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Original Research Article

Evaluation of organic carbon, available phosphorus, and available potassium as a measure of soil fertility

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Abstract

This study evaluated organic carbon, available phosphorus, and available potassium as a measure of soil fertility in the Lower River Benue Basin. Soil samples were collected from farms under cultivation and analysed for physical, chemical, and micro-nutrient properties. Soil fertility status was derived using the soil reaction index, and nutrient index with respect to organic carbon, available phosphorus and available potassium, based on the specific rating chart. The soil irrigation quality was assessed by calculating the Exchangeable Sodium Percentage (ESP) and Sodium Absorption Ratio (SAR). Based on the soil rating chart, most of the soils sampled had medium (30.6%) to high (55.6%) percentages of organic carbon. Only 13.9% of the samples had organic carbon percentages categorised as low. Most of the soils sampled had low amounts of phosphorus (50%) and low amounts of potassium (86.11%). A good percentage (36.11%) of the samples had high content of available phosphorus. The soil ESP and SAR results indicated fertile soils and good irrigation quality. The study has made useful recommendations for farmers and encourages agricultural extension workers to efficiently focus on educating farmers on appropriate crop varieties for cultivation; the best methods to enhance soil nutrients; and the importance of irrigation farming.

Keywords: Available Phosphorus, Available Potassium, Organic Carbon, Soil Fertility, Soil Micro-Nutrients, Soil Nutrients

INTRODUCTION

Agriculture has become a large economic and livelihood venture globally. The current global focus is to make agriculture sustainable. The sustainability of agricultural production systems have become a major concern of agricultural researchers and policy makers in both developed and developing countries (Rossiter, 1995; Medugu, 2006; IITA, 2008; Alademerin and Adedeji, 2010; Rosenberg, 2012). In order to achieve an effective sustainable plan for the development of agriculture, it is important to determine the available potential that exists through land studies. Especially since agriculture is a significant income earner in many parts of the world.

The agricultural sector gross domestic product (GDP) growth rate in Nigeria is the highest contributor to non-oil GDP growth rate. After an initial dip from 6.64% in 2003 to 6.50% in 2004, the growth rate appreciated per annum from 2004 (7.06%) to 7.43% in 2007 (Azih, 2011). With increases in crop yield, agriculture has become an important contributor to the Nigerian economy in the past decade despite the predominance of the oil sector (Oji-Okoro, 2011). This is reflected in the status of Nigeria in the world ranking of crop production by the Food and Agricultural Organisation (FAO). Nigeria ranks high in the production of several crops and is the highest producer of cassava and yam in the world (FAO, 2013; 2015).

According to the Benue State Ministry of Agriculture and Natural Resources (Benue State, 2013), about 80% of the population of Benue state depends on agriculture for their sustenance and livelihood. Major crops grown in Benue state are cassava, rice, soybeans, sesame, citrus, mangoes and yam. Animals reared in the state include catfish, pigs, goats, poultry birds, and cattle. The River Benue and Katsina Ala and their tributaries provide huge opportunities for irrigation farming and fish farming in Benue State.

Literature on soil fertility and nutrient analysis in the Lower River Benue Basin are limited. Information on micro-nutrients and nutrient classification can enhance strategic planning towards sustainable agricultural development in the Lower River Benue Basin. This study therefore aimed to fill gaps in literature on soil nutrient availability in the Lower River Benue Basin to enhance crop cultivation. This was done by analysing the physical, chemical, micro-nutrient properties, and the nutrient index of soils. The findings are important to guide policy makers in strategic planning for sustainable agricultural development.

METHODS

Study area

The area of study is located in the Lower River Benue Basin between Latitudes 7^{o} 13'N and 8^{o}00'N and Longitudes 8^{o}00'E and 9^{o}00'E. Most parts of the Lower River Benue Basin fall within the boundaries of Benue State, Nigeria. The study area covered thirteen Local Government Areas.

Soil sample collection

Soil samples were collected randomly from rice, cassava, and yam farms under cultivation, and these formed samples transects. These farms belonged to farmers who belong to farming cooperative societies in Makurdi, Tarka and Gboko Local Government Areas (L.G.As) in Benue State. A total of 36 soil samples were collected through stratified soil sampling from areas of similar topography, management history and crop performance. The depth of sampling was from 0-30 centimetres (cm). At each sampling point, surface (0 – 15cm) and subsurface (15 – 30cm) soil samples were collected. Secondary data published in journal papers was used to describe soils from other parts of the Lower River Benue Basin.

