NUTRIENT STATUS AND MANAGEMENT OF SOILS IN UGAH VILLAGE AREA OF NASARAWA STATE, NIGERIA

[1]E. A. Olowolafe, [2]M. T. Oluwafemi, [1]S. M. Maton, [1]I. S. Laka, [3]H. K. Mande, [3]M. Obasi, [3]D. D. Sabo, [3]M. M. Richard, [3]D. Babarinsa, [3]G. C. Okechukwu and [1]E. M. Paul

[1]Department of Geography and Planning, University of Jos, Jos, Nigeria.
[2]Department of Computer Science, Federal University, Lokoja, Nigeria.
[3]Department of Environmental Management, Kaduna State University, Kaduna, Nigeria
Corresponding author: eaolowolafe@yahoo.com

Abstract
This study was carried out to assess the nutrient status of soils formed from alluvial floodplain of River Benue around Ugah village in Nasarawa State of Nigeria and to recommend management practices that can help to enhance and sustain the agricultural productivity of the soils. Three main soil mapping units were identified and therefore, three soil profile pits were dug and carefully studied in the area and soil samples collected were analysed for their physical and chemical properties. The results of the study show that the soils of the study area are very low to low in total nitrogen, low to medium in phosphorus, very low to medium in potassium, calcium, magnesium, and CEC. Therefore, with the present low-input agriculture in the area, nutrient depletion will certainly continue, a situation which can lead to total loss of productivity potential and environmental impoverishment. Hence, the need arises now to enhance the nutrient status of the soils on long-term basis and to achieve this, an integrated management package involving erosion control measures, applications of the right types and adequate quantities of inorganic and organic fertilizers together with better cultural practices are required. The roles of agricultural extension agents are also crucial to agricultural sustainability. Hence, there is the need for their regular interactions with the farmers.

Keywords: Nutrients status, Soils management, Soils profile, Soils organic matter

INTRODUCTION

Ugah village area is within the entrenched Mada river valley, which is part of the Benue floodplain in Nasarawa State that is endowed with fertile soils derived from alluvial deposits (Samaila & Ezeaku, 2007). The area is mainly an agricultural community where a wide range of crops that the State is well known for are produced. Agricultural potentials of alluvial soils have been acknowledged worldwide (Hillel, 1991; Troeh, Hobbs & Donahue, 2004). This was what led to ancient civilization in Greece, Egypt and Roman Empire, among others (Hillel, 1991, Troeh et al., 2004, and Brevik & Hartemink, 2010). However, one of the greatest problems presently confronting agriculture in this part of the River Benue floodplain is soil erosion, which has depleted most soils of their required plant nutrients. According to Samaila and Ezeaku (2007), rainfall impacts, fluvial action and human impacts in form of deforestation, overgrazing, incompatible agriculture methods, soil excavation, construction and mining, among others, are responsible for the various types of soil erosion identified in the area (Samaila & Ezeaku, 2007). This, perhaps, may have led to a decline in soil productivity and agricultural output. Despite this fact, there seems to be dearth of empirical evidence on soil management practices, especially among smallholder farmers in the area. Therefore, the purpose of this study was to assess the nutrient status of the soils and the agricultural practices adopted by farmers in managing the soils of the area.

MATERIALS AND METHODS

Study Area

Ugah area is in Nasarawa State, centrally located in the middle belt of Nigeria, between latitudes 8º 12’ and 8º 14’N and longitudes 8º 45’ and 8º 48’E with elevation ranging from 280 to 290 metres above mean sea level. The climate is the wet and dry type classified as tropical rainy (Aw) climate by Koppen (1923). Hence, the area is marked by two distinct climatic conditions. The rainy season lasts usually from April/May to September/October depending on the rainfall pattern for the particular year, while the dry season makes up the remaining period of the year. It is a sub-humid environment characterized by a mean annual rainfall of 1,230mm, peaking in August (Binbol, 2007). The mean annual temperature is about 27ºC, though maximum temperature can reach 39ºC in hottest month of March while minimum value, on the other hand, can drop to 17ºC in December and January when the area comes under the influence of the cool and dry desiccating north-easterly tropical continental air mass (harmattan). The study area lies within the southern Guinea Savanna vegetation zone, which is an open woodland with tall grasses. The area is underlain by the Lafia Formation, which is the youngest Cretaceous sedimentary formation within the middle Benue Trough (Obaje, Lar, Nzegbuna, Moumouni, Chaanda & Goki, 2007). The formation was deposited under continental condition in the Maastrichtian and it lies unconformably on the Agwu Formation and it has suffered significant erosion. It is lithologically characterised by ferruginised sandstones, red, loose sands, flaggy mudstones, clays, and claystones (Obaje et al, 2007).

