A Case of Fertility Status Evaluation and Classification of Floodplain Soils at Onumirikwa River, Ulakwo, Imo State Southeastern Nigeria

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Abstract*- One major challenge of intensive crop production practice in riverine arears is low crop yield due to chemically infertile soils, attributed to poor soil fertility management. This study provides information on fertility status and morphology of floodplain soils using Onumirikwa Ulakwo River, Owerri, Nigeria. In three geomorphic units: (i) crest (ii) terrace and (iii) back-swamp soil was sampled from horizons of three profile pits and analyzed for physico-chemical and morphological properties. Systemic soil categorization was carried out according to USDA classification system. Results showed that Onummirikwa Ulakwo floodplain soil is characterized with sandy loam soil < 1.5 km from the water body. Soil pH, organic carbon content, available phosphorus, and cation exchange capacity were relatively low. Apart from the soil organic carbon content most of the evaluated chemical properties marginally varied in all geomorphic units. Soil aluminum content was relatively high in the back-swamp. These characteristics indicate the soil of this site is chemically infertile for crop production. Soil morphological features show that the floodplain has argillic and kandic horizons within profiles. It is freely drained with no sombric horizons and possesses progressively decreasing SOC content with depth; a clear indication of Kandiudults sub-group of soil. Based on reference soil group of the World Reference Base, the soil of this floodplain is Acrisols. Organic fertilization programmes to local farmers, who use this floodplain for crop production are recommended.

***keywords*: acidic soils, swampy soils, vegetable production site, riverine farming.**

I. INTRODUCTION

In quest for economic adaptations some southeastern Nigerian smallholder farmers depend largely on riverine vegetable production for a living [1]. Dry season vegetable production is their major target [2]; rivers and lakes serve as irrigation source for vegetable crop production [3]. Farmlands located less than 1.5 km away from the water bodies are used for all season crop production. To maximize profit intensive crop production is often carried out i.e., crops are produced on- and off-season [4]. But intensive crop production relatively depletes soil nutrients [5, 6]; and this can exacerbate after crop harvest [7, 8] in particular if the lost nutrients are not replaced through a proper fertility management programme.

Under intensive production systems soil fertility management is crucial [9]; crop yield depends on nutrient uptake, and in turn, soil fertility status [10]. However, the southeastern riverine local farmers barely practise proper soil fertility management. As a result, the soils of southeastern Nigeria are generally low in chemical fertility; they are characterized as soils of low micro- and macro-nutrient content [11, 12], often attributed to improper land use [13]. The local farmers barely replenish nutrients after harvest most likely associated with "*limited income*" [14] to acquire commercial fertilizers. Replenishing lost nutrients after crop harvest as observed in the case of water leaf [15] is crucial for higher yield in vegetable production. Instead, one of the riverine local farmers' options is to change the vegetable production location (within same site) depending on the nearness to water bodies (as sources of irrigation) from the farm-bed. In addition, different topographies – as characterized by Onumirikwa River, Ulakwo affects soil nutrient and in turn crop yield [16, 17]. This is coupled with the fact that soil fertility varies from several centimeters to a few kilometers in the southeastern region [18]. Deductively, all these factors reduce the soil nutrient level as well as vary the morphology of Onumirikwa River, Ulakwo floodplain. Till date, no documented scientific study has particularly hinted on the soil nutrient level as well as classification of this floodplain; this information is vital for fertilization recommendation programme.

The objective of this study is to evaluate the (i) physico-chemical properties of soil as fertility determinants and (ii) soil morphological features of riverine areas using the floodplain at Onumirikwa River, Ulakwo, Imo State, southeastern Nigeria as a selected case. Therefore, we hypothesize the (i) physico-chemical properties and (ii) morphological features of riverine soils vary. In order to test these hypotheses, three topographic units referred to as the different geomorphic units, mainly (i) crest (ii) terrace and (iii) back-swamp were identified based on their respective levels above the river and were selected as the sampling profiles using transect method. Soil was sampled per horizon from the profiles of the three geomorphic units. Through extensive laboratory analyses the physical and chemical properties of the sampled soils were determined. The morphologies of each soil profile are evaluated and reported in this study.

