's data

As a unit increase or decrease of any crop yield is a function of a unit increase or decrease by any of the climate and soil parameters. The result in Table 6 shows that cassava and maize yields were mostly decreased by the parameters based on the negative coefficients. Rainfall and total porosity decreased cassava yields by 0.0169, 0.4265 kgha^{-1} respectively and increased cowpea by 0.0038 and 0.1378 kgha-1, respectively. Rainfall, temperature and soil total porosity decreased maize yield by their unit increases (Table 2). None of the increases or decreases was significant.

The coefficient of determination (R2) of the crop yields ranges from 0.13 to 0.58 (Table 6) showing that variation in cassava, maize and cowpea yields is respectively accounted for by about 58, 36 and 14% rainfall, temperature and soil properties singly or combined. Cassava had the highest value (R2 = 0.58) and cowpea the lowest (R2 = 0.14) with an intermediate value (R2 = 0.36) by maize.

Table 7: Model with average rainfall, temperature and soil properties showing regression coefficients for each crop response function at Umuahia South

Parameters	Cassava	Maize	Cowpea	Rice
Rainfall (r mm)	-0.5139**	-0.1371**	-0.0538	-0.1073
SE	(0.1445)	(0.0702)	(0.0390)	(0.0735)
Temperature (t ^{o}C)	-14.4556***	-11.1758	-4.3925	-8.1310
SE	(11.5906)	(5.8821)	(3.0358)	(6.1135)
Rainfall x Temp (rt)	0.0189**	0.005	0.0019	0.0039
SE	(0.0053)	(0.0026)	(0.0014)	(0.0027)
Available phosphorus	0.0902	-0.0000	0.0116	-0.0235
(mgkg^{-1}) SE	(0.1248)	(0.0376)	(0.0240)	(0.0373)
Base saturation (%)	-0.1182	0.0030	0.0049	-0.0391
SE	(0.1158)	(0.0460)	(0.0328)	(0.0424)
R^2	**0.6614**	**0.5946**	**0.1822**	**0.3867**

Note: Values in brackets are the standard error (SE), $**P<0.05$, *** **P<0.001**
Source: Computation from author's data

The result in Table 7 reveals that in Umuahia South, both rainfall and temperature negatively impacted the entire crop yields. The impact was most significant on cassava (P<0.001) and maize (P<0.05) yield by temperature and others were insignificant. A unit increase in rainfall and temperature decreased cassava crop yield by about 0.51 and 14.45 kgha^{-1}, but the combination of both significantly (P<0.05) increased cassava yield by 0.019 kgha^{-1}. While phosphorus increased maize and cowpea, base saturation decreased cassava and rice (Table 7). The combined interaction effect of rainfall, temperature and soil parameters accounted for about 66, 58, 39 and 18% of the yield variation in cassava, maize, rice and cowpea, respectively.

Table 8: Model with average rainfall, temperature and soil properties showing regression coefficients for each crop response function at Ikot Abasi

Parameters	Cassava	Maize	Cowpea	Rice
Rainfall (r mm)	-0.0063	-0.0081**	0.0010	-0.0018
SE	(0.0191)	(0.0702)	(0.0005)	(0.0038)
Temperature (t ^{o}C)	-0.8996	-0.7661***	0.0654	-0.1283
SE	(1.5087)	(0.1943)	(0.0483)	(0.3349)
Rainfall x Temp (rt)	0.0002	0.0003**	-0.0000	0.0000
SE	(0.0008)	(0.0000)	(0.0000)	(0.0001)
Available phosphorus (mgkg^{-1})	0.1199**	-0.0267**	-0.0045**	0.0083
SE	(0.0489)	(0.0075)	(0.0017)	(0.0116)
Total porosity (%)	0.3039*	0.0965**	-0.0091	0.0286
SE	(0.1346)	(0.0280)	(0.0090)	(0.0591)
R^{2}	**0.7232**	**0.8878**	**0.6755**	**0.1251**

Note: Values in brackets are the standard error (SE), * P<0.01, **P<0.05
(Source: Computation from author's data)

At Ikot Abasi location, both rainfall and temperature increased only cowpea yield but significantly decreased maize by 0.0081 kgha^{-1}(P<0.05) and 0.7661 kgha^{-1} (P<0.001), respectively but a combination of both parameters increased maize (P<0.05) (Table 8). A unit increase in phosphorus and total porosity significantly increased cassava (P<0.05, P<0.01) and maize (0.097 kgha^{-1}, P<0.05). Combined rainfall, temperature and soil properties accounted for the highest percentage variation in maize crop yield (R2 = 89%) followed by cassava (R2 = 72%), cowpea (R2 = 68%) and rice the lowest (R2 = 13%).

Result in Table 9 shows the interaction effect of rainfall, temperature and soil properties on each crop yield across the locations. Rainfall barely increased maize and cowpea and decreased rice and cassava. The trend of temperature effect on crop yields was similar to that of rainfall. It significantly decreased cassava yield (1.2058 kgha^{-1}, P<0.001). Temperature decrease of rice and increase of maize and cowpea was insignificant. Rainfall and temperature combined decreased cowpea yield by 3.1800 kgha^{-1} though it was not significant.

The interaction effect of soil properties shows that soil pH decreased cassava, maize and cowpea yields by 0.9325, 0.2716 and 0.0531 kgha-1, respectively. While soil organic carbon increased the yield of cassava, maize and rice, it tended to decrease that of cowpea. Also, available P significantly ($P<0.001$) increased rice yield (0.0138 kgha^{-1}) and decreased all other crops (Table 9). The result reveals further that a unit increase in cation exchange capacity (CEC) decreased all the crops yield: cassava (0.9451 kgha^{-1}, $P<0.01$), maize (0.2624 kgha^{-1}), cowpea (0.0732 kgha^{-1}), and rice (0.0912 kgha^{-1}).

Table 9: Model with average rainfall, temperature and soil properties showing regression coefficients for each crop response function across study locations

Parameters	Cassava	Maize	Cowpea	Rice
Rainfall (r mm)	-0.0104	0.0011	0.0001	-0.0015
SE	(0.0057)	(0.0110)	(0.0638)	(0.0022)
Temperature (t ^{o}C)	-1.2058***	0.0110	0.0005	-0.1007
SE	(0.4127)	(0.2467)	(0.0638)	(0.2054)
Rainfall x Temp (rt)	0.0003	-0.0000	-3.1800	0.0000
SE	(0.0002)	(0.0001)	(0.0000)	(0.0000)
Soil pH	-0.9325	-0.2796	-0.0531	Nil
SE	(0.8415)	(0.3240)	(0.1055)	
Organic carbon (gkg^{-1})	0.0456	0.0312	-0.0587	0.1045
SE	(0.3230)	(0.1121)	(0.0413)	(0.0697)
Available phosphorous (mgkg^{-1})	-0.0144	-0.0302	-0.0021	0.0138***
SE	(0.0661)	(0.0359)	(0.0081)	(0.0035)
Calcium (c)	2.3245***	0.4054	-0.0574	Nil
SE	(0.8156)	(0.5970)	(0.1438)	
Magnesium (c)	1.9910	0.7367	-0.1521	Nil
SE	(1.3132)	(0.9085)	(0.1949)	
CEC (c)	-0.9451*	-0.2624	-0.0732	-0.0912
SE	(0.4736)	(0.3027)	(0.0704)	(0.1052)
Base saturation (%)	-0.0190	0.0052	0.0084	0.0136
SE	(0.0424)	(0.0266)	(0.0071)	(0.0150)
Total porosity (%)	0.2920	0.0748	-0.0247	-0.0711
SE	(0.2217)	(0.1745)	(0.0341)	(0.0765)
R^2	**0.8442**	**0.4986**	**0.2888**	**0.3437**

Note: Values in brackets are the standard error, **P<0.05, *** P<0.001, (c) = cmolkg-^{1}
Source: Computation from author's data)

The coefficient of determination (R^2) of the interactions between rainfall, temperature, soil properties and crop yields shows that 84, 50, 30 and 34% variation in cassava, maize, cowpea and rice yield, respectively, was accounted for by the climate and soil variables.

Table 10: Effect of rainfall, temperature and soil degradation rates on each crop yield across study locations

Parameters	**Cassava**	**Maize**	**Cowpea**	**Rice**
Rainfall (r mm)	-0.0010	0.0010	-0.0002	-0.0007
SE	(0.0064)	(0.0022)	(0.0007)	(0.0023)
Temperature (t ^{o}C)	-0.6473	-0.0613	-0.0323	-0.0450
SE	(0.4796)	(0.1833)	(0.0616)	(0.2042)
Rainfall x Temp (rt)	0.0000	-0.0000	0.0000	0.0000
SE	(0.0002)	(0.0000)	(0.0000)	(0.0000)
Soil degradation rate	-6.6739	0.0055	-0.0359	1.5801*
(SDR)	(0.2552)	(0.1287)	(0.0319)	(0.8709)
SE				
R^2	**0.7190**	**NA**	**0.2192**	**0.2358**

Note: Values in brackets are the standard error, NA= not available *P<0.01
Source: Computation from author's data

Table 10 presents the result of regression between rainfalls, temperature, soil degradation rates (SDR) and crop yields. A unit increase or decrease in any of the variables leads to a unit increase or decrease in crop yield. While rainfall decreased cassava, cowpea and rice, temperature decreased all the crops' yields in the following order: cassava (0.6473 kgha^{-1}), maize (0.0613 kgha^{-1}), rice (0.0450 kgha^{-1}) and cowpea (0.0323 kgha^{-1}). The interaction effect of all the parameters on the crop yield variation followed similar order with 72, 24 and 22% observed for cassava, cowpea and rice, respectively. The R2 for maize was missing in the print out.

3.5 Soil productivity degradation assessment by farmers

The heads of households used in this assessment had some types of formal education: higher institution level (22%), secondary school level (45%), and primary school level (33%) across the locations. Farmers assessed the productivity of their soils using soil quality indicators. The criteria farmers used to assess changes in soil quality are described in Table 11. Farmers commonly assess soil quality in terms of visual properties such as appearance, feel or taste. For example, observed changes in soil colour (darkness) are used by farmers to evaluate changes in organic matter content. Likewise, soil water content is assessed by feeling the soil. Plant growth and crop yields are used for fertility criteria. Many farmers perceived that their soils were still fertile if crop yields were comparable to those achieved in previous years with the same management level.

Farmers considered that a drop in productivity following long-term cultivation could be attributed to degradation of the soil quality. This is because the yield potential of the crop plants remained good even after years of cultivation, provided an adequate supply of plant available nutrients was maintained through adequate fertilisation to the crop land uses. The occurrence of some wild plant species in the crop fields was a useful indicator of some soil properties. Experienced farmers linked the presence of certain weed species (e.g. *Mimosa pudica and Eupatorium odoratum L*.) to increase acidity. Likewise, species such as Spear grass; *Chrysopogon aciculatus R*. among others were used as indicators of poor nutrient status (soil fertility) and dryness of the soil, both of which are indicators of soil degradation. However, the use of wild plant indicator to judge soil acidity may have some limitation since an occurrence of some species (e.g. *E. odoratum L)* may be due not only to soil acidity, but also to changes in other soil properties (that is, soil moisture and soil fertility) and/or the changes in crop canopy with time.

Farmers were asked to comment on ten indicators of soil quality (Table 11). Most of them recognised that organic matter content, soil fertility, soil moisture storage, soil structure, and weed incidence decreased over time, while soil compaction increased as a result of long-term non-cultivation. It is apparent that these soil indicators were well recognised and easily assessed by farmers.

In contrast, changes in other soil indicators such as thickness of topsoil, and soil erosion were not well recognised by many farmers and answers varied from farmer to farmer (e.g. 29% of farmers interviewed indicated that soil erosion increased along with time of cultivation, while 58% considered soil erosion decreased) (Table 12).

