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# Physico-chemical characteristics and assessment of iron forms of inland swamps under rice culture in Ini Local Government Area, Akwa Ibom State

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## Abstract

*The study was conducted to assess the iron contents in rice cultivated soils in Nna Enin, Ikpe Ikot Nkon and Ogu-Itumbonuso communities, Ini Local Government Area of Akwa Ibom State, Nigeria. The study was to determine the particle size distribution and some chemical properties as well as the contents of forms of iron in rice-cultivated soils. In each of the locations, soil samples were collected from depths of 0-15 and 15–30 cm, after being sub-sampled from bulked samples, a total of eighteen (18) were collected in total. The samples were analyzed in the laboratory using standard procedures. Three forms of iron viz; available, total and organic were analyzed by using hydrochloric acid extraction method, perchloric acid and nitric acid digestion method and ashing method, respectively. Data collected were analyzed after initial summary in each replication (locations) using Analysis of Variances. Significant means were compared using Least Significant Difference at 5% probability level. Correlation analyses were run for the different soil properties and content of forms of iron at 5% probability level to establish their relationship. Results showed that sandy loam texture (NnaEnin and Ikpe Ikot Nkon) and sandy clay loam (Ogu-Itumbonuso) characterized the soils. The soils were non-saline, while the surface and subsurface soils of Nna Enin field had higher contents of organic carbon, total N and effective cation exchange capacity compared to others that were higher in the surface than the subsurface soils. The concentrations of available, organically bound and total Fe were generally very high (>27mgkg$^{-1}$) in all locations, primarily because of the parent material from which the soils were formed. Organically bound Fe of the subsurface soil of Ikpe Ikot Nkon (726.5mgkg$^{-1}$), owing to spatial variations in soil properties was significantly lower than others, which were statistically similar with range from 149.01 to 116.75 mgkg$^{-1}$.With the low pH, available Fe concentrations were high, due to the overall dominance of Fe in the parent material which is suggestive of the potentiality of iron toxicity for rice in the soils. To overcome the toxicity problems, acid soils should be limed; proper soil drainage should be done, as well as nutrients management practices should be done so as to improve the soil fertility.*

**Keywords:** Forms of iron, physical and chemical properties

## Introduction

Soils play major roles in determining the sustainable productivity of crops. Soils are an important source of bio-available nutrients (macro and micro), a shortage or surplus of soil nutrients can limit the growth and performance of any cultivable crop (Ye *et al.*, 2015). The soil serves as the nutrient sink for plants; most of which are readily available in needed amounts while others could be supplemented through fertilization (Kunda *et al.*, 2017). Of sixteen plant nutrients, iron (Fe) is among those nutrients referred to as micronutrients. Others are Zn, Cu, Mn, Mo and B. These elements are required in small quantities for plant growth. Due to their agronomic importance, they tend to assume a vital role in the growth and development of plants without which normal metabolic activities would be hindered (Zayed *et al*., 2011; Cholarajan and Vijayakumar, 2013).

Micronutrients are found in soil in forms such as water soluble, exchangeable, oxides-bound forms, $CO_3$-bound and organic-bound and residual matter in the structure of minerals (Nescouto *et al.*, 2011).Water soluble and exchangeable fractions are considered readily mobile and available, depending on the interaction of chemical and physical properties of the soil, while the residual fraction is not available to plants and micro-organisms.

Populations with monotonous diets consisting mainly of cereals are especially prone to Fe deficiency. Although Fe is abundant in mineral soils, iron is sparingly soluble under aerobic conditions at high soil pH. Iron toxicity is a complex and major nutritional soil constraint affecting rice production in the irrigated and rain fed lowland soils of the tropics and subtropics.Varying levels of soil soluble $Fe^{2+}$ has been reported in literatures to cause Fe-toxicity at pH levels ranging from 3 to 7 (Ottow *et al*., 1982). Critical levels causing toxicity is difficult to determine as different rice cultivars will respond in various ways to excessive $Fe^{2+}$ in what is called ``bronzing" or ``yellowing" symptoms. Soil solution $Fe^{2+}$ causing toxicity has also been reported as ranging between 300 to 500 mg $FeL^{-1}$ and 300 to 600 $mg.kg^{-1}$ in rice tops (Tanaka *et al.*, 1966; Foy *et al*., 1978; Yoshisda, 1981). Iron toxicity of rice plants has been related to a multiple nutritional soil stress (i.e., insufficient supply of K, P, Zn and sometimes Ca and Mg) rather than to a high level of active Fe (Ottow *et al*., 1982).