Physical analysis

Soil samples were air-dried and ground with a wooden roller before sieving with a 2mm mesh. The particle size distribution of the soils was determined using the Bouyoucos hydrometer method. Sodium hexa-metaphosphate was used as a dispersant after which the textural classes was determined using the textural triangle chart developed by the United Stated Department of Agriculture (USDA, 1996).

Chemical analysis

The pH of soil was measured using the soil/water ratio. Scholarly laboratory procedures were used to determine organic carbon, total nitrogen, phosphorus, exchangeable bases (Ca, Mg K and Na), and effective cation exchange capacity (CEC). Micro-nutrients in the soils were also analyzed (Fe, Mn, Ni, V, Co, and Mo). Quality assurance was guaranteed by laboratory officers. The unit of measurement for exchangeable elements was centimoles of positive charge per kilogram (cmol kg^{-1}) while other elements such as phosphorus and micro-nutrient were measured at milligrams per kilogram (mgkg^{-1}).

Soil nutrient index

In order to analyze the soil fertility status of soils in Makurdi, Tarka and Gboko, different indices like soil reaction index, and nutrient index with respect to organic carbon, available phosphorus and available potassium were calculated based on the specific rating chart. The specific rating chart is presented in Table 1. The rating charts were used to rate the soil analysis results and nutrient index respectively. This procedure was used elsewhere in Verma *et al.* (2005) and Ravikumar and Somashekar (2013).

After soil nutrient values have been rated using the soils rating chart, the nutrient index for soils in Makurdi, Tarka, and Gboko were calculated using Equation 1:

$$\text{Nutrient Index} = \frac{\begin{matrix}(1\text{X number of samples rated low})+\\(2\text{X number of samples rated medium})+\\(3\text{X number of samples rated high})\end{matrix}}{\text{Total number of samples}} \quad \text{Equation 1}$$

The results of the calculated nutrient index were thereafter classified using Table 2 which classified soils low, medium or high according to the nutrient index values obtained.

Soil irrigation quality

The soil irrigation quality for the analyzed soils sampled was assessed by calculating the exchangeable sodium percentage (ESP) which identifies the degree to which the absorption and exchange complex of soil is saturated with sodium. The ESP was calculated using Equation 2:

Table 1. Rating chart for analyzed soil nutrient values

Parameter	Category ratings		
Soil pH	Acidity	Neutral	Alkaline
Range	Below 6.0	6.0-8.0	Above 8.0
Soil reaction index	I	II	III
Organic Carbon (C)	Low	Medium	High
Range (%)	Below 0.5	0.5-0.75	Above 0.75
Nutrient index	I	II	III
Available Phosphorus (P)	Low	Medium	High
Range ($mgkg^{-1}$)	Below 2.2	2.2-5.4	Above 5.4
Nutrient index	I	II	III
Potassium (K)	Low	Medium	High
Range ($cmolkg^{-1}$)	0.1	0.1-0.2	Above 0.2
Nutrient index	I	II	III

Ravikumar and Somashekar (2013)

Table 2. Nutrient index categories

Nutrient index	Range	Categories (C, P, K)
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Ravikumar and Somashekar (2013)

$$\mathrm{ESP} = \mathrm{Exchangeable}\ \frac{\mathrm{Na}}{\mathrm{Ca+Mg+K+Na}} \mathrm{X}\ 100 \qquad \text{Equation 2}$$

The Sodium Absorption Ratio (SAR) of the soils was calculated to assess whether the parameter posed a hazard to irrigation in soils of the area. This is because SAR of water is directly related to the absorption of sodium by soil and is a valuable criterion for determining the suitability of irrigable soils. The following Equation (3) was used to calculate SAR:

$$\mathrm{SAR} = \mathrm{Exchangeable}\ \frac{\mathrm{Na}}{\sqrt{\frac{(\frac{\mathrm{Ca}}{\mathrm{Mg}})}{2}}} \qquad \text{Equation 3}$$

RESULTS

Physical composition of soils in the Lower River Benue Basin

Soils in Makurdi were mostly loamy sand. Loamy sand soils have low water holding capacity, good drainage and aeration. Soils from Tarka, and Gboko were mostly sandy loam. Soils with sandy loam texture are moderately drained and moderately aerated. Sandy loam soils have capacity to retain nutrients moderately. Loamy sand and sandy loam soils appear moderately suitable for irrigation, but may be drought prone.

