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Assessment of Some Soil Fertility Characteristics of Abakaliki Urban Flood Plains of South-East Nigeria, for Sustainable Crop Production

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Abstract: There is lack of adequate information on the fertility situations of the soils of Abakaliki urban flood plains. Farming activities have therefore been carried out on the surrounding uplands only. This study was therefore conducted in 2009 raining seasons, to evaluate the fertility status of the flood plains and compare it with the fertility of the uplands with a view to making recommendations for sustainable agricultural production. Soil samples were obtained from the Iyiudene floodplain, Iyiokwu floodplain, Ebonyi river basin and the surrounding upland and subjected to physical and chemical analysis. The soil texture ranged from loam in the upland areas to clay loam in the flood plains and the river basin. Soil bulk density of the upland soils was significantly higher than the flood plains. The bulk density of the flood plains was respectively suitable for crop production. The soil water holding capacity of the upland was rather too low, whereas the floodplains had adequate water holding capacity for crop production purposes. The soil organic matter was generally low for both the upland and the flood plains. However, the floodplains and the river basin soils contained significantly ($p<0.05$) higher organic matter than the upland. The upland soil was very acidic whereas the soils of the floodplains were acidic. The soils available phosphorus was low, however the floodplains had significantly ($p<0.05$) higher soil available P than the upland. Total N, soil pH and exchangeable acidity were significantly ($p<0.05$) higher in the upland soils than in the soils of the floodplains. Whereas the floodplains had significantly ($p<0.05$) higher exchangeable Ca, Mg, Na, CEC and base saturation when compared with upland soils. The overall soil fertility status of the floodplains was therefore superior to the upland soils.

Key words: Soil Characteristics · Soil Fertility · Southeastern Nigeria · Sustainable Crop Production and Urban Floodplains

INTRODUCTION

In most derived savannah like in Abakaliki, streams channels do not accommodate stream flow at certain periods of the raining season. Most of the year, the water levels may be well below the stream bank height, but at certain periods heavy rains can deliver more water than the stream can carry. Such excess water that overflow stream banks and covers adjacent land is considered as flood [1]. The changes in land use associated with urban development affect flooding in the study area in many ways – removing vegetation and soil, grading the land surface, constructing road networks and building of houses increase runoff to stream from rainfall. As a result, the peak discharge, volume and frequency of floods increase in nearby steams; changes to stream channels during urban development can limit the capacity of these streams to convey flood waters [2]. Intensity of rainfall in short period in the study area during raining seasons also leads to extremely high runoffs, reduced infiltration and eventual flood resulting from the impervious layer, high bulk density and crusting [3]. Many human activities increase the severity and frequency of the floods including dumping of domestic wastes into the streams which leads to channel suffocation by these wastes resulting into channel interference.

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Under normal condition, floods are mitigated by flood plains lowland that is periodically inundated during normal flood [1]. These floodplains are usually very fertile, flat and easily farmed. In most of the developed world, floodplains are widely farmed and cleared of vegetation. Farmers go to flooded areas for their activities because flooded areas are usually very fertile for farming; there is availability of water and nutrient for crop growth in these areas. Flooded areas support variety of ecosystem; different species of crop grow in flooded areas (floodplains). However, reports on the effect of flooding on soil properties of the Abakaliki flood plains are rather few, necessitating this study; to evaluate the effect of flooding on the soil properties, compare the nutrient content of the flooded plains with that of adjacent arable land with the intention of ascertaining whether the floodplains could be put to agricultural uses.

MATERIALS AND METHODS

Study Area: The study area is Abakaliki municipality which lies within latitude 16 04'N and longitude 18 65'E, south east of Nigeria. It has a bimodal rainfall pattern from April to November. The total amount of rainfall recorded within this period range from 1,900-2,600 mm annually while the maximum mean daily temperature hovers around 27-31°C through the year [4]. The mean relative humidity is 65-80% [5]. The soil classification is Ultisol, which is hydromorphic, of shale parent material with underlying impervious layer at about 40 cm depth. It is characterized by rampant flooding and water logging which is a precipitate of poor drainage resulting from the impervious layer, high soil bulk density and crusting [3] and recently by poor urban settlement and human activities. The flooding is experienced about the peaks of the rainy season (July and September) and covers the basins and floodplains around the middle and lower courses of the river and the streams.