2. Materials and Method

The selected study site was a floodplain at Onummiriukwa river, Ulakwo, Imo State of Nigeria. According to [19], the study site is a small tropical riverine wetland. It is located on about 70 m above sea level. Its main geological material is coastal plain sand of Benin formation. The climatic condition of this area lies in the humid tropics with high relative humidity (> 60 %), atmospheric temperature (28 – 31 ℃) and rainfall (2500 – 3000 mm). The vegetation of the study site consists of secondary forests-savannah mosaic, mainly influenced by anthropogenic activities. The excessive activities of the local farmers have reduced the density of the forests. Therefore, all year-round vegetable crop production is the major trending agricultural practice on this floodplain.

Three sites were selected for this study based on geomorphic features as well as terrain towards the river (i) crest (ii) terrace and (iii) back-swamp. Crest was close to upland, back-swamp was closer to the river whereas terrace is between crest and back-swamp. The distance between the river and back-swamp was 500 m. A free survey method by transect approach was used, and traverse was cut across, running from the crest passing through terrace and to the back-swamp; thus, maintaining same distance i.e., 500 m amongst physiographic positions using a Handheld Global Positioning System (GPS) Receiver (Garmin Ltd, Kansas USA). Soil profile pits were dug in three geomorphic units. Soil samples per profile were collected based on horizon differentiation and soil matrix. The soil samples were air-dried, except the ones used for bulk density as well as moisture content determination. The air-dried samples were sieved through 2 mm mesh to remove undesired materials. With slight modifications, the physical and chemical properties of these soil samples were determined in the laboratory following the methods of [20].

Soil particle size distribution was determined using the Bouyoucos hydrometer method. Soil $pH_{0.1N\ KCl}$ test was conducted with a pH-meter in a glass electrode. Soil organic carbon (SOC) was determined by wet digestion method. The organic matter (OM) content was estimated by multiplying the values of SOC by a factor of 1.724 i.e., OM $OM = SOC\ x\ 1.724$. Total nitrogen was determined by kjeldahl digestion method. The available phosphorus (P) content was determined using Bray 1 method. Exchangeable acidity was determined by leaching the soil with 1 N KCl and titrating with 0.05 N NaOH. Exchangeable bases (EBs) were extracted with 1 N NH4OAc solution and exchangeable calcium (Ca) and magnesium (mg) determined using Ethylenediaminetetraacetic acid 0.01 N complexometric titration. Exchangeable potassium (K) and sodium (Na) were estimated by flame photometer. Cation exchange capacity (CEC) was determined by ammonium acetate 1.0 M leaching at 7.0 pH. The effective cation exchange capacity (ECEC) was calculated by summing the Ca, Mg, K, Na, Al, and H contents. Percentage base saturation (% BS) was determined as the percentage content of BS in the ECEC. The exchangeable Na percentage (ESP) was estimated as the percentage Na content of the CEC.

The soil was classified on the basis of their morphology and chemical properties into the Reference Soil Group of the World Reference Base - WRB for soil resources [21] and USDA soil taxonomy [22]. All the data obtained from the physico-chemical analyses were subjected to simple statistics.

3. RESULTS AND DISCUSSION

A. *Soil Chemical Properties*

Soil pH was slightly acidic; this varied between 5.4 and 5.9 in the order: back-swamp > terrace > crest (Tab. 1). The closer a geomorphic unit is to the river body, the lower the soil pH. This is most likely attributed to excessive tilting and cultivation of soil, as often observed in our study site, which results to low soil chemical fertility. In a simulation study, low soil pH was strongly associated with nutrient loss [23].

TABLE I. Geomorphic variation of pH, calcium, and aluminum in soils sample at Onummirikwa Ulakwo site, southeastern Nigeria. Crest = uppermost part, terrace = sloppy part and swamp = water-drenched part; all parts are fit for plant cultivation.

Chemical properties	**Crest (n = 4)**	**Terrace (n = 6)**	**Back-swamp (n = 5)**	**Mean (n = 15)**
$pH_{0.1N\ KCl}$	5.43 (± 0.05)	5.45 (± 0.04)	5.58 (± 0.20)	5.50 (± 0.14)
Calcium (mg kg^{-1})	0.63 (± 0.17)	1.27 (± 0.30)	1.36 (± 0.83)	1.13 (± 0.58)
Aluminum (mg kg^{-1})	0.30 (± 0.10)	0.43 (± 0.11)	0.40 (± 0.13)	0.38 (± 0.12)

Therefore, the relatively lower pH of the back-swamp site is most likely attributed to poor soil fertility due to intensive cultivation of the soil for crop production. Another suspected reason could be linked to soil nutrient leaching. There was a contradicting observation in soil Ca content. Calcium values were > two folds higher in back-swamp and terrace compared to crest. The reason for this high value is not known; but it is worth noting that the mean calcium content – 1.13 mg kg-1 for the three geomorphic units is relatively low.