The reported levels of Fe in culture solutions that cause toxicity vary from as low as 10 mg Fe $L^{-1}$ up to 500 mg Fe $L^{-1}$or higher (Tanaka *et al*., 1966). The wide range in the reported Fe toxic levels may be due to differences in the form and source of Fe used, varietal tolerance, the concentrations of other nutrients, temperature, and solar radiation (Marschner and Cakmak, 1989). However, some of the micronutrients pose the problem of toxicity and iron is notorious in rice cultures. Iron toxicity is one of the most important abiotic stresses and widespread nutrient disorder observed to occur in locations where rice is cultivated. According to Cherif *et al.(*2009), iron toxicity could lead to yield losses of 12 – 100 percent. This however, depends on the intensity of the stress and tolerance of the rice cultivars. Iron toxicity occurs primarily when the parent rock material is rich in iron.Alfisols for instance derived from igneous material have relatively higher amounts of total iron than those derived from granite (Sahrawat, 1998). Iron toxicity has also been reported to have been traced to nutrient disorder (Sahrawat, 2004).Fe is associated with the synthesis of chloro-plastic protein and important in the activation of several enzymes in plants.

Dissolved irons generally are transported towards the coast during which some are precipitated out of solution through oxidation to ferric hydroxides (Russak *et al*., 2016). However, even though most dissolved iron sourced from the catchment precipitates out as the water flow towards the coast, groundwater, and river can still accommodate significant quantities of dissolved iron to coastal environments. The input of fulvic acids can maintain iron in solution in brackish to saline coast waters (Larsen, 2012).

Several studies made in Asia and Africa show that Fe toxicity is a major nutrient disorder of rice grown on acid sulfate soils, Ultisols and sandy soils with a low cation exchange capacity, moderate to high in acidity and active Fe ,and low to moderately high in organic matter(Genon *et al.*,1994; Sahrawat *et al.*, 1996; Sahrawat 1998; Moore and Patrick, 1993) made an analysis of soil data in relation to Fe toxicity in Asian soils and suggested that Fe toxicity is common in the young acid sulfate soils (Sulfaquepts) but is rare on the older, more deeply developed acid sulfate soils (Sulfic Tropaquepts) which do not produce high levels of $Fe^{2+}$ upon submergence. Iron toxicity in soils other than acid sulfate soils is often associated with other nutrient disorders. At a very low pH (<4.0), the physiological activity of the rice plant is decreased drastically and this weakens the root functions, which allow rice plants to tolerate high concentration of Fe in soil solution (Tadano and Yoshida, 1978) Additionally, under conditions described above (low pH) lower concentration of Fe in soil solution may cause Fe toxicity.

## Materials and Methods

### *Study Area*

Ini Local Government Area in Akwa Ibom State is located on Latitudes $5^{o}$ $24^{1'}$ and $5^{o}$ $09^{1}$N, Longitudes $7^{o}$ $48^{1}$ and $7^{o}$ $42^{1}$E and altitude 118.3ft above sea level. The specific study locations are Nna Enin (Latitude $5^{o}$22.694 N, Longitude $7^{o}$45.608E), Ikpe Ikot Nkon (Latitude $5^{o}$24.874 N, Longitude $7^{o}$46.498E) and Ogu-Itumbonuso (Latitude $5^{o}$26.646 N, Longitude $7^{o}$45.804E). It has a land area of 320,451 square kilometers. The Local Government Area is bounded on the south by Ikono Local Government Area (LGA), on the north by Abia State, on the east and west by Ibiono Ibom and Obot Akara LGAs, respectively.