The sand fraction of soils collected from cassava farms ranged from 68-87% with a mean of 73.42% for surface soils, and 62-77% and a mean of 72.18% for subsurface soils. The percentage of sand in soil samples from rice farms ranged from 54-74% and a mean of 60.59% in surface soils, and a range of 52-72% and a mean of 64.52% in subsurface soils. The percentage of sand in soils collected from yam farms ranged from 57-84% with a mean of 70.25% for surface soils, and a range of 60-82% with a range of 69%.

Chemical composition of Makurdi soils

The soils in Makurdi are slightly acidic and ranged from 5.5-6.5 with a mean of 5.9. The mean organic carbon percentage was 0.52%. The mean percentage of nitrogen was 0.03% while available phosphorus had a mean of 5.01 $mgkg^{-1}$. The exchangeable bases (Ca, Mg, K, and Na) had a mean of 2.7(cmol kg^{-1}), 2.2(cmol kg^{-1}), 0.09(cmol kg^{-1}), and 0.06 ($cmolkg^{-1}$) respectively. Exchangeable acidity was 0.81 $cmolkg^{-1}$. The mean ECEC was 5.9 $cmolkg^{-1}$ and the mean base saturation was 86.08%.

The micro-nutrient analysis revealed that iron content ranged from 213.18(mg kg^{-1}) – 900.48 ($mgkg^{-1}$) while the mean value for Mn, Ni, V, Co, and Mo were 20.8(mg kg^{-1}), 37.59(mg kg^{-1}), 0.08(mg kg^{-1}), 1.9(mg kg^{-1}), and 1.86 ($mgkg^{-1}$) respectively. All these values were below the permissible limits. The order of concentration was Fe>Ni>Mn>Co>Mo>V.

The values of the micro-nutrients were correlated using the Pearson's product moment correlation coefficient and Spearman's rank correlation coefficient to assess the level of relationship between the elements. The results of the Pearson's correlation showed that Mn and Fe had a strong negative relationship ($p<0.01$) suggesting they are from different parent material and both elements did not show significant relationship with other elements. Mo and Ni showed a strong positive relationship ($p<0.01$) suggesting that they are from the same parent material. The result also showed a partial positive relationship between Ni, V, and Co. Anthropogenic factors played a role in the introduction of the Fe and Mn to the soils. The trend was similar with the results of the Spearman's correlation coefficient.

Chemical composition of Tarka soils

The soils in Tarka are slightly acidic and ranged from 5.3-6.1 with a mean of 5.7. The mean organic carbon percentage was 1.13% which was higher than that of Makurdi. The organic carbon content was high in a few sites. The mean percentage of nitrogen was 0.08% while available phosphorus had a mean of 4.6 $mgkg^{-1}$ which was lower than that of Makurdi. The exchangeable bases (Ca, Mg, K, and Na) had a mean of 2.9(cmol kg^{-1}), 1.47(cmol kg^{-1}), 0.07(cmol kg^{-1}), and 0.06 ($cmolkg^{-1}$) respectively. Exchangeable acidity was 1.23 $cmolkg^{-1}$. The mean ECEC was 5.7 $cmolkg^{-1}$ and the mean base saturation was 78.5%.

The iron content of soils in Tarka ranged from 201.61(mg kg^{-1}) – 934.13 ($mgkg^{-1}$) while the mean values for Mn, Ni, V, Co, and Mo were 26.49(mg kg^{-1}), 56.6(mg kg^{-1}), 0.14(mg kg^{-1}), 0.73(mg kg^{-1}), and 1.88 ($mgkg^{-1}$) respectively. All these values were below the permissible limits. The ranking order of concentration was Fe>Ni>Mn>Mo>Co>V.

The correlation results showed that Fe had a positive and significant correlation ($p<0.05$) with V and Co. This means Fe, V, and Co are most likely from the same parent material. Ni and Mo also showed positive correlation with a significant level ($p<0.01$). Since Ni and Mo showed a strong negative correlation with V, Ni and Mo come from a different parent material. A partial positive correlation exists between Fe and Mn. Spearman's correlation showed a similar trend but there was no strong negative or positive correlation between Fe and the other elements.