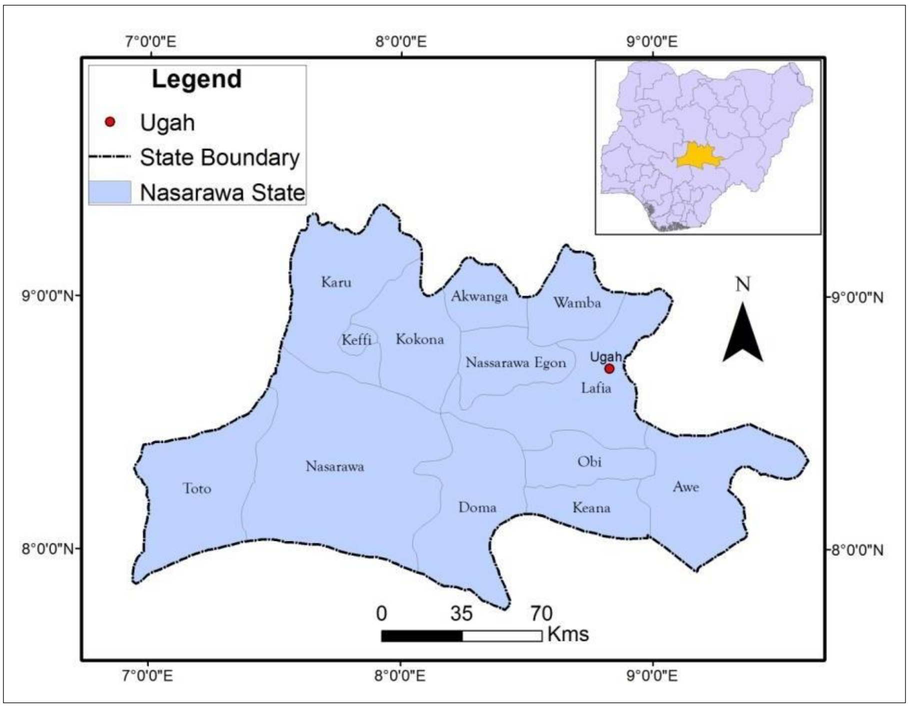

Figure 1 Location map of the Study Area

Fieldwork

There are three soil mapping units that were identified in the area, based on the stereoscopic interpretation of aerial photographs and field observations made in the study area. These are the slightly elevated, the level and the slightly depressed soil mapping units. A soil profile pit was dug to represent each of these three soil mapping units. Soil descriptions were made according to FAO (1977) guidelines, while soils were classified according to USDA (1999; 2003) Soil Taxonomy. The various genetic horizons were sampled for laboratory analysis. Direct field observations were also made on agricultural activities in the area. The field survey took place at the peak of the harvesting period, when most farmers could be found in the field.

Soil Laboratory Analysis

Standard procedures were employed in the detailed laboratory analysis. Laboratory determinations made include the following: Particle size analysis was made by using the hydrometer method outlined by Day (1965) and modified by Gee and Bauder (1986). Measurement of pH was done in a 1:2.5 suspension in water and KCl. Organic matter was determined using the Walkey and Black (1934) method of acid dichromate digestion and the titration was done with ferrous sulphate solution. Available phosphorus was extracted using dilute HCI/NH_4F as described by Bray and Kurtz (1945) while total nitrogen was determined following wet oxidation micro-Kjeldahl method (Bremner & Mulvaney, 1982). The extraction of Ca, Mg, Na and K was made using IN ammonium acetate at pH 7.0 (USDA, 1972), and Ca and Mg were measured by an Atomic Absorption Spectrophotometer (AAS) while K and Na were measured by flame photometer. From this, the ECEC was then calculated by using summation method, while the extraction for CEC was carried out by using 1N KCl solution.

RESULTS AND DISCUSSION

Soil Types

Table 1 presents the physical and chemical properties of the soils. The table shows that the soils are characterised by A-B-C profiles, indicating that all the soil profiles contain A, B and C horizons. The profiles are deep while the A horizon is thicker than 30cm in the three soil profiles. The general relief of the lowland floodplain is slightly undulating, while the main soil mapping units identified are: the slightly elevated, the level and the slightly depressed soil mapping units within the alluvial plain. Inceptisols are were found on both the slightly elevated and level soil mapping units. Soils in the two units have cambic horizons that show evidences of alteration of original alluvial parent materials and soil structure but with no evidence of illuviation and they also have adequate soil depth to classify them as Inceptisols. Soils in the slightly depressed soil mapping unit have argillic horizons because of increase in clay contents down the profile, and very importantly because of the well-developed clay skins which are broken and moderately thick in Bt3 horizon, an indication of illuviation. And since it has base saturation of more than 50%, it was therefore classified as Alfisols.