Table 11: Diagnostics of soil quality indicators (SQI) based on farmers experiences

Soil indicators	Qualitative soil quality indicators used by farmers
1. SOM	Dark colour and good aromatic smell
2. Fertility	Based on yield and plant growth (Biomass). Lush green leaves indicate high fertility, stunted growth suggests poor fertility
3. Compaction	Hard and dry when touched or feeled
4. Structure	Observed soil crumbs during cultivation is a good structure
5. Consistence	Stickiness on hoes when cultivating

6. Moisture	Observed moist feels and dews on leaves at morning periods
7. Surface soil thickness	Observing the depth of dark coloured soil during hoeing
8. Soil erosion	Observing soil surface after rainfall event; comparing yearly variations in topsoil depth during ploughing
9. Weed incidence	Presence of weed species in the field

SOM = soil organic matter. (Source: Romig et al., 1995; Ezeaku & Salau, 2005)

Table 12: Farmer perceptions of change in soil properties with crop cultivation (expressed as a percentage of 90 farmers)

Indicator	Increase	Decrease	No change	No idea
SOM	30	50	13	7
Fertility	26	54	18	2
Compaction	42	24	31	3
Structure	14	58	20	8
Consistence	24	53	17	6
Moisture	38	43	18	1
Surface thickness	22	60	17	1
Soil erosion	29	58	6	7
Weed incidence	26	57	14	3

NB: SOM = soil organic matter. (Source: Author's field data)

Each farmer was asked to rank generally the relative importance of the various soil quality indicators (SQI) as it relates to their crop production. They ranked the SQI in the following increasing order of importance (Table 13): soil organic matter content, soil fertility, topsoil thickness, structure, moisture, compaction, soil erosion, and weed incidence. The last three SQ indicators are considered the least important but are important in conservation programs for soil protection and productivity enhancement.

Each farmer ranked the SQI on a scale from 1 to 9, with 1 being the most important indicator, and 9 being the least important. Soil quality points for each indicator were then totaled, and an overall ranking assigned to each soil variable as could be observed on the result presented in Table 13.

Table 13: Ranking of soil quality indicators based on farmers' perceptions

Indicator	Total SQI point	Overall rank
SOM	90	1
Fertility	104	2
Top soil thickness	136	3
Structure	178	4
Moisture	193	5
Compaction	235	6

Soil erosion	271	7
Weed incidence	294	8

NB: SOM = soil organic matter. (Source: Computation from author's field data)

3.6 Land management practices adopted in farming systems by farmers

Agricultural management practices used by farmers were also sought. Responses by farmers show that the most common traditional practices employed included intercropping (32%), composting/residues manure (30%), slash and burn (23%), and inorganic fertiliser (15%). Increasing soil organic carbon and thus soil fertility and productivity, as well as reducing erosion of the soil were common reasons provided by farmers for using most of the management practices.

3.7 Soil *morphology*, physical and chemical characteristics of the *pedons* studied along a *toposequence* in each study location

3.7.1 Soil morphology

Morphological properties of the soils formed along the *toposequences* are presented in Tables 14-16. Generally, the profile depths are deep (0-155 cm) through the upper to lower slope except pedon 3 and 2 in Umuahia South and Ikot Akpan, respectively. At Nsukka, the soils show variation in morphological properties along the toposequence. The pedons are characterised as well drained sandy loam through sandy clay loam at the surface to sandy clay and clay loam at the sub-soil (Tables 14). The surface pedon colour ranges from yellowish red and light red brown (Pedon 1), brownish red to red brown (Pedon 2) and dark yellowish brown (Pedon 3) to red, reddish brown and yellowish brown at the sub-soil.

The structure ranges from weak moderate angular blocky to sub-angular blocky with friable to slightly plastic consistency (Pedon 1). Pedon 2 has weak moderate coarse granular to coarse angular blocky with friable consistency. The structure of Pedon 3 ranges from crumb granular through sub-angular blocky to coarse granular. The consistencies vary from very friable to firm, while the horizon boundaries across the three pedons showed variation.

Table 14: Field morphological description of Nsukka pedons studied

Soil horizon	Depth (cm)	Colour Matrix	Texture	*Structure	Consistency (moist)	Boundary	Other features (*pores/clay skin)
Pedon 1: Upper slope							
AP	0-20	10YR 5/8yr	Scl	1mgr	Fr	Gs	3mc, n
E	20-45	5YR 6/4lrb	Scl	1mabk	Fr	Gi	2mc, n
Bt$_1$	45-90	5YR 6/4rb	Scl	1mabk	Fr	D	2mc, n
Bt$_2$	90-145	2.5YR 3/6dr	Sc	2msabk	Sp	D	1md, 2npo
Bt$_3$	145-200	7.5YR 4/8r	Cl	1m sabk	Sp	D	1md, 1npo
Pedon 2: Mid slope							
AP	0-18	5YR5/8br	Scl	2 cgr	Fr	Gs	3mc
Bt	18-40	10YR5/4rb	Scl	2 cgr	Fr	As	1cc
Bt$_1$	40-85	10YR4/4rb	Scl	1cabk	Fr	Cw	1mc
Bt$_2$	85-155$^+$	10YR4/4rb	Cl	2cabk	Fi	D	1md
Pedon 3: Lower slope							
AP	0-20	5YR 5/8dyb	Sl	g cr	Vfr	Cw	-
AB	20-65	10YR 3/4dyb	Scl	Sab	Fr	Gw	-
Bt$_1$	65-97	7.5YR 4/4db	Cl	Sab	Vfi	Gs	-
Bt$_2$	97-165	10YR 5/6yb	Cl	gc	Fi	Di	-

*symbols interpreted in the USDA-SCS (1974) special publication on soil profile descriptions.

Munsell colour: yr=yellowish red, r=red, yb=yellowish brown, lrb=light reddish brown, rb=reddish brown, dr=dark red, dyr=dark yellowish red, dyb= dark yellowish brown. **Boundary**: gs = gradual smooth, gi = gradual irregular, d = diffuse, cs = clear smooth, cw = clear wavy. When a dash (-) is present the property is not recorded. **Structure**: 1 = weak, 2 = moderate,, sbk = sub angular blocky, g = granular, c = coarse, cr = crumb, m = medium, 1 = weak, 2 = moderate, s = strong. **Consistency:** fr = friable, vfr = very friable, sp = slightly plastic. **Texture**: scl = sandy clay loam, cl = clay loam, . **Pores:** 1 = few, 2=common, 3=many; m=medium, co=coarse, c=continuous, d=discontinuous. **Clay skin**: 1=few, 2=common, n=thin, po=line the pores (Source: Author's field data)

The morphological features of the pedons studied at Umuahia South are presented in Table 15. The soils across the *toposequence* are generally sandy loam and sandy clay loam at the surface, while sub-surface range from sandy clay loam to sandy clay. The colour matrix of the structures varied. The soil consistence ranges from very friable, friable, slightly firm to firm, while the horizon boundaries were more of gradual smooth and gradual wavy.

Table 15: Field morphological description of Umuahia South pedons

Soil horizon	Depth (cm)	Colour Matrix	Texture	Structure	Consistency (moist)	Boundary	Other features
Pedon 1: Upper slope							
AP	0-17	5YR 3/2	SL	1fsg	Vfr	Cs	m2rts
AB	17-42	5YR 4/3	SL	1fsbk	fr	Gs	m2rts
B	42-70	5YR 4/6	SL	2msbk	fr	Gs	f2rts, m2rts
Bt_1	70-110	5YR 4/4	SCL	2msbk	fr	Gs	3chcl
BC	110-158	5YR 3/2	SCL	2msbk	fr	-	f2rts, 3chcl
Pedon 2: Mid slope							
AP	0-28	5YR 3/4	SL	2msbk	Sfm	Cw	Mirts
AB	28-54	5YR 5/6	SL	2msbk	Fm	Gw	Mirts
Bt_1	54-96	5YR 5/6	SCL	2msbk	Fm	Cw	f2rts
Bt_2	$96\text{-}160^+$	5YR 4/6	SC	2msbk	Vfm	-	f2rts
Pedon 3: Lower slope							
AP	0-22	10YR 4/2	Scl	1msbk	Fr	bi	Mirts
AB	22-45	10YR 4/3	SL	1msg	Fr	Gw	Mirts
Bt_1	45-87	10YR 4/4	SCL	2msbk	Fr	Gw	First
Bt_2	87-145	7.5YR 4/4	SCL	2msbk	Fr	Gw	f2rts

Boundary:, b = broken, c = clear, s = smooth, g=gradual, w = wavy, i = irregular.
When a dash (-) is present the property is not recorded. Structure: sbk = sub angular blocky, sg = single grain, f = fine, m = medium, 1 = weak, 2 = moderate, s = strong.
Consistency: sfm = slightly firm, fm = firm, fr = friable, vfr = very friable. Texture:, scl = sandy clay loam, sl = sandy loam,. (Source: Author's field data).

Morphological property of Ikot Abasi pedons shows that the soil horizons are predominated by sandy clay loam textures at the surface and clay loam at the sub-surface (Table 16). Soil colour ranges from light yellowish grey to dark grey at the upper slope; dark brown to dark grey at mid slope, while lower slope had predominantly dark grey through the profile.

The structure of the soil ranges from weak moderate angular blocky to moderately strong coarse sub-angular blocky (Pedon 1). Weak moderate crumb to moderate granular characterised Pedon 2, while strongly weak angular blocky through weak medium angular blocky to moderate coarse sub-angular blocky are obtained in the lower slope (Pedon 3). The consistence of the pedons varies from friable through firm to very firm. There was observed horizon boundaries variation across the three pedons (Table 16).

Table 16: Field morphological description of Ikot Abasi pedons studied

Horizon	Depth	Colour Matrix	Texture	Structure	Consistency (moist)	Boundary	Other features
Pedon 1: Upper slope							
AP	0-18	10YR 6/2lyg	Scl	1mabk	Fr	Cs	3mrts
AB	18-35	10YR 5/2db	Scl	2 mabk	Fr	Gi	m2rts
Bt$_1$	35-74	10YR 4/2db	Cl	1cabk	Fr	Cw	f2rts, s
Bt$_2$	74-120	2.5YR 5/2gb	Cl	2csabk	Fr	Gd	3chcl
BC	120-170^+	5YR 3/1dg	Cl	3csabk	Fr	-	f2rts,
Pedon 2: Mid slope							
AP	0-16	7.5YR3/2 db	Scl	1mc	Fr	Cw	-
AB	16-37	10 YR6/2lyg	Scl	1mc	Fr	Gw	-
Bt$_1$	37-72	7.5YR5/2 gy	Scl	2mg	Fr	Di	-
Bt$_2$	72-118^+	5YR3/1 dg	Cl	2mg	Fi	D	-
Pedon 3: Lower slope							
AP	0-14	5YR6/1 bg	Scl	1Sabk	Fr	Cw	-
AB	14-65	5YR6/1 dg	Sc	1mabk	Fi	Gi	-
Bt$_1$	65-120	5YR6/1 dg	Cl	1 mabk	Vfr	Cw	-
Bt$_2$	100-155	5YR5/1 dg	Cl	2csabk	Fi	D	-

Boundary: cw= clear wavy, gw= gradual wavy, gd= gradual diffuse, di= diffuse irregular, d= diffuse, gi= gradual irregular, cs= coarse. When a dash (-) is present the property is not recorded. Colour: lyg= light yellowish grey, gb= greyish brown, db= dark brown, gb= greyish brown, bg= brownish grey, dg= dark grey. Structure: 1=weak, 2=moderate, 3=strong, cs= coarse, abk= angular blocky, m= medium, s= strong, c= crumb, g= granular. Consistency: fm= firm, Fi= firm, fr= friable. Texture: scl= sandy clay loam, cl= clay loam. Others: 3mrts= many medium roots. (Source: Author’s field data).

3.7.2 Soil physical properties

Mean soil physical properties of the pedons studied are shown in Tables 17-19. Soil textural result shows variation at the three slope positions in all locations studied.

At Nsukka, soil texture ranges from sandy loam to sandy clay loam, sandy loam and sandy clay loam at Umuahia South, and those of Ikot Abasi range from sandy clay loam to sandy clay. While clay content varies and increases with soil depth in Nsukka and Umuahia South soils, sand fraction decreases with depth. At Ikot Abasi pedons, clay content is relatively constant with increasing depth. The values of silt/clay ratio vary in the range from 0.21 to 1.18 (Nsukka), 0.08 to 0.49 (Umuahia South), and 0.33 to 0.66 in (Ikot Abasi) (Tables 17-19).