Collection of Soil Samples: A reconnaissance survey was carried out on the studied area, traversed by two streams called lyiudene and Iyiokwu. The streams flow through an undulating course with the main sources at Mgbabor and Nkaliki respectively, with other tributaries and terminating at where they converge and empty into Ebonyi River. Random method was used to collect soil samples from the study area. Ten auger samples were collected from each sampling area at 0-20 cm depth at the middle and lower courses of the streams at both east and west sides of the banks. Core samples were also collected respectively from the same areas, for determination of bulk density and total porosity, while six other auger samples were collected at 0-10 cm depth from the respective sampling areas for determination of soil moisture holding capacity. The auger samples were stored in labeled polythene bags. They were dried under shade for three days, crushed, sieved with a 2 mm sieve and taken to the laboratory for the determination of particle size distribution and chemical properties.

Laboratory Methods: Particle size distribution using hydrometer method according to Gee and Bauder [6], available water at field capacity by the method mentioned by Klute [7] and bulk density by Blake and Hartge [8] were determined. Total porosity was calculated from the bulk density values assuming a particle density of 1.65 g cm^{-3}. Soil pH was determined using glass electrode pH meter in water using 1:2:5 soil water ratios. Total nitrogen was determined using macro –Kjeldahl methods [9]. Available phosphorus was determined using Bray 11 methods as described by Page *et al*. [10]. Organic carbon was measured by the Walkey – Black procedure [11]. Exchangeable bases (K, Ca, Mg and Na) and exchangeable acidity (H^+ and AL^+) were determined by Tel and Rao [12]. Cation exchange capacity was determined by the summation of exchangeable bases (K, CA, Mg and Na) and exchangeable acidity (H+ and AL^{3+}) by IITA [13].

Data Analysis: Data obtained were analyzed using one tailed analysis of variance (ANOVA) as described in SAS [14].

RESULT

Physical Properties of the Investigated Soil Samples

Soil Texture: Table 1 shows the soil texture as indicated by particle size distribution of the investigated soil samples. The upland had higher values of sand fraction than the flooded areas, whereas the floodplains had higher values of silt and clay fractions compared to the arable land. The textural class of the soils ranged from clay loam for both flood plains and the river basin to loam for the upland.

Table 1: Particle size distribution of the investigated soil samples

Soil Samples	% Sand	% Silt	% Clay	Textural class
Iyiudene floodplain	36.4	36.8	26.8	Clay loam
Iyiokwu floodplain	32.4	36.8	30.8	Clay loam
Ebonyi River basin	32.4	34.8	32.8	Clay loam
Upland	44.4	34.8	20.8	Loam

Table 2: Some other soil physical properties of the investigated soil samples

Soil Samples	Bulk Density (kg)	Percentage Moisture Retention	Porosity (%)
Iyiudene floodplain	1.20	22.48	54.5
Iyiokwu floodplain	1.30	19.34	51.1
Ebonyi river basin	1.24	24.78	53.3
Upland	1.61	9.88	39.2
FLSD $_{(0.05)}$	0.13	2.89	3.92