Nutrient Status

The contents of total nitrogen in the soils are very low to low. This is because total nitrogen levels between 0. 1 and 0. 2% are taken as low, while below 0.1% are very low for tropical soils (Landon, 1991). The values of total nitrogen contents of the surface soils, as presented in table 1, are 0.14%, 0.11% and 0.14%, while subsoil values are below 0.10% in all the B horizons. Under the intense heat and humid tropical conditions, there is always rapid volatilization and loss of soil nitrogen in the area. Volatilization due to annual vegetal burning and high temperature are among the factors responsible for nitrogen loss in soils of the of the tropical savanna environment (Olowolafe & Dung, 2000). Since organic matter is the main source of nitrogen in soils of the tropics, and once the organic matter is low or very low as in this case (table 1), then it is expected that the nitrogen contents in the soils should also be low. This is a major cause of low nitrogen contents of soils in the tropics (Muller-Samann & Kotschi, 1994). Nitrogen is a very dynamic element, susceptible to leaching in form of nitrate, since the area belongs to a high-rainfall environment. Therefore, soil erosion as well as leaching, may have contributed to nitrogen loss.

Values of available phosphorus (extracted by Bray & Kurtz (1945) method: dilute HCI/NH4F) below 15ppm are regarded as low, while between 15 and 50ppm are regarded as medium for tropical soils (ILACO, 1985; Landon, 1991). This indicates that the soils in the slightly elevated units have medium values in available phosphorus, while soils in the remaining two units are phosphorus-deficient. The acidity of the soils explains this. The exchangeable acid data show that the soils of the level and slightly depressed areas have much exchangeable acidity, and also the soil pH has its lowest values in the depressed areas (with values mostly < 5.5). One of the unique properties of acid tropical soils is high P-fixation (Kamprath, 1984; Courley, 1987). This explains why the soils of the slightly elevated unit have the highest (medium) values of available phosphorus. The problem of P-fixation in acid tropical soils has been traced to Al-P interactions. According to Courley (1987), the high hydrous Al oxide content of many acid tropical soils can result in enormous phosphate-fixing capacities. According to farmers in the area, NPK (15:15:15) is the common compound fertilizer type being used in the area and this contains phosphorus. Management problems often become complex due to pedogenic fixation of added nutrient. This is because very high amount of phosphorus is always converted from soluble to unavailable forms after fertilizer application (Pushparajah & Bachik, 1985).

For exchangeable potassium, the third macronutrient element, it has values of 0.1, 0.5 and 0.3 cmol/kg in the surface soils of slightly elevated, level and slightly depressed units respectively. According to Landon and ILACO (1985) and Landon (1991), values of exchangeable potassium below 0.2 are taken as very low, between 0.2 and 0.3 as low, while between 0.3 and 0.6 are regarded as medium. Therefore, the nutrient element is very low in soils of the slightly elevated units while it is low in those of the depressed areas and medium soils of the level units. According to Landon (1991), in general terms, a response to potassium fertiliser is likely when a soil has exchangeable K value of below 0.2 meq/100g soil and unlikely when it is above 0.4 meq/100g soil, depending upon the soil type and the crop in question. The very low to low potassium levels of some of the soils can be related to leaching, erosion and low potassium content of the soil parent materials.

The other exchangeable bases, calcium and magnesium, sum of total bases, ECEC and CEC have the highest values in soils of the depressions and the lowest values in the soils of the slightly elevated areas. Calcium ranges from very low to low values, magnesium varies mostly from low to high values while CEC varies from very low to medium. As earlier stated, erosion is a serious problem in the area. The tendency is that erosion will remove the finer particles like clay and their colloidal fractions, further down the slope while the coarser or bigger particles like sands will be left behind. Therefore, the removal of such essential finer particles from the elevated areas down to the depressions always occurs through the process of differential sedimentation. Perhaps, this is why the soils of the depressions are higher in clay contents, exchangeable bases, ECEC and CEC. Though, no attempt was made to carry out the clay mineralogical analysis because that is outside the scope of the study, the clay type may also contain some 2:1 types of minerals together with kaolinite in the depressions because of the higher CEC values, as asserted by Samaila and Ezeaku (2007).