### *Climate*

The climate is generally tropical with a temperature of less than $40^{o}$C throughout the year. The study area is located within the humid rainforest zone and has two distinct seasons viz: the rainy and dry-seasons. The rainy season begins from May to October, while the dry season begins from November to April, with a brief harmattan season in December and early January. The average rainfall is between 2,500 and 3,000 mm per annum. The average relative humidity is about 85% at 7.00 hours. The average minimum and maximum temperatures are 27 and 29$^0$C, respectively (Udosen, 2017).

*Geology of the area is missing*

*Soil Sampling*

Soil samples were collected from three rice fields located at Ini Local Area of Akwa Ibom State namely; Nna Enin, Ikpe Ikot Nkon and Itu-mbonuso; and bagged in properly labeled polyethylene bags. In each of the study area, soil samples were collected to represent 0-15 and 15-30cm depths from the three locations. For each of the sampling sites, soil samples were obtained from five places, bulked together and sub-sampled for each of 0-15 and 15-30cm depth. A total of eighteen (18) soil samples were obtained from the three rice fields for laboratory analysis. The soil samples were taken using the soil auger.

*Preparation of Samples and laboratory analyses*

Soil samples were air-dried under laboratory conditions until constant weight was obtained, and sieved through 2mm sieve and preserved for laboratory analyses.

The physico-chemical properties of the soil sampled were analyzed as follows:

a. Soil pH was determined by using digital electronic pH meter in water suspension of 1:2.5 soil/water ratio (Udo *et al.*, 2009)
b. Organic carbon content was determined by the dichromate wet oxidation method (Udo *et al*., 2009).
c. Total nitrogen was determined by macro-kjeldahl digestion and distillation method (Bremmer, 1982)
d. Available phosphorus was determined by the Bray P-1 extraction method and its concentration in the extract was determined by the blue colour method of Murphy and Riley (1962).
e. Exchangeable bases (Ca, Mg, Na, and K) were extracted by 1*M* $NH_4OAc$ solution buffered to pH of 7.Exchangeable Na and K were determined using flame photometer, while Mg and Ca were determined using atomic absorption spectrophotometer (AAS), as outlined by Udo *et al.*, (2009).
f. Particle size distribution was determined by the Bouyoucos hydrometer method after dispersing the soil sample with sodium hexametaphosphate (calgon) solution (Gee and Bauder 1986).
g. Electrical conductivity was determined in 1:2.5 soil/water extract using a conductivity meter or bridge as described by Udo *et al*., (2009).
h. Exchangeable acidity was extracted with 1*N* KCl extraction method, as described by Agbede *et al.*, (2009).
i. Effective cation exchange capacity (ECEC) was determined by summing up total exchangeable bases (TEB) and exchangeable acidity (EA), as described by Summer and Miller, (2009).

j. Base saturation was determined using the relationship BS = TEBx100

*Determination of Iron*

a. Available form of Iron was analyzed by using 0.1mHHydrochloric acid for extraction(Lindsay and Norvell, 1978). 5g of soil was weighed into a 100ml plastic bottle; 50ml of 0.1M HCl was added, and shaken for 1 hour. It was then filtered with Whatman No 42 filter paper, and then the filtrate was put in the sample bottles for determination in Atomic Absorption Spectrophotometer.

b. Total Free Oxides form of Iron was analyzed by using perchloric acid/nitric acid digestion method. (Holmgren, 1967). Reagents used were concentrated perchloric acid ($HClO_4$) and concentrated nitric acid ($HNO_3$). 2g of soil was weighed into 150ml beaker. 20ml of concentrated nitric acid was added with 15ml of concentrated perchloric acid, and then it was allowed to stand for 1 hour on the hot plate of about 200-225$^o$C until the mixture turns white. It was then dissolved the digest with 0.1M Hydrogen Chloride and it was filtered with Whatman No 42 filter paper. It was made to mark with distill water at 250ml volumetric flask. Then turned into preserving sampling bottles for reading using Atomic Absorption Spectrophotometer.

c. Organic form of Iron was analyzed by ashing method (Mckeague, 1967). 2.5g of soil was measured into a crucible, and placed into furnace to ash at a regulated temperature of 300-450$^o$C. It was allowed to cool in the desiccators for some hours,then dissolved with 30ml of 1*N* HCl, while making it up to 100ml with distilled water, it was stored in sampling bottles for determination.