Chemical composition of soils in Gboko

The soils in Gboko are more acidic than soils in Makurdi and Tarka ranging from 5.1-5.8 with a mean of 5.3. The mean organic carbon percentage was 1.3% which was higher than that of Tarka. The mean percentage of nitrogen was 0.1% while available phosphorus had a mean of 13.73 $mgkg^{-1}$ which was the highest. The exchangeable bases (Ca, Mg, K, and Na) had a mean of 3.9(cmol kg^{-1}), 2.3(cmol kg^{-1}), 0.1(cmol kg^{-1}), and 0.07 ($cmolkg^{-1}$) respectively. Exchangeable acidity was 0.86 $cmolkg^{-1}$. The mean ECEC was 7.3 $cmolkg^{-1}$ and the mean base saturation was 88%.

The iron content of soils in Gboko ranged from 201.06 (mg kg^{-1}) – 726.13 ($mgkg^{-1}$) while the mean value for Mn, Ni, V, Co, and Mo were 20.32(mg kg^{-1}), 45(mg kg^{-1}), 0.12(mg kg^{-1}), 0.58(mg kg^{-1}), and 1 ($mgkg^{-1}$) respectively. All these values were below the permissible limits. The order of concentration ranking was Fe>Ni>Mn>Mo>Co>V.

The correlation results of soil micro-nutrients in Gboko showed that Fe and Mn had a strong positive relationship at a significant level ($p<0.01$). Mn and V had a strong positive relationship at a significant level ($p<0.01$). Mn and Co had a positive relationship ($p<0.05$). Vanadium and Cobalt correlated with a positive significance ($p<0.05$). These elements are most likely from the same parent material. Though Fe showed a partial positive relationship with Ni, Ni and Mo did not correlate with any other element. However, the Spearman's coefficient showed that Ni and Mo had a positive and significant ($p<0.05$) relationship. Fe had a positive significant ($p<0.05$) relationship with Mn and Ni. The relationship between Mn and V was positive and significant ($p<0.01$). At a significant level of 5%, there was a positive relationship between Mn and Co.

Soil properties from other parts of Benue State

Abah *et al.* (2013) analysed soil samples from cassava farms in Otukpo, Ohimini, and Katsina Ala L.G. As within Benue State. According to Abah *et al.* (2013), the results showed that cation exchange capacities of the soils were moderate for Otukpo (7.66 $cmolkg^{-1}$), Ohimini (8.20 $cmolkg^{-1}$), and Katsina Ala (8.15 $cmolkg^{-1}$). The organic matter content was high (2.10%, 2.60%, and 3.48% respectively), and comparable to some sites in Tarka and Gboko. The soils pH results (6.0, 6.3, and 6.2 respectively) were comparable to sample results from Makurdi and Tarka but less acidic than samples results from Gboko. Soils from Otukpo had loamy texture, and soils from Ohimini had sandy-silt-clay textures. The soils from Katsina Ala were clay loam. These properties demonstrate good potential for retaining nutrients elements and trace metals within the top soil layer.

Another study conducted in Bassa, Kogi State (Akpan-Idiok *et al.,* 2013) within the flood plain of the Lower River Benue Basin showed results relatively similar to the results from Makurdi, Tarka, and Gboko. The study by Akpan-Idiok *et al.* (2013) showed that the texture of the soils were loamy, clayey, and sandy. The soils were

Table 3. Summary of soil nutrient parameters for Makurdi, Tarka, and Gboko

Location	pH		C (%)		P ($mgkg^{-1}$)		K ($cmolkg^{-1}$)		ESP	SAR
	Range	M	Range	M	Range	M	Range	M		
Makurdi	5.5-6.5	5.9	0.44-0.64	0.52	0.50-42.37	5.01	0.06-0.15	0.09	0.78-1.34	0.05-0.12
Tarka	5.3-6.1	5.7	0.54-2.05	1.13	0.87-20.75	4.56	0.05-0.09	0.07	0.91-2.52	0.04-0.09
Gboko	5.1-58	5.3	0.68-2.13	1.27	1.08-32.50	13.73	0.06-0.14	0.1	0.70-1.45	0.04-0.09

M=mean

acidic (pH, 5.5-6.5) and contained high organic carbon in some sites (0.1-14.3%). The phosphorus levels ranged from 0-8 $mgkg^{-1}$. The exchangeable bases had moderate to high values with calcium and magnesium having the highest values. This was observed in other sites sampled in this study. The ECEC (6.54-22.20 $cmolkg^{-1}$) and base saturation (90-99%) also had high values which support good conditions for crop cultivation.