Agricultural Practices in the Area

Both rainfed and irrigated agriculture are practised in the area and there are both perennial and annual crops. The former includes: oranges, mango, palm, locust beans and cashew, among others. The major annual crops produced in rainy seasons are: yam, rice, maize, sorghum, ground nuts and Beni seed, while the rest are: beans, pepper, cassava, millet and Okra. The cropping calendar for the major rainfed crops is presented in table 2. This starts from the period of planting to weeding, fertilizer application and harvesting. But the irrigated agriculture is carried out mainly for the production of rice together with vegetables, pepper and sometimes with maize. This commences between January and February mainly in places close to the rivers and streams or in places with high water tables, with the use of pump engine and buckets for the required water, as earlier noted by Rahman (2007). Actually, the area is blessed with networks of rivers and streams, which serve as major sources of water for irrigation in the area. Being a floodplain, the rain-fed production of rice extends up to October and November. Vegetables are produced both in rainy and dry seasons. The number of times for weeding varies from one crop to another. It is up to four times for maize; between four to six times for yam and two times for cassava. Simple hand tools are always used for land preparation, planting, weeding and harvesting. Both commercial and subsistent farming are practised and most commercial farmers sell their produce in Assakio while the rest carry theirs to Lafia, Lagos Mile 12, Port Harcourt, Akwanga, Obi, Gwantu or Ashenga for sale.

Soil Management Options for Improved Productivity

Soil management commences with the steps being taken during land clearing and preparation. It starts with the farmers' ability to vary the depth of tillage and weed control according to soil conditions (Johannsen & Carter, 2005). In the study area, many of the farmers practised the annual burning of grasses and crop residues (or bush burning) mostly between February and March, to clear their lands for the necessary tillage operations. However, it has been observed that, in the tropics, it has been observed that such burning is not appropriate for the soils because the ash produced from such burning only leads to temporary increase in pH, available nitrogen, phosphorus, potassium, calcium, magnesium, and some micronutrients and a decrease in exchangeable aluminum levels.

Table 1 Some of the physical and chemical properties of soils in the study area

Horizon	**Depth (cm)**	**pH**					**Exchangeable Cations**				**Total**	**Exch. Acid**	**ECEC**	**Base Sat**	**CEC**
		H2O	KCl	OM %	TN	Avail P ppm	Ca	Mg	K	Na	Bases meq/100g soil	(Al + H)		%	cmol(+)/kg soil
							Soil Profile Pit 1 Data :Typic Endoaquepts								
Ap	0-7	5.4	4.8	1.7	0.14	38.5	0.4	0.4	0.1	0.2	1.2	0.2	1.4	85.0	4.1
A2	7.-35	5.8	5.0	1.2	0.10	45.3	0.7	0.4	0.1	0.2	1.4	0.2	1.6	88.0	4.0
Bw1	35-59	5.8	5.1	0.4	0.06	27.5	0.4	0.5	0.2	0.1	1.2	0.2	1.4	85.0	3.8
Bwg2	59-150	5.4	4.0	0.2	0.04	15.5	0.4	0.5	0.1	0.1	1.2	0.4	1.6	75.0	4.0
Cg1	150+	5.1	3.8	0.1	0.02	4.5	2.0	1.7	0.6	0.1	4.2	0.4	4.8	92.0	7.8
							Soil Profile Pit 2 Data: Fluvaquentic Endoaquepts								
Ap	0-15	6.4	5.4	1.4	0.11	2.2	3.8	1.1	0.5	0.2	5.6	0.6	6.2	90.0	9.6
A2	15-31	6.2	5.5	0.6	0.08	2.1	2.2	1.7	0.5	0.1	4.5	0.6	5.1	88.0	7.3
B1	31-62	5.5	5.4	0.5	0.07	1,5	1.7	2.1	0.5	0.1	4.4	0.6	5.0	88.0	7.3
B2	62-89	5.1	4.4	0.2	0.06	1.0	1.7	1.7	0.5	0.1	4.0	0.7	4.7	85.0	6.2
BC	89-95	5.0	4.2	2.6	0.13	1.5	1.2	1.0	0.3	1.0	3.5	0.2	3.7	96.0	6.0
C1	95-153	5.3	4.6	0.7	0.07	1.0	0.7	0.8	0.3	0.4	2.2	0.3	2.5	88.0	7.6
							Soil Profile Pit 3 Data: Typic Kandiaqualfs								
Ap	0-19	4.0	3.2	1.5	0.14	4.7	1.2	1.3	0.3	0.2	3.1	4.0	7.1	44.0	20.4
A2	19-31	4.6	3.2	1.0	0.11	0.9	1.0	1.3	0.2	0.3	2.8	2.4	5.2	54.0	16.1
Bw1	31-73	4.7	3.0	0.4	0.09	0.5	1.5	2.2	0.2	0.4	4.3	1.6	5.9	73.0	14.2
Bt2	73-110	5.0	3.5	0.3	0.06	0.2	2.0	3.9	0.2	0.6	6.8	0.4	7.2	94.0	20.6
Bt3	110-141	5.0	3.9	0.1	0.05	0.1	2.6	4.6	0.2	0.8	8.2	0.6	8.8	93.0	15.3
BC	141-156	5.4	3.7	0.1	0.01	0.1	1.7	2.6	0.1	0.4	4.9	0.3	5.2	94.0	10.4