Table 17: Mean soil physical properties of Nsukka pedons studied

Soil horizon	Depth (cm)	Sand %	Clay %	Silt %	Clay + Silt	Silt/Clay ratio	Texture	Bd gcm^{-3}	Ks cm/hr
Pedon 1: Upper slope									
AP	0-20	61	29	10	39	0.34	Scl	1.34	0.28
AB	20-45	60	28	12	40	0.43	Scl	1.34	0.31
Bt$_1$	45-90	58	32	10	42	0.31	Scl	1.37	0.22
Bt$_2$	90-145	54	38	8	36	0.21	Sc	1.39	0.16
BC	145-200	44	33	23	56	0.69	Cl	1.4	0.26
Pedon 2: Mid slope									
AP	0-18	50	24	26	50	1.08	Scl	1.32	0.51
AB	18-40	46	27	32	59	1.18	Scl	1.37	0.40
Bt$_1$	40-85	46	30	24	54	0.80	Scl	1.36	0.31
Bt$_2$	85-155$^+$	44	37	19	56	0.51	Cl	1.4	0.20
Pedon 3: Lower slope									
AP	0-20	68	18	14	32	0.77	Sl	1.32	0.88
AB	20-65	47	33	20	53	0.60	Scl	1.33	0.24
Bt$_1$	65-97	43	34	23	57	0.67	Cl	1.35	0.24
Bt$_2$	97-165	43	38	19	57	0.50	Cl	1.48	0.19

NB: Bd= bulk density, Ks= saturated hydraulic conductivity.
Source: Author's field data

Soil bulk density (Bd) data presented in Table 17 ranges from 1.34 to 1.40 gcm-3 (Upland slope), 1.32 to 1.40 gcm-3 (Mid slope), and 1.32 to 1.48 gcm-3 in lower slope at Nsukka. Corresponding Bd values at Umuahai South are from 1.37 to 1.61 gcm-3 (Table 18), and 1.31 to 1.34 gcm-3 at Ikot Abasi (Table 19). Generally, bulk density values at the surface horizons are higher and increased in value with profile depth and converse was the case for soil hydraulic conductivity values.

The values for saturated hydraulic conductivity (ks) range from 0.19 to 0.88 cm hr^{-1} at Nsukka (Table 17), 0.25 to 3.51 cmhr^{-1} at Umuahia South (Table

18), and 0.17 to 39 cmhr^{-1} at Ikot Akpan (Table 19). Higher Ks at the surface suggests that Ap horizon conduct water more rapidly than other horizons that have restricted conductivity of water due to clay accumulation.

For a tropical soil, to which the study areas belong, and following Landon (1984) classification of very rapid (>12.5 cmhr^{-1}), rapid (8-12.5 cmhr^{-1}), moderately rapid (6-8 cmhr^{-1}), moderate (2-6 cmhr^{-1}), slow (0.8-2 cmhr^{-1}) and very slow (<0.8 cmhr^{-1}), the values for conductivity is very slow for Nsukka soils, moderately slow to very slow in the soils of Umuahia South, and slow to very slow in the soils of Ikot Akpan. The variation of Ks among slope positions may be attributed to land use and management.

Table 18: Mean soil physical properties of Umuahia South pedons studied

Soil horizon	**Depth (cm)**	**Sand %**	**Clay %**	**Silt %**	**Clay + Silt**	**Silt/Clay ratio**	**Texture**	**Bd gcm^{-3}**	**Ks cm/hr**
Pedon 1: Upper slope									
AP	0-17	80.30	13.80	5.90	19.70	0.42	SL	1.44	1.5790
AB	17-42	80.10	16.80	3.10	19.20	0.18	SL	1.45	1.0136
B	42-70	75.61	18.55	5.84	24.39	0.31	SL	1.49	0.8020
Bt_1	70-110	73.81	22.70	3.49	26.20	0.15	SCL	1.51	0.4807
BC	110-158	72.78	24.80	2.42	24.22	0.09	SCL	1.54	0.3812
Pedon 2: Mid slope									
AP	0-28	78.60	19.40	2.00	21.48	0.10	SL	1.37	0.7110
AB	28-54	77.52	18.78	3.70	22.50	0.10	SL	1.40	0.7741
Bt_1	54-96	68.01	29.52	6.47	35.99	0.22	SCL	1.49	0.2471
Bt_2	96-160	62.03	35.00	2.97	37.97	0.08	SC	1.49	0.1697
Pedon 3: Lower slope									
AP	0-22	70	28	2.00	30.00	0.71	Scl	1.42	0.28
AB	22-45	80.24	17.16	2.60	19.76	0.15	SL	1.44	0.9631
Bt_1	45-87	74.22	23.20	2.58	25.76	0.11	SCL	1.45	0.4523
Bt_2	87-145	72.24	25.20	2.56	27.76	0.10	SCL	1.51	0.3663

NB: Bd = bulk density, Ks = saturated hydraulic conductivity.
Source: Author's field data

Table 19: Mean soil physical properties of Ikot Abasipedons studied

Horizon	Depth	Sand %	Clay %	Silt %	Clay + Silt	Silt/Clay ratio	Texture	Bd gcm^{-3}	Ks cm/hr
Pedon 1: Upper slope									
AP	0-18	54	34	12	46	0.35	Scl	1.31	0.20
AB	18-35	51	32	17	49	0.53	Scl	1.31	0.25
Bt_1	35-74	41	39	20	59	0.51	Cl	1.31	0.18
Bt_2	74-120	40	38	24	62	0.62	Cl	1.36	0.20
BC	$120-170^+$	41	38	24	62	0.63	Cl	1.36	0.19
Pedon 2: Mid slope									
AP	0-16	50	30	20	50	0.66	Scl	1.34	0.29
AB	16-37	48	32	19	52	0.57	Scl	1.35	0.26
Bt_1	37-72	46	33	20	54	0.58	Scl	1.35	0.25
Bt_2	$72-118^+$	45	34	21	55	0.61	Cl	1.37	0.23
Pedon 3: Lower slope									
AP	0-14	68	25	7	22	0.46	Scl	1.31	0.39
AB	14-65	55	36	9	36	0.33	Sc	1.32	0.17
Bt_1	65-120	43	38	19	57	0.50	Cl	1.35	0.19
Bt_2	120-155	42	39	19	58	0.48	Cl	1.43	0.18

NB: Bd = bulk density, Ks = saturated hydraulic conductivity.
Source: Author's field data

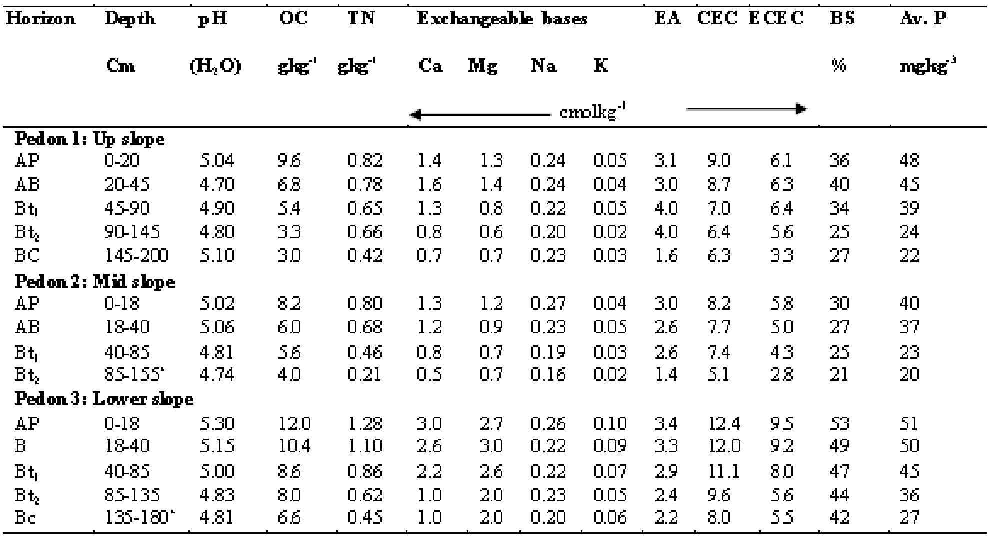
3.7.3 Soil chemical properties

The soil chemical properties of the representative profile pits for Nsukka, Umuahia South and Ikot Abasi are presented in Tables 20, 21 and 22, respectively.

The soils of Nsukka are strongly acid to very strongly acid. The soil pH in water varies from 4.80 to 5.30 in Nsukka (Table 20), 4.6 to 6.2 in Umuahia South soils (Table 21), and 4.7 to 6.4 in Ikot Abasi (Table 22). Highest soil pH was observed in surface horizons and may be associated to cropping system that returns crop residues after harvest. Low pH in sub-surface may be associated with leaching.

Soil organic carbon (SOC) contents observed on different physiographic units range between 3.0 and 12.0 gkg^{-1} at Nsukka (Table 20), 4.5 and 20.2 gkg^{-1} in Umuahia South soils (Table 21), and from 6.0 to 12.2 gkg^{-1} in Ikot Abasi (Table 22).

Table 20: Mean soil chemical properties of Nsukka pedons studied

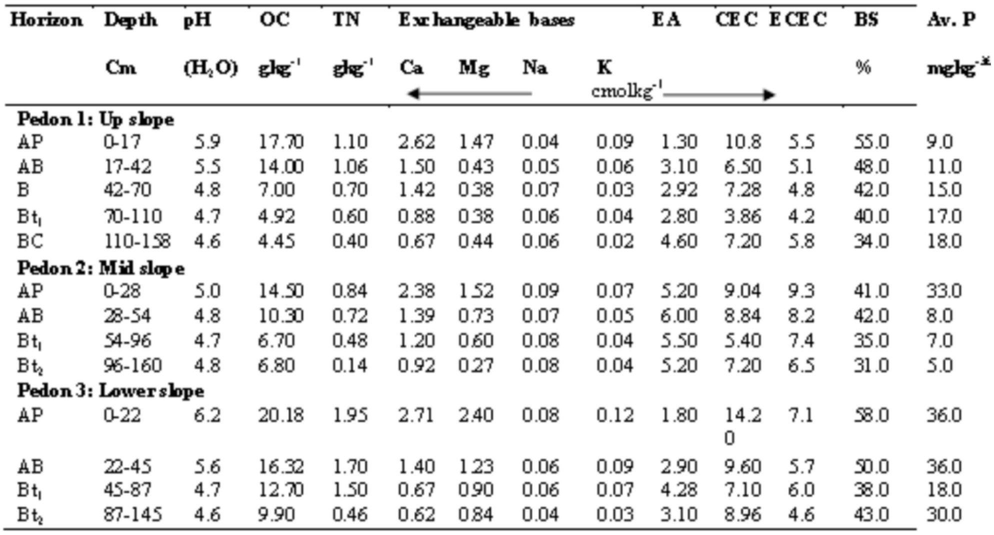


Horizon	Depth	pH	OC	TN	Exchangeable bases				EA	CEC	ECEC	BS	Av. P
	Cm	(H_2O)	gkg^{-1}	gkg^{-1}	Ca	Mg	Na	K				%	mgkg^{-3}
					←			cmolkg^{-1}			→		
Pedon 1: Up slope													
AP	0-20	5.04	9.6	0.82	1.4	1.3	0.24	0.05	3.1	9.0	6.1	36	48
AB	20-45	4.70	6.8	0.78	1.6	1.4	0.24	0.04	3.0	8.7	6.3	40	45
Bt_1	45-90	4.90	5.4	0.65	1.3	0.8	0.22	0.05	4.0	7.0	6.4	34	39
Bt_2	90-145	4.80	3.3	0.66	0.8	0.6	0.20	0.02	4.0	6.4	5.6	25	24
BC	145-200	5.10	3.0	0.42	0.7	0.7	0.23	0.03	1.6	6.3	3.3	27	22
Pedon 2: Mid slope													
AP	0-18	5.02	8.2	0.80	1.3	1.2	0.27	0.04	3.0	8.2	5.8	30	40
AB	18-40	5.06	6.0	0.68	1.2	0.9	0.23	0.05	2.6	7.7	5.0	27	37
Bt_1	40-85	4.81	5.6	0.46	0.8	0.7	0.19	0.03	2.6	7.4	4.3	25	23
Bt_2	85-155'	4.74	4.0	0.21	0.5	0.7	0.16	0.02	1.4	5.1	2.8	21	20
Pedon 3: Lower slope													
AP	0-18	5.30	12.0	1.28	3.0	2.7	0.26	0.10	3.4	12.4	9.5	53	51
B	18-40	5.15	10.4	1.10	2.6	3.0	0.22	0.09	3.3	12.0	9.2	49	50
Bt_1	40-85	5.00	8.6	0.86	2.2	2.6	0.22	0.07	2.9	11.1	8.0	47	45
Bt_2	85-135	4.83	8.0	0.62	1.0	2.0	0.23	0.05	2.4	9.6	5.6	44	36
Bc	135-180'	4.81	6.6	0.45	1.0	2.0	0.20	0.06	2.2	8.0	5.5	42	27

Source: Author's field data

Result of soil organic nitrogen (SON) shows a range between 0.42 and 0.82 gkg^{-1} (Pedon 1), 0.21 and 0.80 gkg^{-1} (Pedon 2), and 0.45 and 1.28 gkg^{-1} (Pedon 3) at Nsukka (Table 20). Those of Umuahia South soils show a variation of 0.14 to 1.95 gkg^{-1} across Pedons 1 to 3 (Table 21), while a range between 0.20 and 2.10 gkg^{-1} was obtained in the soils of Ikot Abasi (Table 22).