*Data Analyses*

Data were analyzed at two soil depths (0-15cm) and (15-30cm), after initial summary of data in each replications (Locations) using analysis of variances (ANOVA). Significant means were compared using Least Significant Difference (LSD) at 5% probability level. Correlations were run for the different soil properties and content of forms of iron at 5% probability level to establish their relationships according to Gen-Stat Discovery Edition 3, Gen-Stat Release 7.22 DE (PC/Windows XP) Copyright 2008, and VSN International Ltd.

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## Results and discussion

### *Particle size distribution and some Chemical Properties of the studied Soils*

### *Particle Size Distribution*

Sand content was significantly ($P<0.05$) high in surface soils, with Nna Enin having the mean of 782.3gkg$^{-1}$(Table 4.1), followed by Ikpe Ikot

Nkon with 695.7 $gkg^{-1}$ and Ogu-Itumbonuso with 649.0 $gkg^{-1}$, while in the subsurface soils, Nna Enin had 669.0 $gkg^{-1}$, Ikpe Ikot Nkon with 602.3 $gkg^{-1}$ and Ogu-Itumbonuso with 675.7 $gkg^{-1}$.

The values of silt content ranges from 83.8 $gkg^{-1}$ in Nna Enin (0-15cm) to 197.1 $gkg^{-1}$ in Ikpe Ikot Nkon (15-30cm), while clay content ranged from 133.8 $gkg^{-1}$ in Nna Enin (0-15cm) to 227.2 $gkg^{-1}$ in Ogu-Itumbonuso (0-15cm). Ogu-Itumbonuso had the highest clay contents in the studied soils. The surface and subsurface soils had contrasting textures of sandy loam and sandy clay loam, respectively. There was significant difference in sand content in all the locations and soil depths, while silt content in 0-15cm (soil depths) was not significant, but it was significant in 15-30cm soil depths. Clay content was significantly different in all locations and soil depths.

*Soil pH*

Soil pH values in water ranged from 3.45 at Ogu-Itumbonuso (0-15cm) to 5.63 at Ogu-Itumbonuso (15-30cm), while pH (KCl) ranged from 3.44 at Nna Enin (0-15cm) to 3.90 at Ikpe Ikot Nkon (15-30cm). Generally, mean values of pH ($H_2O$) were higher than those of pH (KCl). There was no significant effect in pH ($H_2O$), but there was significant difference in pH (KCl).

*Electrical conductivity*

Electrical conductivity (EC) was highest in Ogu-Itumbonuso (15-30cm) with 0.24$dSm^{-1}$(Table 4.2), which was not significantly ($P<0.05$) different from those of Nna Enin (15-30cm) with 0.23 $dSm^{-1}$, OI (0-15cm) with 0.22 $dSm^{-1}$, IIN ( 0-15cm) with 0.21 $dSm^{-1}$, but was significantly ($P<0.05$) higher than those of NE (0-15cm) with 0.20 $dSm^{-1}$ and IIN (15-30cm) with 0.17 $dSm^{-1}$. The values of EC were generally low in all the locations (surface and subsurface) which showed that the soils were non-saline. Values in 15-30cm soil depths were significantly difference from the values in 0-15cm soil depths.

*Organic carbon*

Mean concentration of organic carbon in the soils ranged from 16.0$gkg^{-1}$ to 61.8$gkg^{-1}$ in both the surface and subsurface soils. The values were all significantly different.

*Total nitrogen*

Total nitrogen ranged from 0.04$gkg^{-1}$ at Ikpe Ikot Nkon (15-30cm) to 0.22$gkg^{-1}$ at Nna Enin (15-30cm) (Table 4.2), Nna Enin (15-30cm) had total nitrogen that was apparently higher than those of other locations and depths. Total nitrogen was significantly different by the values in the locations and soil depth.

*Available phosphorus*

Available phosphorus ranged from 29.79$mgkg^{-1}$ in Ogu-Itumbonuso (15-30cm) to 42.23 $mgkg^{-1}$ in Ikpe Ikot Nkon (0-15cm). Available phosphorus was significantly different by the values in location and soil depth.