Table 2 Cropping calendar for the major annual rain-fed crops

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yam			---	---	---	---	---	---	---	---	---	
Rice						---	---	---	---	---		
Maize					---	---	---	---				
Sorghum					---	---	---	---	---	---		
Groundnut					---	---	---					
Beni seed								---	---	---		

Shortly after, however, the levels of available nitrogen, potassium, sulphur, copper and boron will become adversely affected and organic matter in the surface soils will decrease sharply, while there will also be initiation of erosion, reduced porosity and infiltration, among others (Grove , 1952; Grigg, 1970; Sanchez, Bandy, Villachica & Nicholaides, 1982). Generally, in the Savannah area, bush burning destroys the natural structure of surface soils due to reduction in the biological activity, it accelerates soil erosion and reduces the organic matter, sulphur and phosphorus content of soils (Kowal & Kassam, 1978).

Therefore, since land clearing method and weeding operations are considered important to the sustainability of agricultural systems (Junge, Abaidoo, Chikoye, & Stahr, 2008), the practice of annual burning of grasses and crop residues can be avoided. If the materials are incorporated into the soils, it has a far-reaching positive effect. The use of mechanical land preparation, particularly in the slightly elevated unit can also be avoided, so as to reduce the possibility of soil structural destruction. Instead, the use of simple hand tools like hoes and machetes can be continued for land clearing, tillage, seeding and fertilizer application to reduce the effects of mechanical destruction of soil structure and porosity, as earlier recommended for soils of similar ecological environments (Odunze, 2006 & Ogunkunle, 2009). Since sheet and rill erosion features are common, more attention can be given to ridging across the slope with the use of hand tools, strip farming and high crop density to provide dense crop/vegetation cover to reduce erosion as desirable. This is particularly important because of the sandy nature and the weak structure of the surface soils in the slightly elevated and level units, which can render the soils more susceptible to erosion. Strip cropping can be practised in such a way that crops that can withstand erosion alternate with those that cannot withstand it. It is also much better still if crop rotation, involving legumes, can be included in the strip cropping. Improvement of surface soil condition by adding crop residues, household manure and animal manure together with maintenance of surface roughness using minimum tillage, as proposed for sustainable agriculture (Dolan, Clapp, Allmaras, Baker & Molina., 2006; Haddaway, Hedlund, Jackson, Kätterer, Lugato, Thomsen, Jørgensen & Isberg, 2017; Jahangir, Jahan & Mum., 2018), are essential to improve soil nutrients, control run-off water, and at the same time improve soil infiltration so as to reduce erosion.

Farmers in the area apply both inorganic and organic fertilisers. The inorganic fertilisers applied are mainly urea and NPK (particularly 15:15:15). The former is always applied to vegetables and pepper while the latter, also sometimes combined with the former, is always applied to the cereals (maize, rice and millet) and the tuber crops (yams and cassava). However, ground nut, Beni seed and beans are not fertilized because the farmers are aware that leguminous crops have the ability to fix nitrogen and enhance soil productivity. For most of the rainfed cereals and other crops, inorganic fertilisers were always applied once and this is always by broadcasting or spraying particularly for rice, vegetables, pepper and Okra; side placement or ring methods for maize, sorghum, millet and tuber crops. Organic fertilisers applied in the area are town wastes, cow dung and rice shaft/husks, which they spread on the farms and incorporate into the soils during land preparations.

Unfortunately, farmers have been applying fertilisers wrongly by following blanket recommendation. The absence of soil testing in the study area is responsible for indiscriminate use of fertilisers. Therefore, this may have led to the use of wrong type of fertiliser, over-fertilisation or under-fertilisation and all these have consequences on both the soils and the environment. Another problem in the area is that majority of the farmers do not always have access to extension officer's advice. This is a great draw-back on our national agricultural policy. Considering the present nutrient levels of the soils, the issue of increasing soil nutrient stock through appropriate fertilizer input is essential. The right types and sufficient amounts of inorganic fertilizers with their frequencies and times of application, worked out on the basis of the types of crop, are recommended. The amounts of fertilizer to be applied ought to be sufficient to take care of high yields and losses due to leaching and crop removal. For agricultural land use to be productive and sustained, restoration of fertility is imperative. This is because the macro-nutrients examined in this study are either very low or low in the soils of the area.