Table 21: Mean soil chemical properties of Umuahia South pedons studied

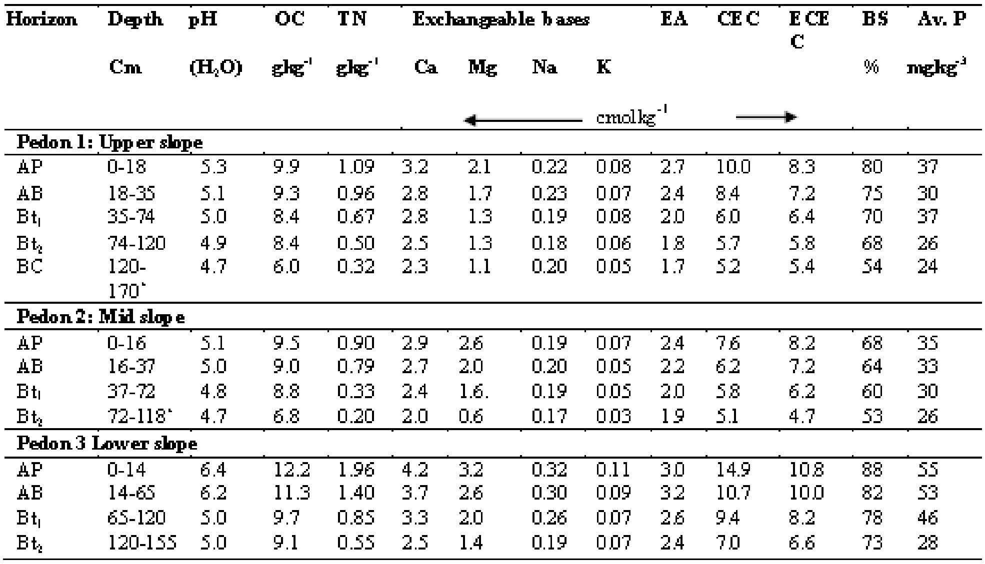


Horizon	Depth	pH	OC	TN	Exchangeable bases				EA	CEC	ECEC	BS	Av. P
	Cm	(H_2O)	gkg^{-1}	gkg^{-1}	Ca	Mg	Na	K				%	mgkg^{-*}
					←			cmolkg^{-1}		→			
Pedon 1: Up slope													
AP	0-17	5.9	17.70	1.10	2.62	1.47	0.04	0.09	1.30	10.8	5.5	55.0	9.0
AB	17-42	5.5	14.00	1.06	1.50	0.43	0.05	0.06	3.10	6.50	5.1	48.0	11.0
B	42-70	4.8	7.00	0.70	1.42	0.38	0.07	0.03	2.92	7.28	4.8	42.0	15.0
Bt_1	70-110	4.7	4.92	0.60	0.88	0.38	0.06	0.04	2.80	3.86	4.2	40.0	17.0
BC	110-158	4.6	4.45	0.40	0.67	0.44	0.06	0.02	4.60	7.20	5.8	34.0	18.0
Pedon 2: Mid slope													
AP	0-28	5.0	14.50	0.84	2.38	1.52	0.09	0.07	5.20	9.04	9.3	41.0	33.0
AB	28-54	4.8	10.30	0.72	1.39	0.73	0.07	0.05	6.00	8.84	8.2	42.0	8.0
Bt_1	54-96	4.7	6.70	0.48	1.20	0.60	0.08	0.04	5.50	5.40	7.4	35.0	7.0
Bt_2	96-160	4.8	6.80	0.14	0.92	0.27	0.08	0.04	5.20	7.20	6.5	31.0	5.0
Pedon 3: Lower slope													
AP	0-22	6.2	20.18	1.95	2.71	2.40	0.08	0.12	1.80	14.20	7.1	58.0	36.0
AB	22-45	5.6	16.32	1.70	1.40	1.23	0.06	0.09	2.90	9.60	5.7	50.0	36.0
Bt_1	45-87	4.7	12.70	1.50	0.67	0.90	0.06	0.07	4.28	7.10	6.0	38.0	18.0
Bt_2	87-145	4.6	9.90	0.46	0.62	0.84	0.04	0.03	3.10	8.96	4.6	43.0	30.0

Source: Author's field data

Results of exchangeable basic cations (Ca, Mg, K, Na) shows that calcium ranges from 0.5 to 3.0 cmolkg^{-1} on Nsukka pedons (Table 20), 0.22 to 1.14 cmolkg^{-1} on Umuahia South pedons (Table 21), and 2.0 to 4.2 cmolkg^{-1} on Ikot Abasi pedons (Table 22). Exchangeable Ca under all slope positions varied with depth but higher values were obtained in lower slopes when compared to other slope positions. The corresponding locational values for Mg^{2+} are 0.07 to 3.0 cmolkg^{-1}, 0.3 to 2.4 cmolkg^{-1}, and 0.6 to 3.2 cmolkg^{-1}. Potassium (K^+) varies from 0.02 to 0.0.10 cmolkg^{-1}, 0.02 to 0.12 cmolkg^{-1}, and 0.03 to 0.11 cmolkg^{-1} following similar location sequence.

Table 22: Mean soil chemical properties of Ikot Abasi pedons studied



Horizon	Depth	pH	OC	TN	Exchangeable bases				EA	CEC	ECEC	BS	Av. P
	Cm	(H_2O)	gkg^{-1}	gkg^{-1}	Ca	Mg	Na	K				%	mgkg^{-3}
						←		cmolkg^{-1}		→			
Pedon 1: Upper slope													
AP	0-18	5.3	9.9	1.09	3.2	2.1	0.22	0.08	2.7	10.0	8.3	80	37
AB	18-35	5.1	9.3	0.96	2.8	1.7	0.23	0.07	2.4	8.4	7.2	75	30
Bt_1	35-74	5.0	8.4	0.67	2.8	1.3	0.19	0.08	2.0	6.0	6.4	70	37
Bt_2	74-120	4.9	8.4	0.50	2.5	1.3	0.18	0.06	1.8	5.7	5.8	68	26
BC	120-170*	4.7	6.0	0.32	2.3	1.1	0.20	0.05	1.7	5.2	5.4	54	24
Pedon 2: Mid slope													
AP	0-16	5.1	9.5	0.90	2.9	2.6	0.19	0.07	2.4	7.6	8.2	68	35
AB	16-37	5.0	9.0	0.79	2.7	2.0	0.20	0.05	2.2	6.2	7.2	64	33
Bt_1	37-72	4.8	8.8	0.33	2.4	1.6.	0.19	0.05	2.0	5.8	6.2	60	30
Bt_2	72-118*	4.7	6.8	0.20	2.0	0.6	0.17	0.03	1.9	5.1	4.7	53	26
Pedon 3 Lower slope													
AP	0-14	6.4	12.2	1.96	4.2	3.2	0.32	0.11	3.0	14.9	10.8	88	55
AB	14-65	6.2	11.3	1.40	3.7	2.6	0.30	0.09	3.2	10.7	10.0	82	53
Bt_1	65-120	5.0	9.7	0.85	3.3	2.0	0.26	0.07	2.6	9.4	8.2	78	46
Bt_2	120-155	5.0	9.1	0.55	2.5	1.4	0.19	0.07	2.4	7.0	6.6	73	28

Source: Author's field data

Cation exchange capacity (CEC) data for Nsukka pedons ranges from 5.1 to 12.4 cmolkg^{-1}, 3.9 to 14.2 cmolkg-1 on the pedons of Umuahia South, and 5.2 to 14.9 cmolkg^{-1}, indicating variations across all pedons studied (Tables 20-22). The results further revealed that base saturation (Bs) varied in all the pedons and in most cases decreased with depth and increased downslope. At Nsukka, the range is from 21 to 53 cmolkg^{-1}, 31 to 68 cmolkg^{-1} (Umuahia South), while those for Ikot Abasi range between 53 and 88 cmolkg^{-1}.

There were observed differences in the values of available P on the pedons across the toposequences. Higher values of available P (range: 24 to 55 mgkg^{-1}) were obtained on the pedons of Ikot Abasi (Table 22), followed by those of Umuahia South (Table 21) and least on Nsukka pedons (Table 20). However, the values tended to increase down slope.

3.7.4 Soil classification based on USDA Soil Taxonomy (2003) edition

The soils of Nsukka are predominantly ultisols with less than 60% base saturation on False-bedded sandstone of the Cretaceous origin (Akamigbo & Asadu, 1983) and classified as loamy, mixed, isohyperthermic Typic Paleustults. Soils of Umuahia South are Alfisols with less than 60% base saturation and classified as fine loamy, mixed, isohyperthermic Typic Haplustalfs. The soils of Ikot Abasi are inceptisols underlain by sedimentary bedrock on weakly unconsolidated quaternary coastal plain sands (Petters et al., 1989). The studied pedons have ustic moisture regime, a base saturation (by NH4OAc) of 60% or more in the horizons between 25 and 75 cm from mineral surface, and CEC (by 1N NH4OAc pH) of less than 24 cmol (+) kg^{-1}. The soil is classified as coarse loamy, mixed, isohyperthermic Oxic Dystrusteps.

4.0 DISCUSSION

The mean annual rainfall and air temperature values obtained from the locations over the 12 year period (2000-2011) indicates some degree of variations, due probably to the differences in *agroecology* (Figures 2). The anomaly result in Table 1, which shows rainfall and temperature years being below the normal values for Nsukka, Umuahia South and Ikot Abasi corroborate other reports (Udosen, 2006; Petters et al., 1989; Wolfram & Lobel., 2010).

The minor variation in air temperature for each location (Figurer 5; Table 1) is confirmed by earlier report that temperature variation is more localised than rainfall (Ezeaku, 2006). Accordingly, the rule of increase or decrease in air temperature coincides with the time of maximum temperature occurring with the approach of the vernal equinox and the clearing of the harmattan haze which allows for maximum solar energy receipt; a period of dry season and perhaps harmattan natural phenomenon. High air temperatures from November to February could also be contributed by *clorofluoro* carbon which attack the ozone layers and cause some depletion of the stratosphere. Minimum air temperatures observed from April to September coincide with the period of cloud cover and heavy rains.

Based on the results in Table 1, it was largely observed that rainfall decline in the three locations were greater than their increase, an indication that temperature is increasing into the future. This is in line with the report of Moran & Morgan (1994), which explained that whenever the energy that enters the earth– atmosphere system does not balance the energy that leaves the earth– atmosphere shifts to a new equilibrium state and thereby changes the planet's climate. Therefore, a steady climate can only be experienced in these locations, if the quantities (temperature and rainfall) are the same throughout time or do not significantly depart from their mean values. But a significant departure either below or above the normal values or its maintenance over a long period of time would shift to a new equilibrium.

Results of interactions between the climate parameters and crop yields (Tables 2-5) indicate that temperature changes have a much stronger impact on crop yields than rainfall (precipitation) changes. This finding corroborates Wolfram & Lobel (2010) report (that the marginal impact of one standard deviation change in precipitation is smaller compared to one standard deviation change in temperature. Climate fluctuation decreases into the future for rainfall and increases into the future for temperature.