Odoh *et al.* (2014) presented the properties of soils around Benue cement company Gboko, Benue state. According to Odoh *et al.* (2014), the soil results revealed the textural attributes of the soils. The sand fraction ranged from 70.70-74.70%, silt ranged from 10.70-17.70%, and clay ranged from 10.20-16.60%. The chemical properties show that pH had a range of 6.60-7.50. Others were organic carbon (2.86-3.21), ECEC (13.80-19.80), total nitrogen (0.05-0.09%), available phosphorus (43.54-78.00 $mgkg^{-1}$), Ca (4.23-8.25 $cmolkg^{-1}$), Mg (2.25-4.55 $cmolkg^{-1}$), K (0.18-0.37 $cmolkg^{-1}$), Na (0.33-0.67 $cmolkg^{-1}$), exchangeable acidity (0.77-1.55 $cmolkg^{-1}$) and base saturation (78.55-89.75%). Odoh *et al.* (2014) posited that the soil results with higher nutrient availability were capable of supporting crops grown in the area, such as yam, maize, cassava and groundnut.

Soil nutrient index and classification

The range of soil pH, C, P, K, exchangeable sodium percentage (ESP), and sodium absorption ratio (SAR) for soils in Makurdi, Tarka, and Gboko are presented in Table 3. The soils in Gboko were slightly more acidic than soils in other areas sampled. The soils in Gboko contained more percentage of organic carbon than soils in Tarka and Makurdi. The situation was similar for phosphorus and potassium.

The soil samples nutrient values were rated using the soil nutrient rating chart. The results are presented in Table 4. Most of the soil samples (75%) were categorised as acidic with a soil reaction index of I (pH below 6.0) while 25% percent were categorised as having a soil reaction index of II (pH 6.0-8.0).

Based on the soil rating chart, most of the soils sampled had medium to high percentages of organic carbon. Only 13.9% of the samples had percentages categorised as low. Most of the soils sampled had low amounts of phosphorus (50%) and low amounts of potassium (86.11%). A good percentage (36.11%) of the samples had high content of available phosphorus.

Soils from other parts of the Lower River Benue Basin were assessed using the nutrient rating chart. The results from Otukpo showed the pH values had a soil reaction index of I, and that of Ohimini and Katsina Ala had soil reaction index of II. The pH soil reaction of index for soils in Bassa ranged from I to III, while that of Benue Cement Company area was index II.

The nutrient index for organic carbon was Otukpo (III), Ohimini (III), and Katsina Ala (III). The organic carbon nutrient index for Bassa ranged from I to III, while Benue Cement Company Gboko was (III).

The phosphorus nutrient index for Bassa ranged from I to III, and that of Benue cement company Gboko was III. The potassium nutrient index for Bassa ranged from I to II only, and the results from Benue Cement Company Gboko ranged from I to III.

Following from the soil nutrient values calculated using the nutrient index formula, soils in Benue State were generally classified as HML based on organic carbon, available phosphorus and potassium concentrations. Soils in Makurdi were classified as LLL based on nutrient index values, while soils in Tarka were classified as HLL. Soils in Gboko were classified as HHL. Even though variations may exist as evident from the classifications of Makurdi, Tarka and Gboko, Table 5 shows the soil nutrient values and the general soil nutrient classification for Benue State.

The classification order of soil nutrients was Gboko (HHL)>Tarka (HLL)>Makurdi (LLL). These infer that organic carbon and phosphorus increased a bit with movement away from the River Benue. All the soils assessed have various degrees of fertility and are suitable for cultivation of crops such as yams, cassava, and rice. However, these soils require fertility management practices such as the use of organic fertilisers and inorganic fertilisers to balance the composition of soil nutrients such as organic carbon, phosphorus, potassium, and nitrogen.