Table 3: Some soil chemical properties of the investigated soil samples

	O.M.	pH	Nitrogen	Available-P	K	Ca	Mg	Na	CEC	Exch. Acidity	Base Saturation
Soil Samples	(%)	(H_2O)	(%)	(ppm)	---------------------------------------(Cmol/Kg)----------------------------------						(%)
Iyiudene floodplain	2.93	6.15	0.13	28.2	0.15	11.20	5.20	0.09	18.72	2.08	88.89
Iyiokwu floodplain	3.11	5.39	0.12	29.2	0.13	10.40	5.60	0.09	18.18	1.96	89.22
Ebonyi river basin	2.65	5.95	0.13	34.8	0.13	12.00	5.20	0.13	19.67	2.16	88.76
Upland	2.06	4.38	0.15	18.5	0.17	8.40	3.60	0.04	15.09	2.88	80.91
FLSD $_{(0.05)}$	0.14	10	0.02	4.4	0.03	0.17	0.11	0.02	0.53	0.63	1.40

Other Soil Physical Properties: Some other physical properties of the investigated soil samples are presented in Table 2. The bulk density values for the floodplains and the river basin were significantly lower than that of the upland, whereas the soil densities of the floodplains were statistically comparable with the river basin soil. The soil total porosity of the Iyiokwu and Iyiudene flood plains and the Ebonyi river basin were correspondingly higher than the soil total porosity of the upland, owing to the lower soil density of the areas. It was also observed that the soil water retention capacity was higher with the floodplains and the Ebonyi river basin than the upland. The soils of the Iyiudene flood plain and Ebonyi river basin areas also had higher moisture retention capacity than the Iyiokwu floodplain.

Chemical Properties of the Investigated Soil Samples

Soil pH, Organic Matter, N and P: The result in Table 3 shows that the floodplains and the river basin had higher pH values than the upland. The pH values of the Iyiudene floodplain and the Ebonyi river basin were also significantly ($p<0.05$) higher than the pH values of the Iyiokwu floodplain and the upland. Soil pH was also significantly ($p<0.05$) higher with the Iyiudene floodplain than the Ebonyi river basin, whereas the pH of the upland and the Iyiokwu floodplain were comparable. The floodplains and the river basin soils had significantly ($p<0.05$) organic matter levels than the upland, whereas the Ebonyi river basin had significantly ($p<0.05$) higher organic matter levels compared to the organic matter levels of the Iyiudene and Iyiokwu floodplains. The upland soils had significant ($p<0.05$) higher N values than the floodplains and the river basin. The result also indicated that the floodplains and the river basin had significantly ($p<0.05$) higher values of available phosphorus than the upland.

Exchangeable Bases: The floodplains and the river basin had significantly ($p<0.05$) higher soil exchangeable Ca, Mg and Na contents compared to the upland, whereas significantly ($p<0.05$) higher levels of exchangeable K was detected on the upland than the Iyiudene floodplain, Iyiokwu floodplain and the Ebonyi river basin. The soil of the Iyiokwu floodplain also had significantly ($p<0.05$) higher Mg content than the Iyiudene floodplain and the soil of the Ebonyi river basin, whereas the Ebonyi river basin contained significantly ($p<0.05$) higher exchangeable Na than the Iyiudene and Iyiokwu floodplains.

Exchangeable Acidity, Cation Exchange Capacity and Base Saturation: The upland had significantly ($p<0.05$) higher exchangeable acidity values compared to the floodplains, whereas soil cation exchange capacity was significantly ($p<0.05$) higher in the soils of the Iyiudene, Iyiokwu floodplains and Ebonyi river basin than the upland. The soils of the Ebonyi river basin also had significantly higher CEC than the Iyiudene and Iyiokwu floodplains. Base saturation was significantly ($p<0.05$) higher in the floodplains and river basins than the upland, whereas the floodplains and the river basin had comparable levels of base saturation.

DISCUSSION

Physical Properties of the Investigated Soil Samples

Soil Texture: The upland had higher percentage of sand fraction. Ordinarily, soil textural composition rarely changes, but in this case it was believed that the different land uses; the arable cultivated upland and flooded fallow lowland over a long time could have let to the transportation of dislodged lighter soil particles (silt and clay) to the lower plains where they accumulated on the topsoil influencing the texture of the top soil layer. Aniekwe *et al*. [4] had observed changes in soil properties owing to changing land uses in Abakaliki area.