Aluminum (Al) content of the soil varied between 0.2 – 0.6 mg kg-[1] within all the sampled profile horizons in the three geomorphic units (Tab. 1). This amount is high enough to retard crop growth in general. One negative effect of Al-toxicity is increased soil acidity, which in turn reduces soil nutrient status [24]. This is a clear indication that the vegetable crops (or other crops) grown at this site will likely exhibit general nutrient deficiencies, and in turn low crop yield.

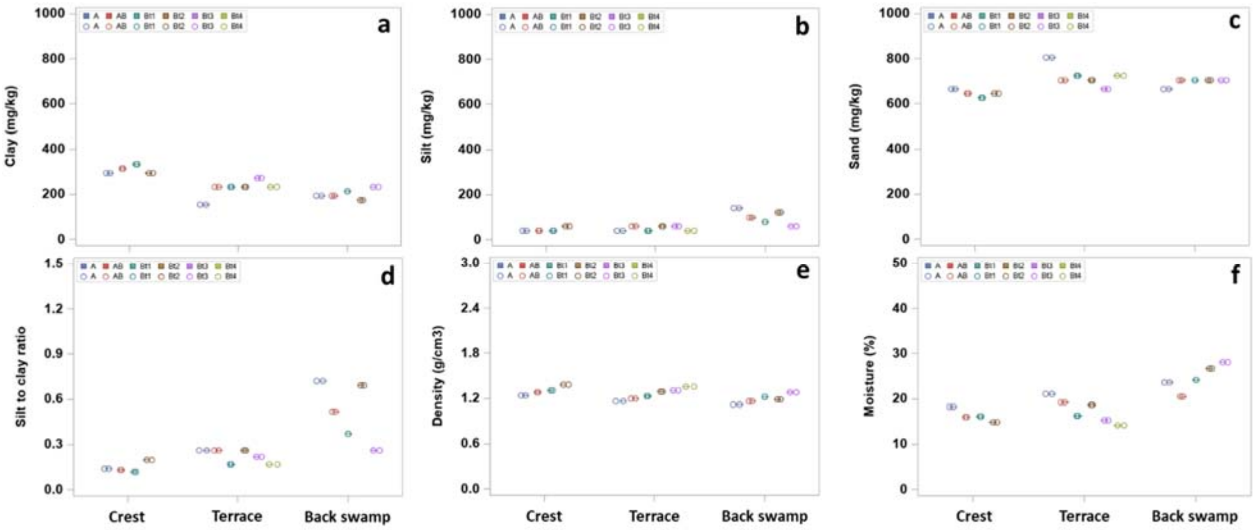

Figure 1. Geomorphic variation of (a) clay (b) silt (c) sand (d) silt to clay ratio (e) density, and (f) moisture content of soil at different profile horizons of a selected site at Onummirikwa Ulakwo, southeastern Nigeria. Data points represent measurement values whereas different colors represent different profile horizons as specified in the key legend. Crest, terrace, and back-swamp represent the uppermost, sloppy, and water-drenched parts of the site, respectively.

To mitigate potential low yield effect on crops, the application of organic manure [25] is essential. Local farmers of this region can afford organic manure [26] compared to commercial fertilizer application.

B. Soil Physical Properties

Clay, silt, and sand content varied moderately between profile horizons per geomorphic unit in the order: sand > clay > silt (Fig. 1a, b and c). Crest, terrace, and back-swamp showed clay contents of 309, 227 and 202 mg kg^{-1}, respectively (Fig. 1a). Compared to crest and terrace silt content, back-swamp showed about two folds greater silt content. However, silt content was generally low in all the three geomorphic units, with an observed mean value of 65 mg kg^{-1} (Fig. 1b). In consequence, this triggered a huge variation in the silt to clay ratio analysis among the three geomorphic units (data not shown).