Ikot Abasi and Umuahia South had higher average crop yields, while Nsukka had lower crop yields. This would mean higher yield sensitivities to temperature increases in Ikot Abasi and Umuahia South and lower sensitivities to higher temperatures in Nsukka (Tables 2-5). This is in tandem with Wolfram & Lobell (2010) report showing that impacts seem to be less sensitive towards higher temperature increases, a claim that crop varieties with higher average yields are more susceptible to unfavorable weather conditions.

The result of the particle size distribution indicating different textural composition and classes among the locations (Tables 6-8) corroborates Hillel's (1980) earlier report that textural classes are intrinsic properties of the soils that are sufficiently permanent and has high influence on the physical and chemical properties of the soils. FitzPatrick (1986) noted that textural class is a function of weathering in association with parent materials influenced by climate over time. The study found that textural classes in cultivated soils did not vary with those of fallow soils but differed in terms of clay contents, which were higher in the latter. This finding was corroborated by Troech & Thompson (1993).

Low bulk density (Bd) values obtained in cultivated soils relative to fallow soils could be associated to lower clay and organic carbon contents as well as continuous cultivations that loosens, granulates and crushes the soil particles. Hartemink et al. (2008) have shown that a decrease in organic matter and modification of its dynamics impact negatively on aggregate formation.

On the other hand, high Bd in fallow soils compared with cultivated soils agrees with some authors (Ojeniyi 1989; Pando et al., 2004), who reported higher Bd with zero tillage compared with conventional tillage, an indication that the continuous exposure of untilled soils to intensive rainfall, without mechanical tillage, could reduce aggregate stability and compact the soil. The lower values of soil saturated hydraulic conductivity in cultivated soils when compared with fallow soils could be associated to land use effects (Swartz et al., 2003; Mbagwu et al., 1983).

The pH of the soils in water varies from 4.93 in Ikot Abasi, 5.01 in Nsukka and 5.7 in Umuahia South. The soil pH of 5.7 in Umuahia South is in the range of 5.5 to 6.5 considered reasonably well for plant growth and development (Ezeaku et al., 2002). Low pH in soils is associated to high rainfall that causes leaching, acid rains and low content of carbonate minerals in the parent materials (Akamigbo & Asadu, 1983). However, low or high soil pH could be influenced by the amount and type of fertilisers normally used and the amount of leaching (Steenwerth et al., 2002).

Agricultural soils represent a potential carbon sink (Lal, 1998), hence the amount of carbon content at a site reflects the long-term balance between carbon uptake and release mechanism (Ne'emeth et al., 1998) as well as soil properties and land use changes (Senthil et al., 2006). Soil OC values in cultivated soils are consistently lower that those obtained in fallow soils (Tables 6-8).

Higher SOC values in fallow soils could be due to higher vegetation that returns greater quantities of biodegraded organic materials to the soil with minimal disturbance. But lower SOC values observed in cultivated soils could be indicative of very high biological degradation of the soils. The practice of bush burning in preparation to cultivation is a common practice in the sites studied and this practice could destroy soil organisms. It can also cause reduction in the biodiversity of the soils flora and fauna and reduction in SOC.

Some authors (Enwezor et al., 1989; Lal, 1998) have shown that SOC depletion may be, in part, due to crop uptake exacerbated by continuous cropping without adequate measure of nutrient replacement either through the use of inorganic fertiliser or other forms of soil conservation measures. Harpstead (1973) noted that low SOC content is a phenomenon associated with constant cultivation and high temperatures that rapidly break down organic matter (OM) and inhibit nitrogen fixation by rhizo-bacteria.

The contents of soil organic nitrogen (SON) were generally low in the cultivated soils when compared to fallow soils. This trend is an indication of nutrient loss in the farms due to continuous cultivation as well as nutrient loss during the harvesting period. Agbede (2009) showed that nitrogen as a mobile element can easily be lost under continuous cultivation due to exposure and washing away of top soil and plant nutrients by sheet erosion. The high N content under fallow could be a result of nutrient recycling since the amount extracted gets returned to the soil as a litter.

The value of Ca, Mg and K in the cultivated soils of the study areas is, respectively, below critical limits of 2.0, 4.0 and 1.5 cmol kg^{-1} for fertile soils (FAO 1976; Landon, 1984), an indication that they may not be limiting crop production in the general area. The average values of exchangeable sodium in all the soils are below the critical limit of 15% suggested by Hudson & Voorhees (1995) to cause sufficient structural break down through dispersion to affect permeability of soils. More K+ obtained in Ikot Abasi and Umuahia South may be due to higher crop residues or added fertilisers, while more K+ in fallow relative to cultivated soils may be due to returning of leaves and stems.

Cation exchange capacity of a soil increases with increases in soil pH (Spark, 1995). Thus, low CEC of the soils studied could have been accounted for by low pH of the soils. The implication of low soil pH, CEC and SOC is decrease in biological activities, which has its own adverse effect on productivity of soils. In addition, decrease in CEC, especially in cultivated soils, suggests decrease in buffering capacity, and it is a cause for concern as the soils with low to medium CEC can be catalogued as unsustainable (Enwezor et al., 1989). They attributed low CEC value of tropical soils to the dominance of kaolinitic clays (low content and medium-coarse texture) in the fine earth fraction, an indicative of low nutrient reserve of the soils.

The relatively higher phosphorus (P) availability in Ikot Abasi soils (Table 8) relative to other locations (Tables 6 and 7) could be attributed to higher organic materials from mulch materials used as management practice. Buerkert et al. (2000) found an increased P availability due to mulch materials in West Africa. Low phosphorus and hence deficiency in the soils of Nsukka and Umuahia South (Tables 6 & 7) could be related to low phosphates (<1%) in parent rock (Best, 1982) and leaching by intense rainfall. According to Enwezor et al., (1989) high weatherability of the soils, presence of kaolinitic clay as the dominant mineral, and adsorption reaction by soil constituents could cause low P availability.

Results in Tables (6-8) revealed predominantly low contents of soil chemical properties and varying soil degradation rates. Soil degradation rates varied with Nsukka cultivated soils being most affected (SDR=3.4), followed by Ikot Abasi (SDR=2.6) and Umuahia South the least degraded (SDR=2.5). This suggests that land use conversions and intensification could lead to ecological degradation, and consequently decline of soil physico-chemical properties. Test of significance shows that agricultural intensification significantly affected the cultivated soils of Nsukka ($P<0.01$) and Umuahia South ($P<0.05$) but did not significantly affect Ikot Abasi soils. These findings synchronise with earlier reports (Lal 1998, 1999; Islam et al., 2000; Zalidis et al., 2002; Thomas et al., 2006; Ezeaku 2011b).

Farmers' assessment of soil productivity degradation shows that productivity could drop following long-term cultivation and attributed the phenomenon to degradation of the soil quality. These findings relate to earlier report (Ezeaku & Salau, 2005) for Southern guinea savannah of Nigeria. The use of the soil quality indicators (SQI) by farmers for productivity assessment were indications that they well recognised the SQIs, hence could serve as soil health card (Romig et al., 1995). Also, farmers' application of traditional land management practices is an indication of coping mechanisms to increase soil productivity and livelihood systems. Bryan et al. (2013), Deressa et al. (2009) Kato et al. (2011) made similar observations.

Soil *morphology*, physical and chemical characteristics of the pedons studied along the *toposequences* varied from one land form to another. While clay content varies and increases with soil depth in Nsukka and Umuahia South soils, sand fraction decreases with depth. At Ikot Abasi pedons, clay content was relatively constant with increasing depth. Little or no clay mobility suggests a high order of stability in the clay fraction of these soils. This stability has been attributed to cementation by *sesquioxides* (http://wgharris.ifas.ufl.edu).

Clay movement in Nsukka and Umuahia soils could be associated with elluviation-illuviation processes going on the soil, indicating deposition of clay from the surface areas, culminating into enrichment of the sub-surface depths. Higher sand fractions at the surface could be attributed to water erosion/infiltration that removes humus and clay fraction leaving the inert and coarse fragments behind. Sandy loam characteristic of the mineral subsurface as observed in Umuahia South depicts oxic horizons. Even though silt content varies, it did not maintain any definite pattern of distribution (Table 15). Variation in soil texture may have been influenced more by slope position and not land use and management.

Majority of silt/clay ratios are less than unity, thus suggesting high to low degree of weathering of the parent materials. Nwaka & Kwari (2000) reported that parent materials with silt/clay ratio of less than unity was considered low; signifying high weatherability of the soils and pedogenesis. Also, the consequence of high weatherability is predisposition of the soil to sheet and gully erosion due to low organic carbon and high clay dispersion ratio.

There were variations in soil organic carbon (SOC) contents observed on the different physiographic units. The result shows SOC decline with depth and increased downslope. This observation is synonymous with Tsui et al. (2004) report that SOC is largely concentrated in the top soil, while SOC concentration not only decline exponentially with depth but related to position on the hillslope. The result on SOC content indicates that it increases exponentially with clay, although some authors (Ayanaba et al, 1996) have shown that high clay content observed on lower lands does not necessarily reflect high SOC.

But, the Mean SOC obtained on Ikot Akpan pedons is lower than those of Umuahia South. This may be related to higher intensity of rainfall events and increased rainfall totals that would increase leaching rates in the upslopes, and cause temporary flooding or water saturation downslope, hence reduced organic matter decomposition and low SOC.

High SOC at the uplands when compared to mid slope may be associated to its flatness, a characteristic that may offer some natural protection from erosion and hence SOC accumulation (Brubaker et al., 1993). But increases of SOC downslope may be related to higher vegetative cover that biodegrades to produce more carbon stock and erosion processes from hill slope position (Ne’emeth et al., 1998). The result on SOC content also indicates that it increases exponentially with clay, although some authors (Ayanaba et al., 1996) have shown that high clay content observed on lower lands does not necessarily reflect high SOC.

The SON levels followed similar pattern to that of SOC, which are found highest on the surface horizons and lowlands than subsurface and on mid- and up- slopes. The relative lower SON in mid slopes when compared to other slope positions could be due to its susceptibility to soil erosion by either wind and/or water (Buol et al., 1990). The high N content under lower slopes may be a result of nutrient recycling since the mount extracted gets returned to the soil as a litter. This is in line with Kristensen et al., (2000) who found SON to be highly influenced by slope position and land use.

Higher contents of exchangeable cations on lower slope than upper slope positions could be associated to higher vegetation density that has more extensive surface roots for nutrient extraction, and return of leaves and stems that biodegrade to release more cations (Campo et al., 2000). Leaching could have also contributed to the low K+ values in uplands (Huluggale, 1994).

The high P availability, especially in lower slope pedon soils could be attributed to higher organic materials from the vegetation (Buerkert et al., 2000). Enwezor et al. (1989) related low phosphorus content of the mid- and up-slope soils to leaching and adsorption reaction by soil constituents.

5.0 CONCLUSION

The results reveal variations in rainfall, temperature and soil properties in each of the study locations. It was found that rainfall and temperature of the sites showed persistent departure from normal as they fluctuated around the Mean values, either below or above. Whereas this fluctuation decreases into the future for rainfall, it increases into the future for temperature. Percentage temperature change shows 56 and 59 below normal Mean in Nsukka and Ikot Abasi and 39% in Umuahia South, indicating increases into the future.

However, low rainfall and temperature data input (less than 30 years) used in this study is not enough to conclude that the climate of the three locations is experiencing a change. But, it tends to indicate that if this observed anomalies continue unabated over a long period of time, climate change may occur.

The contents of soil fertility parameters were predominantly low, indicating decline of soil physico-chemical properties due to degradation. Soil degradation rates varied with Nsukka cultivated soils being most affected (SDR=3.4), followed by Ikot Abasi (SDR=2.6) and Umuahia South the least degraded (SDR=2.5). Test of significance shows that agricultural intensification significantly affected cultivated soils of Nsukka ($P<0.01$) and Umuahia South ($P<0.05$) and did not have significant effect on Ikot Abasi cultivated soils.

Interaction effects of rainfall, temperature and some soil properties (BS %, total porosity) on crop yields (Tables 6-8) were mostly negative. On the overall, temperature changes had a much stronger impact on crop yields than rainfall (precipitation) changes. At Nsukka, the yields of cassava and maize were predominantly decreased by rainfall, temperature and some soil (BS %, total porosity) parameters. At Umuahia South rainfall significantly decreased cassava (0.5139 kgha^{-1}, $P<0.05$) and maize (0.1371 kgha^{-1}, $P<0.05$) yields and decreases of cowpea and rice yields were not significant. Temperature decreased all crop yields in the order of cassava (14.4556 kgha^{-1}, $P<0.001$), maize (11.1758 kgha^{-1}), cowpea (0.0538 kgha^{-1}) and rice (8.1310 kgha^{-1}). Temperature may have contributed significantly to the observed 66 and 58% variation in cassava and maize yield, respectively.