Other Soil Physical Properties: The higher soil bulk density of the upland was anticipated. The soil of the study area had been noted by many researchers to have high bulk density and to suffer from compaction problems [3, 15, 16]. This situation was however ameliorated by the flooding on the flood plains and the river basin. The runoff from the upland and flooding from the river and streams deposited layers of alluvial materials on the floodplains and the river basin which had not yet consolidated unlike the soils of the upland. Also, the decayed organic residue of the vegetation of the floodplains and the basin areas produced higher levels of organic matter which reduced the soil density. The organic matter acting as the soil binding materials created higher soil porosity and reduced soil density. The low level of moisture retention in the upland was rather very severe and could constitute a serious impediment to crop production. The soil cultivation practices normally distort the continuity of pores leading to increased water runoff and reduced water infiltration. It was believed that the improved soil water retention of the flooded lands was an attribute of reduced density, improved porosity and higher organic matter content and reduced water runoff compared to the cultivated upland. These properties reflect improved soil structure for the floodplains and the river basin.

Chemical Properties of the Investigated Soil Samples: Soil pH, organic matter, N and P: The higher levels of organic matter detected on the flood plains and river basin soils were attributable to the accumulation of residues of the fallow vegetation over a long term and the deposits brought by the flood water. The clearing and cultivation of the upland led to organic residue decomposition and loss of organic materials to seasonal water runoff and erosion. The soil of the study area is however noted to have low organic matter levels [3, 17] which drastically affected the organic matter status of the soils generally.

The various soil areas are rather acidic. Several researchers had earlier reported that the soils of the area are acidic and of low fertility [16-18]. The low organic matter levels of the soil were assumed to have contributed in part to the low soil pH. The higher pH values of the floodplains were attributed to the higher Ca and Mg levels. These elements naturally displaced H^+ ion from the exchange complex into the soil solution, where they are leached. This situation is even more intensive under strongly acidic soil conditions as obtains in the study area. Synder [19] equally reports that after a soil is flooded regardless of its original pH before flooding, the pH will approach neutrality (pH 6.5-7.5).

The lower N values of the floodplains could be as a result of losses of N through various sources. Nitrogen being a very mobile element is prone to be loosed easily through leaching and percolation under flooded situation and volatilization once the flood water recedes. This could account for a reasonable depletion of the element in the floodplains, which could adversely affect crop production. Nelson and Terry [20] observed drastic loss of soil nitrogen after flooding. The low total N of the floodplains also conforms to the observations of Valiela and Teal [21] that estuarine wetlands tend to have N limitations.

The significantly higher soil available P on the flooded soils was understandable. This is because the easiest way to increase soil P is to improve soil moisture content. Nathan [22] also observed that flooding generally increases the availability of P to crops. The higher pH of the flood plain and the river basin soils could also have encouraged the solubilization of organic P which might have led to the release of inorganic P bound in soil minerals. The decay and mineralization of the vegetation residues could have in turn led to the release of organic P in residues in the floodplain areas. Ukpong [23] reported high available P levels in the Creek / Calabar River swamps. The general low level of available P indicates that P may be chemically bound as phosphates of Fe and Al owing to the observed high acidity of the soils of the study area. This observation is in agreement with the findings of Ibia and Udo [24] and Effiong *et al*. [25].