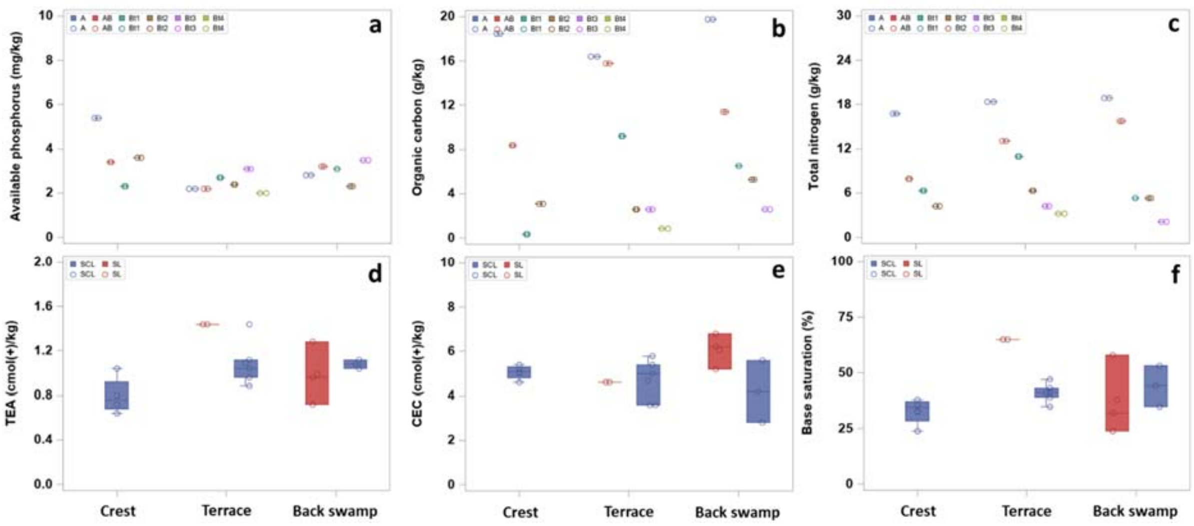

Figure 2. Geomorphic variation of (a) available phosphorus (b) organic carbon (c) total nitrogen (d) total exchangeable acid (e) cation exchange capacity, and (f) base saturation of soil at different profile horizons (a, b, and c) and in different textural classes (d, e, and f) of a selected site at Onummirikwa Ulakwo, southeastern Nigeria. Data points represent measurement values whereas different colors represent different profile horizons as specified in the key legend. Crest, terrace, and back-swamp represent the uppermost, sloppy, and water-drenched parts of the site, respectively

Despite these differences, these values were not influenced by the profile horizons. E.g., in terrace and back-swamp, silt to clay ratio was always higher in A horizon, whereas it was higher in Bt2 for crest (Fig. 1d). On the contrary, AB horizon recorded the least values for crest (0.15) and terrace (0.22). This marginal difference indicates uniformity in the soil profiles of the three geomorphic units. An interpretation to this is probably due to the similarity in the origin of their parent material as reported by [19] as well as the post depositional weathering effect in this site.

In all the three geomorphic units, sand content was > 60 % in the sampled soils of this floodplain (Fig. 1c). This is an indication of well-drained, low aggregate stability and relatively low chemically infertile soils. Soil density was similar in all the three geomorphic units and profile horizons with an average value of 1.2 g cm^{-3} (Fig. 1e). The suspected reason for this might be the similarity in sand content.

The soil moisture content was 16, 17 and 25 % in crest, terrace, and back-swamp, respectively (Fig. 1f). As expected, the back-swamp is located closer to the river and has higher silt and moisture content due to its small pore sizes, and prospects for relatively high capillarity. The available P was 3.7, 2.4 and 3.0 mg kg^{-1} for crest, terrace, and back-swamp (Fig. 2a), respectively. It is obvious that these values are extremely low to enhance crop yield.

Neither soil profile horizons (Fig. 2a) nor geomorphic location influenced the soil P. On the contrary, soil organic carbon content was hugely influenced by soil profile horizons in particular (Fig. 2b). A and AB horizons contained more OM than the rest. Geomorphic location has only a slight effect on the OM content. In general, the average value of SOC was 8.2 g kg^{-1}. Considering the textural class of our soil – sandy loam, the SOC was relatively low.