The study also found that rainfall and temperature decreased most of the crop yields. The decrease of maize was significant ($P<0.05$) to very highly significant ($P<0.001$). Available P and total porosity also decreased cassava, maize and cowpea yields at $P<0.05$. Variations in cassava (72%), maize

(89%), cowpea (68%) and rice (13%) were accounted for by the combinational interaction effects of rainfall, temperature, available P and total porosity parameters. On the overall, it could be seen from the analyses of interactions that higher average crop yields, especially at Ikot Abasi and Umuahia South had higher yield sensitivities to temperature increases than Nsukka with lower yield sensitivities to higher temperatures.

Independent of location, the interaction effect of rainfall, temperature and soil properties decreased cassava yield (1.2058 $kgha^{-1}$, $P<0.001$) and a combination of the two climate variables decreased cowpea yield by 3.1800 $kgha^{-1}$. Soil properties especially CEC and available P decreased most of the crop yields. However, Ca highly significantly ($P<0.001$) increased rice and cassava yields. Furthermore, regression between land degradation and crop yields revealed that cassava and cowpea yield decreased by 6.6739 and 0.0359 $kgha^{-1}$, respectively.

Farmers' ranking of the relative importance of the various soil quality indicators as it relates to their crop production showed the following increasing order of importance: soil organic matter content, soil fertility, topsoil thickness, structure, moisture, compaction, soil erosion, and weed incidence. The last three SQ indicators are considered the least important but are important in conservation programs for soil protection and productivity enhancement. Responses by farmers show that the most common traditional practices employed included intercropping, composting/residues manure, slash and burn, and inorganic fertiliser use.

The soils on the three land forms that describe the survey area namely: hill crest, side (mid) slopes and lower slopes, are quite distinct in their morphological and some physico-chemical characteristics. Productivity limitations of the soils are erosion menace that resulted in low soil pH and low nutrient status.

6.0 POLICY IMPLICATIONS AND RECOMMENDATIONS

The study found that rainfall decreases into the future whereas; it was increasing into the future for temperature. Temperature increase, on one hand, contributed significantly ($P<0.05$) to the observed 66 and 58% variation in cassava and maize yields, respectively. Land degradation, on the other hand, affected all crop yields but most significantly decreased cassava and cowpea yield by 6.6739 and 0.0359 $kgha^{-1}$ respectively.

Continuous decrease of these crops by every unit (1^0C) increase in temperature and rainfall decrease has critical negative implication for food security in the future.

The following recommendations are therefore made to help address the problems:

1. Land preparation and crop management techniques need adaptation to the anomalies of rainfall and temperature. Also planting crops early and covering the mounds with green and/or dry grasses or leaves provides protective cover against extreme temperature and help to conserve moisture. Adapting and planting diversified crop varieties resistant to extreme weather conditions are necessary to serve as insurance measure.

2. Furthermore, water and energy budget studies for the cropping systems of the AEZs are necessary to provide data for the breeding of high temperature resistant crops. In addition, making furrows and bonds in farms to retain water is important antidote to temperature increases.

3. To armour the soils of the study locations against any future negative effect of climate change, or against other extremes in external circumstances such as nutrient depletion by high-intensity rains, the best that land users could do, would be to manage their soils to give them maximum physical resilience through a stable, heterogeneous pore system by maintaining a closed ground cover as much as possible. This could be achieved through incorporation of leguminous crops into the traditional farming, leaving the crop residues on the farms to serve as mulch and soil cover. This would minimise secondary effects such as increased CH4 or N2O emission from the reduced soil and increase nutrient quality, microbiological activities and biodiversity (flora and fauna) of farmers' soils.

4. A combination of green soil conservation measures is recommended as

adaptation strategies in response to perceived climate change and abating land degradation due to erosion. These include planting diversifying crop variety, cover crops/mulch and alley cropping system, planting improved crop type, planting in early rains and covering the mound/ridges with live and/or dead mulch materials for soil and water conservation. All of these would moderate soil and atmospheric temperature, improve infiltration, soil moisture and its holding capacity, increase soil organic carbon contents, improve productivity of the soils, and enhance the agricultural potential of the areas.

5. Combined use of lime (e.g. oxides or carbonates of Ca and Mg), organic manure (e.g. poultry droppings and cow dung) and inorganic fertiliser as integrated plant nutrient management system would balance the input and offtake of nutrients over a cropping cycle or over the years, while maintaining soil nutrient levels low enough to minimise losses and high enough to buffer occasional high demands.

6. The soils on the three landforms require special erosion control mechanisms. Conversion to contour ploughing and the establishment of vetiver grass hedges in-between cultivated crops would reduce soil erosion and enhance their agricultural potentials. Again, the lower slopes are smaller in land area but with higher productivity potentials. These soils are particularly suitable for moist loving crops like swamp rice (Oryza sativa), plantain/banana (Musa spp). However, with suitable drainage in raining seasons, other arable crops can be economically cultivated.

7. Further research and development (R&D) in these areas (1-5) is important to fostering the development of climate-friendly technologies, its deployment and diffusion.

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APPENDICES

Appendix A: Test of significance between cultivated and fallow soils in sites studied

Nsukka Group Statistics

	Landtype	N	Mean	Std. Deviation	Std. Error Mean
Dr	Cultivated	14	3.36	.842	.225
	Fallow	14	2.36	1.008	.269

		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Dr	Equal variances assumed	0.37	0.55	2.85	26	0.01	1	0.35	0.28	1.72
	Equal variances not assumed			2.85	25.2	0.01	1	0.35	0.28	1.72

Umuahia South

	Landtype	N	Mean	Std. Deviation	Std. Error Mean
Dr	cultivated	14	2.50	.855	.228
	fallow	14	1.93	.730	.195

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Dr	Equal variances assumed	1.15	0.29	1.9	26	0.07	0.57	0.3	-0.05	1.19
	Equal variances not assumed			1.9	25.4	0.07	0.57	0.3	-0.05	1.19

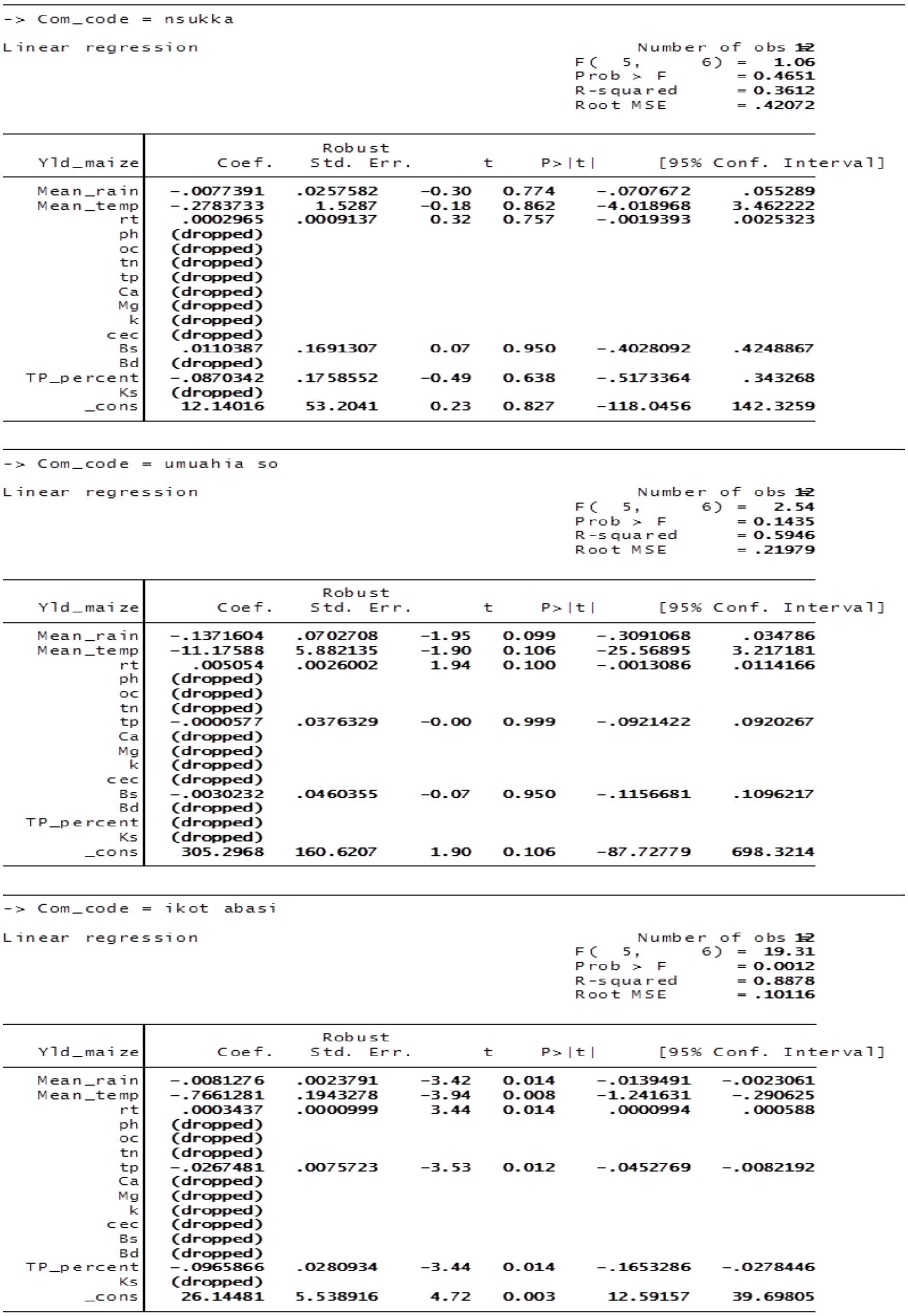
Ikot Abasi					
	Landtype	N	Mean	Std. Deviation	Std. Error Mean
Dr	cultivated	14	2.64	.929	.248
	fallow	14	2.07	.997	.267

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper

Dr	Equal variances assumed	0.05	0.83	1.57	26	0.13	0.57	0.36	-0.18	1.32
	Equal variances not assumed			1.57	25.9	0.13	0.57	0.36	-0.18	1.32

Location	Landtype	Mean Dr	Std. Error Mean	Mean Difference	t	Sig. (2-tailed)
Nsukka	cultivated	3.36	0.225	1.000	2.849	0.008
	fallow	2.36	0.269			
Umuahia South	cultivated	2.5	0.228	0.571	1.902	0.068
	fallow	1.93	0.195			
Ikot Abassi	cultivated	2.64	0.248	0.571	1.569	0.129
	fallow	2.07	0.267			

Appendix B:



```
-> Com_code = nsukka

Linear regression                               Number of obs 12
                                           F(  5,      6) =   1.06
                                           Prob > F       = 0.4651
                                           R-squared      = 0.3612
                                           Root MSE       = .42072

------------------------------------------------------------------------------
             |               Robust
   Yld_maize |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0077391   .0257582    -0.30   0.774    -.0707672     .055289
   Mean_temp |  -.2783733     1.5287    -0.18   0.862    -4.018968    3.462222
          rt |   .0002965   .0009137     0.32   0.757    -.0019393    .0025323
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  (dropped)
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |   .0110387   .1691307     0.07   0.950    -.4028092    .4248867
          Bd |  (dropped)
  TP_percent |  -.0870342   .1758552    -0.49   0.638    -.5173364     .343268
          Ks |  (dropped)
       _cons |   12.14016    53.2041     0.23   0.827    -118.0456    142.3259
------------------------------------------------------------------------------

-> Com_code = umuahia so

Linear regression                               Number of obs 12
                                           F(  5,      6) =   2.54
                                           Prob > F       = 0.1435
                                           R-squared      = 0.5946
                                           Root MSE       = .21979

------------------------------------------------------------------------------
             |               Robust
   Yld_maize |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.1371604   .0702708    -1.95   0.099    -.3091068     .034786
   Mean_temp |  -11.17588   5.882135    -1.90   0.106    -25.56895    3.217181
          rt |    .005054   .0026002     1.94   0.100    -.0013086    .0114166
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  -.0000577   .0376329    -0.00   0.999    -.0921422    .0920267
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  -.0030232   .0460355    -0.07   0.950    -.1156681    .1096217
          Bd |  (dropped)
  TP_percent |  (dropped)
          Ks |  (dropped)
       _cons |   305.2968   160.6207     1.90   0.106    -87.72779    698.3214
------------------------------------------------------------------------------

-> Com_code = ikot abasi

Linear regression                               Number of obs 12
                                           F(  5,      6) =  19.31
                                           Prob > F       = 0.0012
                                           R-squared      = 0.8878
                                           Root MSE       = .10116

------------------------------------------------------------------------------
             |               Robust
   Yld_maize |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0081276   .0023791    -3.42   0.014    -.0139491   -.0023061
   Mean_temp |  -.7661281   .1943278    -3.94   0.008    -1.241631    -.290625
          rt |   .0003437   .0000999     3.44   0.014     .0000994     .000588
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  -.0267481   .0075723    -3.53   0.012    -.0452769   -.0082192
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  (dropped)
          Bd |  (dropped)
  TP_percent |  -.0965866   .0280934    -3.44   0.014    -.1653286   -.0278446
          Ks |  (dropped)
       _cons |   26.14481   5.538916     4.72   0.003     12.59157    39.69805
------------------------------------------------------------------------------
```

.