Soil Exchangeable Bases: Significantly higher soil Ca, Mg and Na level were observed in the flooded soils than the unflooded upland. Some of these elements could have been eroded from the upland during runoff and deposited on the floodplains by the flood water. On the other hand nutrient mining by crops could have contributed to the reduction of these elements in the upland. The release of the organic forms of Ca and Mg from the organic matter increased their levels in the flooded soils which had higher organic matter deposits. Also, the higher soil moisture of the flooded soils could have assisted the release of the inorganic Ca and Mg from the soil minerals. The levels of soil K content varied among the floodplains. The inconsistency of the soil K content among the study areas could be as a result of the variation in soil minerals and constituents amongst the different sites of the study area. The higher exchangeable K found in the upland than the floodplain soils could be attributed to small content in the organic matter and the flood water supply. There could also have been losses of K through leaching and percolation in the floodplains. Higher rates of K losses have been reported to occur in Wetlands according to IFPRI [26], whereas Ambeager [27] reported losses of K through erosion and leaching. The soil Na content was higher on the flooded areas than the Na content of the upland. Naturally flood water carries along salts which are deposited on the soil as the flood water recedes and as evaporation takes place leaving salt crusts and crystals. This situation was adduced for the higher Na content of the flood plains and the river basin areas.

Exchangeable Acidity, Soil Cation Exchange Capacity and Base Saturation: Exchangeable acidity was significantly ($p<0.05$) higher in the upland than the floodplains and river basin. Amberger [27] pointed out that flooding affects the exchangeable acidity of soils. The levels of exchangeable acidity of the study soils were such that could cause serious problems to crop production. The variability in soil cation exchange capacity was in response to variation in vegetation residue type and soil organic matter levels. Organic matter is the store of essential elements, hence the higher the soil organic matter levels, the higher the soil CEC and buffer capacity. The transportation of elements, in the flood water and runoff from the streams and arable land increased the element contents of the river flood plains and the basin thus increasing their CEC. Percent base saturation was high in both upland and the floodplains. Base situation was above 50% in all the cases which forms the separating index between fertile soils and less fertile soils [28]. This was surprising considering the low CEC of the soils in the study area.

Fertility Inference: Some important soil chemical characteristics that influence the rating of soils suitability for crop production include pH, organic matter, total N, available P and exchangeable bases [18, 28, 29] and physical properties including texture, structure, temperature, bulk density, porosity, moisture and drainage [30, 31]. The soils have particularly low organic matter content. However, the observed higher organic matter values of the flood plains reflect higher productivity and reduced decomposition and mineralization rates in wetland environments. Kyuma [32] and Patrick [33] reported that such situations result in accumulation of organic matter.

Based on the result of the soil chemical analysis, it is apparent that the soils are generally acidic, low in organic matter, total N, available P and cation exchange. According to the ratings capacity of Landon [28] and Enwezor *et al*. [18], the soils are low in fertility and cannot sustain optimum crop production.

For improved crop yields on short term, mineral fertilizers could be recommended as a stop-gap to promote higher crop yields. However, for a long-term sustainable crop production, soil fertility restoration measures affordable to farmers should be adopted. Among these measures are the uses of organic manure and burnt rice husk which is abundant in the area to improve the soils physical and chemical constraints. Alternatively green maturing practices (e.g. groundnut and other non-food legumes) should be introduced as a very economic measure for soil fertility improvement and regeneration. This measure according to Yadav *et al*. [34] increases crop yields by 20-30%, improves soil chemical N and P by 25%, restores natural fertility and stimulates plant growth.

CONCLUSION

The result of this study confirms that the soils of the studied area (Abakaliki) the study area has low fertility and suffers major productivity constraints. The inhabitants engage the upland soils in crop production; predominantly root crops and grain crops, while the flood plains had been abandoned over the years as unsuitable for agricultural purposes. There has been recent rapid urbanization of the area, which has led to the flood plains being chocked with houses aggravating the flooding problem. This study has revealed that the flood plains are even of higher fertility than the uplands and could be put to superior crop production activities. However in order to ensure optimum crop production, there is to need to alleviate the inherent fertility constraints of the soils. The use of organic residues such as burnt rice husk which is abundant in the study area to solve the soils physical and chemical constraints is recommended, to improve the fertility and crop yields. The inhabitants should use these measures to produce rice crops in the flood plains during the raining seasons and subsistence vegetable production using minor irrigation practices during the dry seasons.

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