The low level of organic matter and total nitrogen is a challenge to agricultural productivity. Soil organic matter and total nitrogen are important components of agricultural sustainability (Xue & An, 2018). Therefore, it is important to enhance and maintain C and N contents in soils to avoid degradation and implementing sustainable productivity management (Lal 2014; Campbell & Paustian 2015). The content of soil organic carbon matter is one of the main indicators of the soil quality and health (Zhao, Liu, Wang & Zhao, 2015; Kwiatkowska-Malina 2018). There is the need to pay more attention to practices that can increase soil organic matter. Organic matter composition influences soil productivity by determining the physical, chemical, and biological soil characteristics (Liu, Shao & Wang 2011), and it can also reduce fertilizer input and irrigation, raise the harvest, and cover the yield gap (Chabbi, Lehmann, Ciais, Loescher, Cotrufo, Don & SanClements, 2017; Oldfield, Bradford & Wood, 2019). Agricultural land has the potential to accumulate a large amount of soil organic matter, which should be maintained and improved by implementing a good land management system.

The cultural practices adopted for soil management by the farmers include mixed cropping, crop rotation, monoculture, alley cropping and bush fallow. For mixed cropping, the farmers use it for the purposes of weed control, crop diversification and soil management. However, crop mixing as practised by the farmers is inappropriate, because they hardly incorporate legumes in the mixture for soil nitrogen enhancement. For example, a mixture of maize and yam or maize and rice without legume for a long time can deplete the soil of nitrogen. Table 3 presents the major crop rotation patterns in the study area. Considering the fact that yams, rice, maize and cassava are heavy feeder-crops that absorb a great deal of nutrients from the soils, legumes are supposed to be well incorporated into the crop rotation much more than what is presently in practice. Alley cropping is also being practised, whereby they have trees of oranges, mango, palm, acacia, locust beans and cashew in their farms that are often pruned and their leaves and branches are used as mulching materials that eventually decay to add nitrogen to the soils. Though a good practice, but the trees are not many and they are also not in straight-line rows as in the modern-concept of alleys.

Table 3 Crop rotation patterns

	First Year	Second Year	Third Year
1	Yam	Maize	-
2	Yam	Maize	Cassava
3	Yam	Maize	Rice
4	Yam	Cassava	Ground nut

Monocropping is adopted mostly to avoid over-crowding of crop stands, particularly for rice, maize, yams and pepper. This practice has been in existence in the area for up to between 25 and 50 years now. Agricultural sustainability certainly requires an appropriate cropping system. Monocropping of cereals (maize, sorghum and rice) for a long time without mixing or rotating with legumes, as practised in the study area, is inappropriate and very unscientific. According to Agboola (1987), such practice does not give the benefit of diversification, exposes farmers to risk in case of adverse climatic conditions, leads to rapid depletion of soil nutrients and outbreak of pests and diseases. In the same vein, Wijanarko and Purwanto (2018) reported that intensive monocropping of cassava for more than 30 years, on a Typic Hapludult, contributed to decreasing macro-nutrients concentration. Similarly, such a system caused a decrease of pH, total N and C, available P, K, Ca, and Mg, and CEC because of decrease in soil organic matter (Wijanarko & Purwanto, 2017). It is therefore recommended that crop rotation and mixed cropping which involve annual and perennial legumes ought to be practised for biological N-fixation. Nowadays, N-fixing legumes have become essential choice because of the increased cost of N fertilisers (Ovalle & Espinoza, 2012). These systems combine phases of legumes of different duration in which N is fixed and accumulates in the soils, and followed by phases of cereal crops, growing during which accumulated nitrogen is extracted, because of the need to develop more sustainable farming systems.

CONCLUSION

From the results of the study, it is concluded that the soils of the study area are very low to low in total nitrogen, low to medium in phosphorus, very low to medium in potassium, calcium, magnesium, and CEC. Therefore, with the present low-input agriculture in the area, nutrient depletion will certainly continue, a situation which can lead to total loss of productivity potential and environmental impoverishment. Hence, the need arises now to enhance the nutrient status of the soils on long-term basis and to achieve this, an integrated management package involving erosion control measures, applications of the right types and adequate quantities of inorganic and organic fertilizers together with better cultural practices are required. The roles of agricultural extension agents are also crucial to agricultural sustainability. Hence, there is the need for their regular interactions with the farmers.

REFERENCES

Agboola, A, A. (1987). Farming system in Nigeria. Land development and management of acid soils in Africa II: IBSRAM Proceedings No. 7 Lusaka and Kasama, Zambia, 9th – 16th, April, 1987, 67 – 81.

Binbol, N. L. (2007). Climate. In: Akwa et al (Ed). Geographical perspective on Nasarawa State. A publication of the Department of Geography, Nasarawa State University, Keffi, Nigeria, 35 – 42.