Results of regressions between climate parameters, soil property degradation rates and crop yields

```
-> Com_code = nsukka

Linear regression                                      Number of obs = 12
                                                       F(  5,      6) =   0.57
                                                       Prob > F       = 0.7208
                                                       R-squared      = 0.1364
                                                       Root MSE       = .13005

------------------------------------------------------------------------------
             |               Robust
  Yld_cowpea |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |   .0038569    .008567     0.45   0.668    -.0171057    .0248195
   Mean_temp |   .2292823   .5310465     0.43   0.681    -1.070142    1.528706
          rt |  -.0001314   .0003041    -0.43   0.681    -.0008755    .0006127
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  (dropped)
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |   .0358041   .0415924     0.86   0.422    -.0659688     .137577
          Bd |  (dropped)
  TP_percent |   .0378329    .053383     0.71   0.505    -.0927905    .1684563
          Ks |  (dropped)
       _cons |  -8.822267   16.42944    -0.54   0.611    -49.02366    31.37913
------------------------------------------------------------------------------

-> Com_code = umuahia so

Linear regression                                      Number of obs = 12
                                                       F(  5,      6) =   1.68
                                                       Prob > F       = 0.2721
                                                       R-squared      = 0.1822
                                                       Root MSE       = .17226

------------------------------------------------------------------------------
             |               Robust
  Yld_cowpea |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0538196   .0390854    -1.38   0.218    -.1494582     .041819
   Mean_temp |  -4.392551   3.035802    -1.45   0.198    -11.82089    3.035789
          rt |   .0019961   .0014449     1.38   0.216    -.0015394    .0055316
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |   .0116011   .0240675     0.48   0.647    -.0472898    .0704921
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |   .0049866   .0328395     0.15   0.884    -.0753687    .0853419
          Bd |  (dropped)
  TP_percent |  (dropped)
          Ks |  (dropped)
       _cons |   119.1316   83.85237     1.42   0.205     -86.0478    324.3109
------------------------------------------------------------------------------

-> Com_code = ikot abasi

Linear regression                                      Number of obs = 12
                                                       F(  5,      6) =  33.43
                                                       Prob > F       = 0.0003
                                                       R-squared      = 0.6755
                                                       Root MSE       = .03076

------------------------------------------------------------------------------
             |               Robust
  Yld_cowpea |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |   .0010072   .0005784     1.74   0.132    -.0004081    .0024226
   Mean_temp |   .0654411   .0483385     1.35   0.225     -.052839    .1837213
          rt |  -.0000387    .000024    -1.61   0.158    -.0000973      .00002
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  -.0045529    .001794    -2.54   0.044    -.0089426   -.0001632
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  (dropped)
          Bd |  (dropped)
  TP_percent |  -.0091585    .009008    -1.02   0.349    -.0312003    .0128832
          Ks |  (dropped)
       _cons |   .2301748   1.284281     0.18   0.864    -2.912347    3.372697
------------------------------------------------------------------------------

.
```

```
-> Com_code = umuahia so

Linear regression                               Number of obs 12
                                                F(  5,      6) =   2.43
                                                Prob > F       = 0.1548
                                                R-squared      = 0.3867
                                                Root MSE       = .20948

------------------------------------------------------------------------------
             |               Robust
    Yld_rice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.1073731   .0735628    -1.46   0.195    -.2873749    .0726287
   Mean_temp |  -8.131065   6.113507    -1.33   0.232    -23.09028    6.828148
          rt |   .0039663   .0027182     1.46   0.195    -.0026849    .0106175
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  -.0235214   .0373598    -0.63   0.552    -.1149375    .0678947
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  -.0391861   .0424307    -0.92   0.391    -.1430103     .064638
          Bd |  (dropped)
  TP_percent |  (dropped)
          Ks |  (dropped)
       _cons |   224.6929   166.5368     1.35   0.226     -182.808    632.1937
------------------------------------------------------------------------------

-------------------------------------------------------------------------------
-> Com_code = ikot abasi

Linear regression                               Number of obs 12
                                                F(  5,      6) =   2.56
                                                Prob > F       = 0.1415
                                                R-squared      = 0.1251
                                                Root MSE       = .18496

------------------------------------------------------------------------------
             |               Robust
    Yld_rice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |   -.001841   .0038756    -0.48   0.652    -.0113242    .0076423
   Mean_temp |  -.1283765   .3349757    -0.38   0.715    -.9480325    .6912795
          rt |   .0000703   .0001588     0.44   0.674    -.0003184    .0004589
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |   .0083559   .0116224     0.72   0.499    -.0200831    .0367949
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  (dropped)
          Bd |  (dropped)
  TP_percent |   .0286474   .0591564     0.48   0.645    -.1161031    .1733979
          Ks |  (dropped)
       _cons |   3.470368   9.466085     0.37   0.726    -19.69231    26.63304
------------------------------------------------------------------------------
```

```
. regress Yld_cassava Mean_rain Mean_temp rt   Nsukkadummy Umuahia, vce(robust)

Linear regression                                      Number of obs 36
                                                   F(  5,     30) =  24.98
                                                   Prob > F       = 0.0000
                                                   R-squared      = 0.7366
                                                   Root MSE       = .76673

------------------------------------------------------------------------------
             |               Robust
 Yld_cassava |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0035966   .0062582    -0.57   0.570    -.0163775    .0091843
   Mean_temp |  -.7105913   .4703612    -1.51   0.141    -1.671197    .2500145
          rt |   .0001282   .0002393     0.54   0.596    -.0003605     .000617
 Nsukkadummy |  -1.442527   .3825837    -3.77   0.001    -2.223867   -.6611864
     Umuahia |  -.5190966   .4584684    -1.13   0.267    -1.455414    .4172207
       _cons |   30.86004   12.40592     2.49   0.019     5.523774    56.19631
------------------------------------------------------------------------------

. regress Yld_maize Mean_rain Mean_temp rt   Nsukkadummy Umuahia, vce(robust)

Linear regression                                      Number of obs 36
                                                   F(  5,     30) =   9.52
                                                   Prob > F       = 0.0000
                                                   R-squared      = 0.4056
                                                   Root MSE       = .30134

------------------------------------------------------------------------------
             |               Robust
   Yld_maize |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0002326   .0022003    -0.11   0.917    -.0047261     .004261
   Mean_temp |  -.0938736   .1798849    -0.52   0.606    -.4612477    .2735005
          rt |   7.22e-06   .0000876     0.08   0.935    -.0001716     .000186
 Nsukkadummy |   -.237953    .187523    -1.27   0.214     -.620926    .1450201
     Umuahia |  -.3157992   .1294515    -2.44   0.021    -.5801745   -.0514239
       _cons |   4.860828   4.566502     1.06   0.296    -4.465212    14.18687
------------------------------------------------------------------------------

. regress Yld_cowpea Mean_rain Mean_temp rt   Nsukkadummy Umuahia, vce(robust)

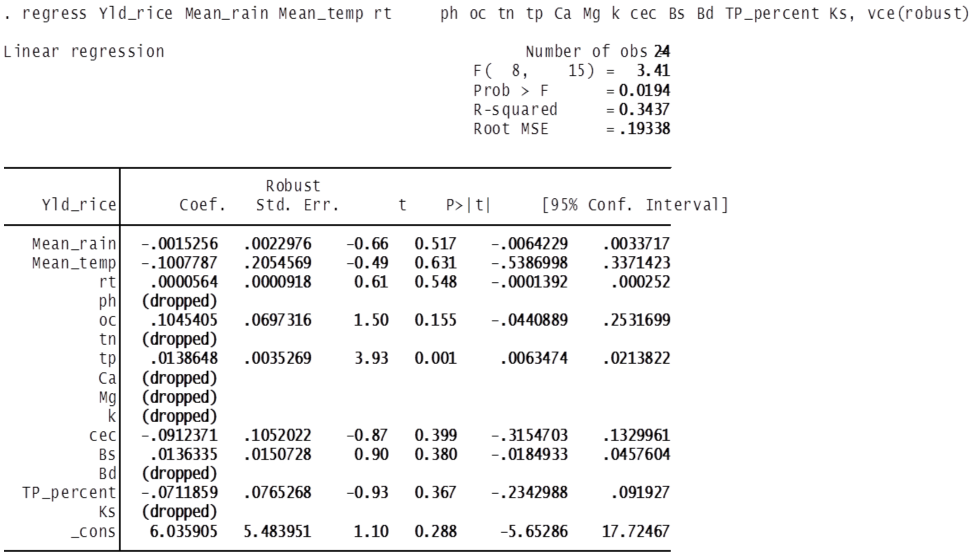
Linear regression                                      Number of obs 36
                                                   F(  5,     30) =   2.76
                                                   Prob > F       = 0.0362
                                                   R-squared      = 0.2192
                                                   Root MSE       = .10685

------------------------------------------------------------------------------
             |               Robust
  Yld_cowpea |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0002554   .0007822    -0.33   0.746    -.0018529     .001342
   Mean_temp |  -.0321601   .0626683    -0.51   0.612    -.1601457    .0958256
          rt |   .0000112   .0000308     0.36   0.719    -.0000518    .0000741
 Nsukkadummy |  -.0498829   .0421118    -1.18   0.246    -.1358867    .0361209
     Umuahia |   .0069628   .0453172     0.15   0.879    -.0855872    .0995128
       _cons |    2.10389   1.597104     1.32   0.198     -1.15783    5.365611
------------------------------------------------------------------------------

. regress Yld_rice Mean_rain Mean_temp rt   Nsukkadummy Umuahia, vce(robust)

Linear regression                                      Number of obs 24
                                                   F(  4,     19) =   1.50
                                                   Prob > F       = 0.2407
                                                   R-squared      = 0.2358
                                                   Root MSE       = .18542

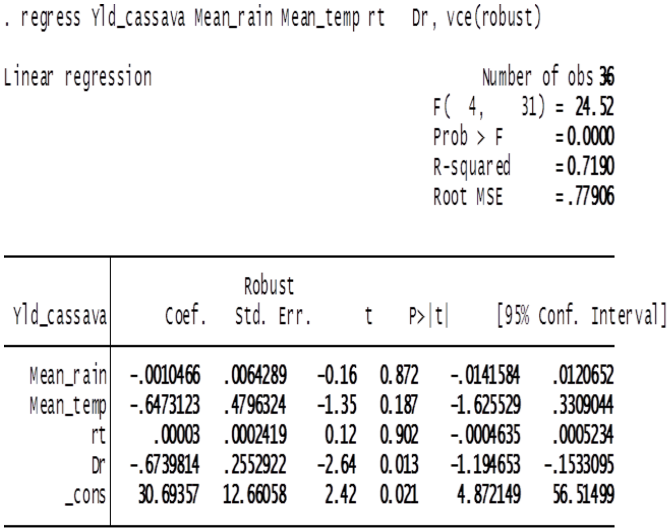
------------------------------------------------------------------------------
             |               Robust