Soil irrigation quality

Exchangeable sodium percentage (ESP) is the para-

Table 4. Rating of soil nutrient values using the soil nutrient rating chart

Parameters	**Categories and No. of soil samples**		
Soil pH	Acidic	Neutral	Alkaline
Range	Below 6.0	6.0-8.0	Above 8.0
Soil reaction index	I	II	III
Makurdi	7	5	0
Tarka	8	4	0
Gboko	12	0	0
Total	27	9	0
Percentage	75%	25%	
Organic Carbon (C)	Low	Medium	High
Range (%)	Below 0.5	0.5-0.75	Above 0.75
Nutrient index	I	II	III
Makurdi	5	7	0
Tarka	0	4	8
Gboko	0	0	12
Total	5	11	20
Percentage	13.9%	30.55%	55.55%
Available Phosphorus (P)	Low	Medium	High
Range (mg/kg)	Below 2.2	2.2-5.4	Above 5.4
Nutrient index	I	II	III
Makurdi	8	3	1
Tarka	8	2	2
Gboko	2	0	10
Total	18	5	13
Percentage	50%	13.89%	36.11
Potassium (K)	Low	Medium	High
Range (cmolkg^{-1})	Below 0.1	0.1-0.2	Above 0.2
Nutrient index	I	II	III
Makurdi	10	2	0
Tarka	12	0	0
Gboko	9	3	0
Total	31	5	0
Percentage	86.11%	13.89%	

Table 5. Nutrient index values of soils sampled in Benue State

Parameter	**Nutrient index values**	**Remark**
Organic carbon (C)	2.42	H
Available phosphorus (P)	1.86	M
Potassium (K)	1.13	L
Location	Nutrient index values	Remark
Makurdi (C,P,K)	1.58, 1.42, 1.17	L, L, L
Tarka (C,P,K)	2.7, 1.5, 1.0	H, L, L
Gboko (C,P,K)	3.0, 2.7, 1.25	H, H, L

H = High; M= Medium; L= Low

meter which measures the adsorption and exchange capacity of soil and determines whether soil is saturated with sodium. ESP levels are contributory determinants of soil pH, as high pH levels increase the alkalinity of soil. Therefore it is important to ensure soil has acceptable sodium absorption and exchange limits where irrigation farming is considered. The range of exchangeable sodium percentage for soils in Benue State were 0.78-1.34 (Makurdi), 0.91-2.52 (Tarka), and 0.70-1.45 (Gboko). The exchangeable sodium percentage for soils from Bassa ranged from 0.57 to 0.99 while those from the Benue Cement Company area had ESP of 4.39. Though all these ESP values fall into the excellent category, the ESP for the Benue Cement Company area was the highest. Table 6 shows the ESP classification of soils in Makurdi, Tarka, and Gboko according to empirical

Table 6. ESP levels for soils in the Lower River Benue Basin

Categories	ESP (%)	Makurdi	Tarka	Gboko	Bassa	BCC*
Excellent	<20	0.78-1.34	0.91-2.52	0.70-1.45	0.57-0.99	4.39
Good	20-40					
Permissible	40-60					
Doubtful	60-80					
Unsuitable	>80					

*Benue Cement Company area, Gboko LGA.

Table 7. Sodium absorption ratio of soils in the Lower River Benue Basin

Categories	SAR	Makurdi	Tarka	Gboko	Bassa	BCC*
Excellent	<10	0.05-0.12	0.04-0.09	0.04-0.09	0.03-0.07	0.16
Good	10-18					
Doubtful	18-26					
Unsuitable	>26					

*Benue Cement Company area Gboko.

literature and as used by Prasanth *et al.* (2012). As shown in Table 6, these soils fall under excellent category, which is a good indication of fertile soils and good irrigation quality.

Sodium absorption ratio (SAR) measures the suitability of land for irrigation purposes because sodium concentration can reduce soil permeability and cause soil structure Prasanth *et al.* (2012). The extent to which sodium is absorbed by the soils is important because irrigation water with high values of SAR may become a hazard to crops in soils with already high SAR values. Irrigation waters with high SAR values will affect the levels of calcium and magnesium in the soil. This results in weakening the ability of the soil to maintain stable aggregates and eventually loss of soil structure. Reduced infiltration and permeability of the soil to water limits successful crop production. Table 7 details the SAR status of soils analysed according to Prasanth *et al.* (2012). The SAR range for soils in Makurdi, Tarka, Gboko, Bassa, and the Benue Cement Company area Gboko all fall within the excellent category. These results further attests to the very good quality of these soils for irrigation farming.

DISCUSSION

These findings present the nutrient index of soils in the Lower River Benue Basin. The findings provide useful insight to guide farmers towards soil nutrient enhancement and better productivity. These results attest to the wide applicability of the soil nutrient index method by Verma *et al.* (2005) and Ravikumar and Somashekar (2013).