Bray, R. H. and Kurtz, L. T. (l 945). Determination of total, organic and available phosphorus in soils. *Soil Science*, 59, 39-45.

Bremner, J. M. (1965). Total nitrogen. In: C. A. Black et al. (Ed.). Methods of soil analysis, Part 2. Agronomy 9:1149-1178. Am. Soc. of Agronomy, Inc., Madison, Wisconsin.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: L. A. Page (Ed) Methods of soil analysis. Agronomy 9 monograph. American Society of Agronomy, Wisconsin 892-901.

Brevik, E. C. and Hartemink, A. E. (2010). Early soil knowledge and the birth and development of soil science. *Catena* 38, 23 – 33.

Campbell, E. E., and Paustian, K. (2015). Current developments in soil organic matter modeling and the expansion of model applications: A review." *Environmental Research Letters* 10 (12), 12-24.

Chabbi, A., Lehmann, J., Ciais, P., Loescher, H. W., Cotrufo, M. F., Don, A., & SanClements, M. (2017). Aligning agriculture and climate policy. *Nature Climate Change* 7, 307–309.

Courley, L. M. (1987). Breeding sorghum for acid soils of the humid tropics. In: IBSRAM (1987): Land dev. and management of acid soils in Africa, IBSRAM Proceedings 7, 261- 273.
Day, P. R. (1965). Particle fractionation and particle size analysis. In: Black, C. A. (ed)

Methods of soil analysis, Part 1. Agronomy No. 9. American Society of Agrnomy, Madison Wisconsin, U. S. A.

Dolan, M. S., Clapp, C.E., Allmaras, R. R., Baker, J. M., and Molina, J. A. E. (2006). Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. *Soil Till. Res*. 89, 221-231.

FAO (1977). Guidelines for Soil profile description. FAO, Rome.

Gee, G. W. and Bauder, J. W. (1986). Particle size analysis. In: Klute, A. (Ed). Methods of soil analysis. Tropical and mineralogical methods. Agronomy. Am. Soc. of Agron, Madison, Part 1. Wisconsin, 383-411.

Grigg, D. (1970). *The harsh lands*. London, Macmillan.

Grove, A. T. (1952). Land use and soil conservation on the Jos Plateau. Geol. Survey of Nig. Bulletin No. 22. P 63.

Haddaway, N.R., Hedlund, K., Jackson, L.E., Kätterer, T., Lugato, E., Thomsen, I.K., Jørgensen, H.B., Isberg, P. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environ. Evidence* https://doi.org/10.1186/s13750017-0108-9.

Hillel, D. (1991). Out of the earth: Civilisation and the life of the soil. University of California Press, Berkeley, California.

ILACO, B. V. (1985). Agricultural Compendium: For rural development in the tropics and subtropics. Elsevier, Amsterdam-Oxford New York- Tokyo. P. 738.

Jahangir, M. M., Jahan, R. I. and Mumu, N. J. (2018). Management of soil resources for sustainable development under a changing climate. *J. Environ. Sci. & Natural Resources*, 11(1&2), 159-170

Johannsen, C. J. and Carter, P. G. (2005). Site-specific soil management. In: Hillel, D. Encyclopedia of Soils in the Environment. 4, 149 – 155). Elsevier Academic Press.

Junge, B., Abaidoo, R., Chikoye, D. and Stahr, K. (2008). Soil Conservation in Nigeria Past and present on-station and on-farm initiatives. Soil and Water Conservation Society

Kamprath, E. J. (1970). Exchangeable aluminium as a criterion for liming leached mineral soils. Soil Science Society American Proc. 34, 252-54

.

Koppen, W.S. (1923). Die Klimate der Erede. Walter der Gruyter, Berlin.

Kowal, J. M. and Kassan A. H (1978). Agricultural ecology of Savannah. A study of West Africa. Clarendon press. Oxford pp 403.

Kwiatkowska-Malina, J. (2018). Qualitative and quantitative soil organic matter estimation for sustainable soil management. *Journal of Soils Sediments* 18: 2801–2812.

Lal, R. (2014). Soil Carbon Management and Climate Change. In *Soil Carbon*, edited by A. E. Hartemink and K. McSweeney, 339. Cham, Switzerland: Springer.

Landon, J.R (Ed) (1991). Booker Topical soil Manual. A handbook for soil survey agricultural land evoluation in the tropics and subtropics. Paper-back Edition. Longman sci. and Technical, U.K P. 474.

Liu, Z., Shao, M. and Wang, Y. (2011). Effect of Environmental Factors on Regional Soil Organic Carbon Stock across the Loes Plateau Region, China. *Agriculture, Ecosystems & Environment* 142, 184–194.