    Yld_rice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0007703   .0023352    -0.33   0.745    -.0056579    .0041174
   Mean_temp |  -.0450764   .2042462    -0.22   0.828    -.4725686    .3824159
          rt |   .0000308   .0000929     0.33   0.744    -.0001637    .0002253
 Nsukkadummy |  (dropped)
     Umuahia |  -.2212251   .1219312    -1.81   0.085    -.4764301    .0339798
       _cons |   2.867551   5.164301     0.56   0.585    -7.941454    13.67656
------------------------------------------------------------------------------
```



```
. regress Yld_rice Mean_rain Mean_temp rt     ph oc tn tp Ca Mg k cec Bs Bd TP_percent Ks, vce(robust)

Linear regression                                     Number of obs 24
                                              F(  8,     15) =    3.41
                                              Prob > F       = 0.0194
                                              R-squared      = 0.3437
                                              Root MSE       = .19338

------------------------------------------------------------------------------
             |               Robust
    Yld_rice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0015256   .0022976    -0.66   0.517    -.0064229    .0033717
   Mean_temp |  -.1007787   .2054569    -0.49   0.631    -.5386998    .3371423
          rt |   .0000564   .0000918     0.61   0.548    -.0001392     .000252
          ph |  (dropped)
          oc |   .1045405   .0697316     1.50   0.155    -.0440889    .2531699
          tn |  (dropped)
          tp |   .0138648   .0035269     3.93   0.001     .0063474    .0213822
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  -.0912371   .1052022    -0.87   0.399    -.3154703    .1329961
          Bs |   .0136335   .0150728     0.90   0.380    -.0184933    .0457604
          Bd |  (dropped)
  TP_percent |  -.0711859   .0765268    -0.93   0.367    -.2342988     .091927
          Ks |  (dropped)
       _cons |   6.035905   5.483951     1.10   0.288     -5.65286    17.72467
------------------------------------------------------------------------------
```



```
. regress Yld_cassava Mean_rain Mean_temp rt   Dr, vce(robust)

Linear regression                                     Number of obs 36
                                              F(  4,     31) =   24.52
                                              Prob > F       = 0.0000
                                              R-squared      = 0.7190
                                              Root MSE       = .77906

------------------------------------------------------------------------------
             |               Robust
 Yld_cassava |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0010466   .0064289    -0.16   0.872    -.0141584    .0120652
   Mean_temp |  -.6473123   .4796324    -1.35   0.187    -1.625529    .3309044
          rt |     .00003   .0002419     0.12   0.902    -.0004635    .0005234
          Dr |  -.6739814   .2552922    -2.64   0.013    -1.194653   -.1533095
       _cons |   30.69357   12.66058     2.42   0.021     4.872149    56.51499
------------------------------------------------------------------------------
```

```
------------------------------------------------------------------------------
             |               Robust
   Yld_maize |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |   .0010769   .0022396     0.48   0.634    -.0034908    .0056446
   Mean_temp |  -.0613779   .1833381    -0.33   0.740    -.4352985    .3125426
          rt |  -.0000432   .0000886    -0.49   0.629    -.0002239    .0001374
          Dr |   .0055179    .128712     0.04   0.966    -.2569919    .2680277
       _cons |   3.847044   4.462216     0.86   0.395    -5.253706    12.94779
------------------------------------------------------------------------------

. regress Yld_cowpea Mean_rain Mean_temp rt    Dr, vce(robust)

Linear regression                                      Number of obs =      36
                                                       F(  4,    31) =    3.48
                                                       Prob > F      =  0.0184
                                                       R-squared     =  0.2192
                                                       Root MSE      =  .10512

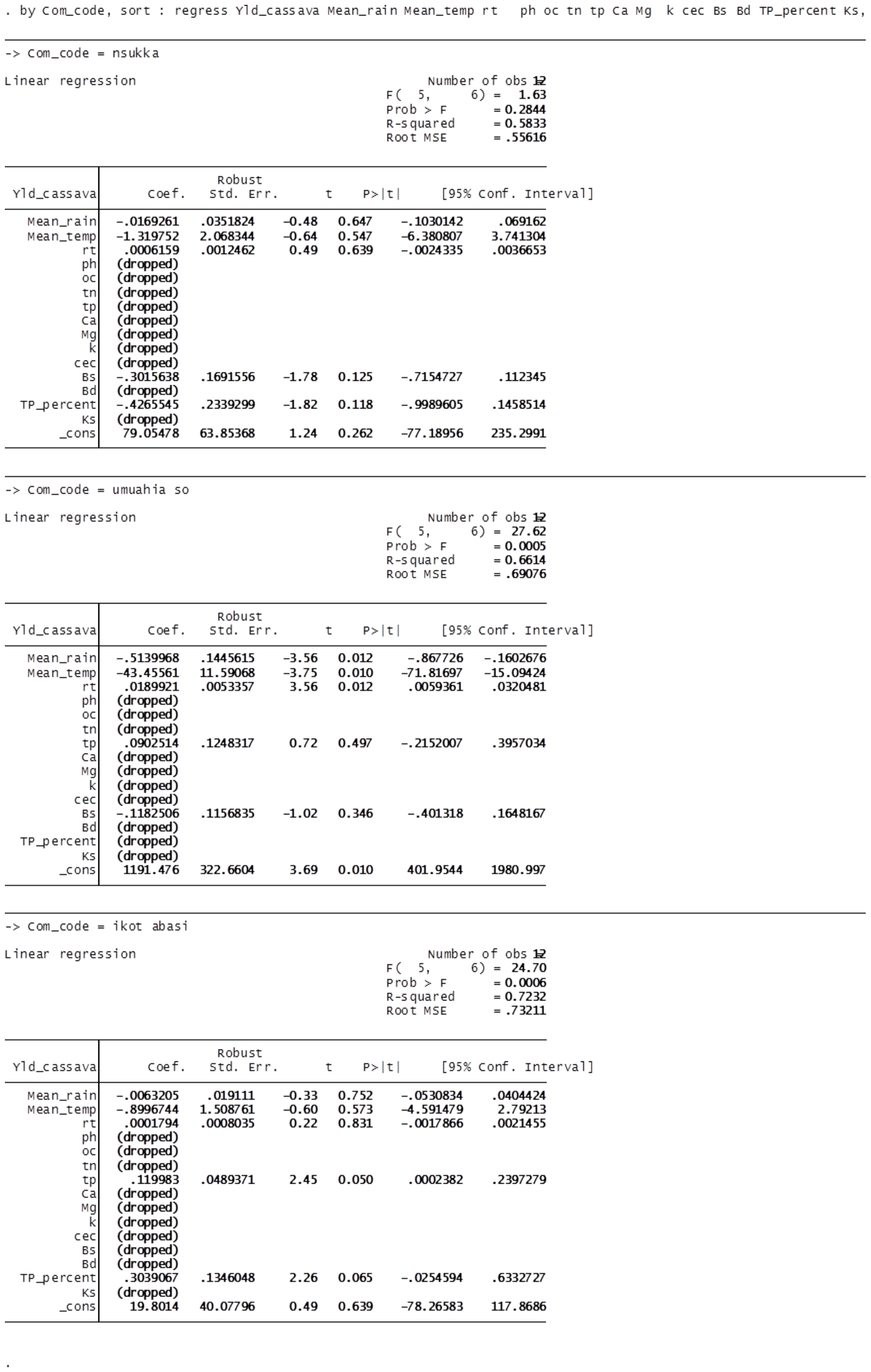
------------------------------------------------------------------------------
             |               Robust
  Yld_cowpea |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0002635   .0007734    -0.34   0.736    -.0018407    .0013138
   Mean_temp |  -.0323593   .0616293    -0.53   0.603    -.1580531    .0933344
          rt |   .0000115   .0000305     0.38   0.709    -.0000507    .0000737
          Dr |  -.0359372   .0319513    -1.12   0.269    -.1011023    .0292278
       _cons |   2.204891   1.534188     1.44   0.161    -.9241057    5.333888
------------------------------------------------------------------------------

. regress Yld_rice Mean_rain Mean_temp rt    Dr, vce(robust)

Linear regression                                      Number of obs =      24
                                                       F(  4,    19) =    1.50
                                                       Prob > F      =  0.2407
                                                       R-squared     =  0.2358
                                                       Root MSE      =  .18542

------------------------------------------------------------------------------
             |               Robust
    Yld_rice |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0007703   .0023352    -0.33   0.745    -.0056579    .0041174
   Mean_temp |  -.0450764   .2042462    -0.22   0.828    -.4725686    .3824159
          rt |   .0000308   .0000929     0.33   0.744    -.0001637    .0002253
          Dr |    1.58018   .8709373     1.81   0.085    -.2427132    3.403072
       _cons |  -1.304123   5.633426    -0.23   0.819    -13.09502    10.48677
------------------------------------------------------------------------------

.
```



```
. by Com_code, sort : regress Yld_cassava Mean_rain Mean_temp rt   ph oc tn tp Ca Mg  k cec Bs Bd TP_percent Ks,

-------------------------------------------------------------------------------------------------------------------
-> Com_code = nsukka

Linear regression                                     Number of obs 12
                                                      F(  5,      6) =   1.63
                                                      Prob > F       = 0.2844
                                                      R-squared      = 0.5833
                                                      Root MSE       = .55616

------------------------------------------------------------------------------
             |               Robust
 Yld_cassava |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0169261   .0351824    -0.48   0.647    -.1030142     .069162
   Mean_temp |  -1.319752   2.068344    -0.64   0.547    -6.380807    3.741304
          rt |   .0006159   .0012462     0.49   0.639    -.0024335    .0036653
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |  (dropped)
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  -.3015638   .1691556    -1.78   0.125    -.7154727     .112345
          Bd |  (dropped)
  TP_percent |  -.4265545   .2339299    -1.82   0.118    -.9989605    .1458514
          Ks |  (dropped)
       _cons |   79.05478   63.85368     1.24   0.262    -77.18956    235.2991
------------------------------------------------------------------------------

-------------------------------------------------------------------------------------------------------------------
-> Com_code = umuahia so

Linear regression                                     Number of obs 12
                                                      F(  5,      6) =  27.62
                                                      Prob > F       = 0.0005
                                                      R-squared      = 0.6614
                                                      Root MSE       = .69076

------------------------------------------------------------------------------
             |               Robust
 Yld_cassava |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.5139968   .1445615    -3.56   0.012     -.867726   -.1602676
   Mean_temp |  -43.45561   11.59068    -3.75   0.010    -71.81697   -15.09424
          rt |   .0189921   .0053357     3.56   0.012     .0059361    .0320481
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |   .0902514   .1248317     0.72   0.497    -.2152007    .3957034
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  -.1182506   .1156835    -1.02   0.346     -.401318    .1648167
          Bd |  (dropped)
  TP_percent |  (dropped)
          Ks |  (dropped)
       _cons |   1191.476   322.6604     3.69   0.010     401.9544    1980.997
------------------------------------------------------------------------------

-------------------------------------------------------------------------------------------------------------------
-> Com_code = ikot abasi

Linear regression                                     Number of obs 12
                                                      F(  5,      6) =  24.70
                                                      Prob > F       = 0.0006
                                                      R-squared      = 0.7232
                                                      Root MSE       = .73211

------------------------------------------------------------------------------
             |               Robust
 Yld_cassava |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Mean_rain |  -.0063205    .019111    -0.33   0.752    -.0530834    .0404424
   Mean_temp |  -.8996744   1.508761    -0.60   0.573    -4.591479     2.79213
          rt |   .0001794   .0008035     0.22   0.831    -.0017866    .0021455
          ph |  (dropped)
          oc |  (dropped)
          tn |  (dropped)
          tp |    .119983   .0489371     2.45   0.050     .0002382    .2397279
          Ca |  (dropped)
          Mg |  (dropped)
           k |  (dropped)
         cec |  (dropped)
          Bs |  (dropped)
          Bd |  (dropped)
  TP_percent |   .3039067   .1346048     2.26   0.065    -.0254594    .6332727
          Ks |  (dropped)
       _cons |    19.8014   40.07796     0.49   0.639    -78.26583    117.8686
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MATE MASIE

“What I here, I keep” symbol of wisdom, knowledge and understanding

NEA ONNIMNO SUA A, OHU

“He who does not know can know from learning” Symbol of life-long education and continued quest for knowledge

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ISBN: 978-9988-633-49-3
9 789988 633493