The textural class of soils were found to be suitable for cultivation of crops including roots and tuber crops. A study by Sumithra *et al.* (2013) has stated that cultivation of tuber crops in flood plains and sloping lands have potential for nutrient loss. The textural class of soils observed are said to possess low potassium reserves and low ion exchange capacity which determine the quantity of ions that soils can retain against leaching (Edem, 2007). An increase in organic matter content of the soils during cultivation usually improves the nutrients retention capacity of such soils.

The chemical properties were below permissible limits and showed no indication of contamination. The micro-nutrients were below permissible limits and some of them have positive significant relationships suggesting common parent material. Parent material is found to have a profound influence on distribution of micro-nutrients (Mustapha and Fagam, 2007) and accounts primarily for the spatial occurrence. According to Noe and Hupp (2007), the distribution mechanism of particulate nutrients in flood plains is a function of flood hydrology during overbank flooding events. Nutrient processing in floodplains are functions of climate, seasonality, geomorphology, and surface-subsurface hydrologic exchange (Noe and Hupp, 2007). These mechanisms account for the order of spatial occurrence of nutrients analysed for the study area using the soil nutrient index.

Evidence of anthropogenic impact on soil nutrients in the study area was not significant probably due to the predominance of traditional farming methods and inconsistent use of fertilizers and herbicides. However, recent studies have shown that ineffective addition of soil enhancement nutrients in developing settings have begun to alter nutrient cycling and affect human health (Brevik and Sauer, 2015). Therefore, it is necessary to monitor the application of inorganic fertilisers in the study area due to the weak availability of nutrients observed. The use of inorganic fertilizers may enhance soil fertility. However, the excessive use of inorganic fertilizers and herbicides has negative implications for soil quality in the long term and this should be discouraged.

In order to increase output while maintaining the soil in good conditions, farmers should consider the cultivation of improved crop varieties, shifting cultivation, and soil treatment with organic fertilizers. Mixed cropping with leguminous crops enhances soil conditions when roots and tuber crops are cultivated.

There are studies that show that farmers especially in sub-Saharan Africa practise intensive farming on small farms with low use of external inputs (Funes-Monzote, 2008), these methods cannot be transferred to vast commercial scales due to costs associated with transportation, labour, and soils depleted of nutrients. Soils with inadequate nutrients such as the results provided in this paper have given rise to the intensive use of external inputs in intensive farming (Vanlauwe *et al.,* 2010).According to Vanlauwe *et al.* (2010), the promotion of effective farm management practises should be done through farmer education and capacity building on integrated soil fertility management through intense interaction between farmers and extension services.

The values for sodium provided imply that the soils in the study area have good potential for irrigation farming with the use of stream and groundwater during the dry season. This can enhance productivity and improve the quality of the soils. Groundwater with high sodium content should not be used as this can displace calcium and magnesium in soils and adversely affect soil texture. The findings of this study can further be used for soil classification mapping. The study therefore makes the following recommendations to farmers in the study area and farmers in similar settings:

- Continuous intensive farming should be discouraged and farmers should allow fallow periods or practise land rotation.
- Inorganic fertilisers should be utilised effectively to prevent increase in soil acidity and the aluminium content in soil.
- Organic manure and composting should be applied on farm lands during cultivation and pre-farming seasons to enhance the properties of soil.
- The practice of bush burning as a form of farm preparation which is prevalent in the study area should be firmly discouraged.
- Farmers should join cooperative societies to leverage on pooled knowledge and resources which enhance opportunities in labour saving practices such as use of farm machinery for cultivation, weeding and harvesting.
- Organic carbon in soil can be preserved through zero tillage practices.
- Farmers in the study area should engage in the cultivation of crops that tolerate moderately acidic soils, and explore the option of irrigation farming to optimise income.

CONCLUSION

The study has evaluated nutrient index of organic carbon, available phosphorus, and available potassium as a measure of soil fertility in the Lower River Benue Basin. The study has revealed significant nutrient gaps through classification of soil nutrients through procedures that are beneficial to agricultural and soil researchers globally. The study has demonstrated significantly that organic carbon, available phosphorus, available potassium, nitrogen, and soil pH can be used to measure fertility of soils for agricultural purposes. The study therefore recommends that farmers in the study area and beyond embrace appropriate farm practises. The study also recommends that agricultural extension workers should efficiently focus on educating farmers on appropriate nutrient enhancement practises for cultivation, and the importance of irrigation farming. These recommendations would gradually introduce farmers to soil conservation.

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