Mullers- Samman, K.M and Kotschi, J.(1994). Sustaining growth: Soil fertility management in tropical smallholdings. (CTA; GTZ. Transl: Christine Ernstine and Simon Chater). Weikersheim: Margraf. P. 486.

Obaje, N. G., Lar, U. K. Nzegbuna, I. A., Moumouni, A., M. S. Chaanda and N. G. Goki (2007). Geology and mineral resources. In: Akwa et al (Ed). Geographical Perspective on Nasarawa State. A publication of the Department of Geography, Nasarawa State University, Keffi, Nigeria, 13 – 34.

Odunze, A. C. (2006). Soil properties and management strategies for some sub-humid Savanna zone Alfisols in Kaduna State, Nigeria. *Samaru Journal of Agricultural Research* 22, 3 – 14.

Ogunkunle, A. O. (2009). Management of Nigeria soil resources for sustainable agricultural productivity and food security. In: Fasina, A. S., Ayodele, O. J., Salami, A. E., and Ojeniyi, S. O. (Eds). (2009). Management of Nigeria soil resources for enhanced agricultural productivity. Proceedings of the 33rd Annual Conference of the Soil Science Society of Nigeria, held at University of Ado Ekiti, Ekiti State, Nigeria. March 9th – 13 th, 9 – 24.

Olowolafe, E. A. and Dung, J. E. (2000). Soils derived from biotite-granites on the Jos Plateau, Nigeria: Their nutrient status and management for sustainable agriculture. *Resources, Conservation and Recycling* 29, 231-244.

Oldfield, E. E, Bradford, M. A. and Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. *Soil* 5: 15–32.

Ovalle, C. and Espinoza, S. (2012). Crop rotation with legumes. In: Schwilch, G. et al (Eds). Desire for green land. Options for sustainable land management in dry lands WOCAT, 93-96.

Purwanto, B. H. and Alam, S. (2020). Impacts of intensive agricultural management on carbon and nitrogen dynamics in the humid tropics. *Soil Science and Plant Nutrition* (1), 50-59,

Pushparajah E. and Bachik, A. T. (1987). Management of acid Tropical Soils in Southeast Asia. In: IBSRAM (International Board for Soil Research and Management): Manament of Acid Tropical Soils for Sustainable Agriculture: Proceedings of an IBSRAM inaugural workshop, Bangkok, Thailand. 24th April – 3rd May, 1985, 13 – 39.

Rahman, S. A. (2007). Crop Production. In: Akwa et al (Ed). Geographical Perspective on Nasarawa State. A publication of the Department of Geography, Nasarawa State University, Keffi, Nigeria. 43 – 53.

Samaila, K. I. and Ezeaku, P. I. (2007). Soils and Erosion. In: Akwa et al (Ed). Geographical perspective on Nasarawa State. A publication of the Department of Geography, Nasarawa State University, Keffi, Nigeria. 43 – 53.

Sanchez, P. A., Bandy, D. E., Villachica, J. H. and Nicholaides, J. J. (1982). Amazon Basin soils: Management for continuous crop production. *Science* 216, 821-827.

Troeh, F. R., Hobbs, J. A., Donahue, R. L. (2004*). Soil and water conservation for productivity and environmental protection.* 4th Ed. Prentice Hall, Upper Saddle River, NJ.

USDA (1972). Soil survey laboratory methods and procedures for collecting soil samples. Soil survey investigation report. No. 1.

USDA, Soil Survey Staff. (1999): Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Second edition. USDA Agriculture Handbook No. 436. Soil Management Support Services. Technical Monograph No. 19.

USDA, Soil Survey Staff. (2003). Keys to soil taxonomy. 9th Ed. USDA.

Walkey, A. and Black, C.A. (1934). An examination of the method for determining soil organic matter and a proposal for modification of the chromic acid titration method. *Soil Science* 37, 29-38.

Wijanarko, A., and Purwanto. B. H. (2017). Effect of land use and organic matter on nitrogen and carbon labile fractions in a typic hapludult. *Journal of Degraded and Mining Lands Management* 4 (3), 837–843.

Wijanarko, A., and Purwanto, B. H. (2018). Effect of long of land use and cropping system on soil fertility and cassava yield. *Journal of Degraded and Mining Lands Management* 5 (4): 1327–1334.

Xue, Z. and An, S. (2018). Changes in soil organic carbon and total nitrogen at a small watershed scale as the result of land use conversion on the Loess Plateau. *Sustainability* 10, 4757.

Zhao, Y. G., Liu, X. F., Wang, Z. L. and S. W. Zhao, S. W. (2015). Soil organic carbon fractions and sequestration across a 150-yr secondary forest chronosequence on the Loess Plateau, China. *Catena* 133, 303–30