A similar trend of SOC was observed in total nitrogen content. The average value of 9.3 g kg^{-1} was observed with slight variation in different geomorphic units (Fig. 2c). P, SOC and N appear to be the most important factor for soil fertility. SOC determines physical and chemical properties of the soil, moisture holding capacity, infiltration, and the activities of micro-organisms [27]. The yield of vegetable crops, as the smallholder farmers of this floodplain preference, are mostly triggered by soil P as reported by [10, 28]; therefore, the higher the soil available P, the greater the chances of higher crop yield.

Total exchangeable acid (TEA) is 0.8, 1.1 and 1.0 for crest, terrace, and back-swamp, respectively (Fig. 2d). CEC was similar on average across the crest, terrace, and back-swamp (Fig. 2e); however, it varied greatly between 2.8 – 6.8 mol (+)/kg with relatively wide range in silty loam soil. BS showed a similar trend as CEC in the range of 24 – 65 % (Fig 2f). Back-swamp recorded the highest variation in TEA, CEC and BS. There is a positive relationship between SOC and total N content (Fig. 3 in appendix).

C. Soil Classification

Based on the USDA Soil Taxonomy [22] criteria, the soil order of Onumirikwa River, Ulakwo, Imo State, Nigeria is Ultisol. The site is located in the humid tropics and has soils that are acidic in nature. As confirmation, the soils are depleted in calcium, magnesium (data not shown) and potassium (see Tab. 1 and appendix) - typical chemical properties of Ultisol, coupled with the observed low CEC of < 16 cmol/kg and BS at the 2.0 m depth.

The floodplain is located in an environment with Udic soil moisture regime i.e., an environment of < 90 cumulative days of dryness in a normal year. These soils are friable and well drained due to their high sand content. Consequently, qualifying the soils into Udults sub-order. The soils have vertically continuous subsurface horizons, and either argillic or kandic diagnostic subsurface horizons within their profiles. The SOM decreases progressively with depth – a typical characteristic of Kandiudults sub-group. The soils great group of our study site is Arenic Kandiudults due to its sandy as well as skeletal particle size class nature, which is clearly visible throughout the extending layer from mineral soil surface to the top of their Kandic horizons. Based on these morphological features, the World Reference Base (WRB) for soil resources [21] legend for these soils is Acrisols. Whether other floodplain soils of Nigeria have similar legend requires further investigation since our study was only based on only one case floodplain evaluation.

D. Implications of the nutrient status, the soil class, and the way forward

Low plant available P in particular as well as SOC indicate efforts must focus on boosting the soil chemical fertility of the floodplain sites. One of the major reasons for low crop yield in the southeastern Nigeria is low chemical fertility [11]. Intensive dry season vegetable crop production, as often done in this floodplain, without replenishing the soil nutrient gradually depletes soil nutrients to a level of low yield status. Since this is already evident in the floodplain site of our study site, options to increase the nutrient level of the soils of Onummirikwa Ulakwo, Owerri are therefore recommended.

Acrisols – the reference soil group of our study site, are extremely acidic due to their sandy-loamy surface nature; sandy soils are moderate in chemical fertility [29]. The major disadvantage of acidic soils is their ability to bind soil available P by Al [30]; the direct consequence of this is low crop yield. P is an essential nutrient and should be supplied through fertilization programs. In the context of smallholder farmers who often rely on floodplain sites for dry season vegetable production, organic manure in forms or urines and animal dung should be applied. However, the quantity should be moderated since leaching can occur if supplied in excess, which can in turn pollute ground water.

4. CONCLUSIONS AND OUTLOOK

This study shows Onumirikwa River, Ulakwo floodplain soil is low in chemical nutrients to levels that could decrease crop yield. The soils of the three geomorphic units of this floodplain belong to *Kandiudults* sub-group and *Acrisol* group and are characterized with moderate fertility. Confirming our hypotheses, the physical and chemical properties of riparian sites located < 1.5 km away from the water body do not vary. Taking our study site as a selected case for southeastern Nigerian floodplain, there is a need to improve the soil fertility status of other floodplains in this region. Nevertheless, it is recommended to investigate more floodplains in order to obtain floodplain-specific information. In conclusion, the information provided by this study is crucial for proper soil fertility management programmes at Onumirikwa River, Ulakwo floodplain. A recommendation is the implementation of organic soil fertility management options (dungs and composts) by the local farmers of this floodplain.

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