*Exchangeable bases (Ca, Mg, K and Na)*

Locations and soil depths did not have significant effects on the concentration of Ca and Mg (Table 4.2), while changeable Ca was highest at Nna

Enin (0-15cm) having 4.27 cmolkg$^{-1}$ and the least value of 2.200 cmolkg$^{-1}$ at NE (15 - 30cm). Soils of Nna Enin (0-15cm) had the highest exchangeable Mg of 2.99cmolkg$^{-1}$, which was not significantly (P<0.05) higher than those of Ogu-Itumbonuso (15-30cm) 2.6cmolkg$^{-1}$ Ikpe Ikot Nkon (15-30cm), but was higher than that of Ikpe Ikot Nkon (0-15cm) 2.24cmolkg$^{-1}$ which was in turn significantly higher than those of Ogu-Itumbonuso(0-15cm) with (1.50cmolkg$^{-1}$) and Nna Enin (15-30cm) with (1.30cmolkg$^{-1}$). There was an irregular order of concentration in the surface (0-15cm) and subsurface (15-30cm) soils of the locations.

Exchangeable K values ranged from 0.10cmolkg$^{-1}$in Ikpe Ikot Nkon (15-30cm) to 0.26cmolkg$^{-1}$in Ikpe Ikot Nkon (15-30cm) and 0.26cmolkg$^{-1}$in Nna Enin (0-15cm) (Table 4.2). Exchangeable Na obtained from the studied soils ranged from 0.13cmolkg$^{-1}$ in Ogu-Itumbonuso (15-20cm) to 0.17cmolkg$^{-1}$ in Ikpe Ikot Nkon (15-30cm). K, Na, EA were not significantly different, while Mg and Ca were significantly different.

### *Exchangeable aluminum and exchangeable acidity (Exch acidity = Exch $H^+$ + Exch $Al^{3+}$)*

Exchangeable aluminum ranged from 1.51cmolkg$^{-1}$ in Ogu-Itumbonuso (15-30cm) to 3.33 cmolkg$^{-1}$ in Nna Enin (0-15cm), while exchangeable acidity ranged from 2.63cmolkg$^{-1}$ in Ogu-Itumbonuso (15-30cm) to 5.24cmolkg$^{-1}$ in Nna Enin (0-15cm). Both Exchangeable Al and Exchangeable acidity had their minimum values at Ogu-Itumbonuso (15-30cm) and maximum values at NnaEnin (0-15cm).Exchangeable aluminum and exchangeable acidity were significantly different in different soil depth and locations.

### *Effective Cation Exchange Capacity and Base Saturation*

The effectivecation exchange capacity (ECEC) was 12.89cmolkg$^{-1}$ obtained at Nna Enin (0-15cm) and was significantly higher than the 10.59cmolkg$^{-1}$, obtained at Ikpe Ikot Nkon (0-15cm). But the value of ECEC ranged from 8.42cmolkg$^{-1}$ in Nna Enin (15-30cm) to 12.89cmolkg$^{-1}$ in Nna Enin (0-15cm) (Table 4.2). The values of base saturation (BS) ranged from 46.32% obtained in Nna Enin (15-30cm) to 71.62% obtained in Ogu-Itumbonuso (15-30cm).The highest BS of 71 62% was statistically equal to 62.03% obtained at Ikpe Ikot Nkon (15-30cm). The Base Saturation of Nna Enin (0-15cm) was in turn statistically similar to 52.76% in Ogu-Itumbonuso (0-15cm), 50.31% in Ikpe Ikot Nkon (0-15cm) and 46.32% in Nna Enin (15-30cm).Effective Cation Exchange Capacity was significantly different at 0-15cm soil depth, but not significantly different in 15-30cm soil depth.

### *Contents of Forms of Fe in the Rice Fields Studies*

The Different forms of iron in the soils of rice farms in Ini LGA of Akwa Ibom State are presented in Table 4.3. The Table shows that Nna Enin (0-15cm), Nna Enin (15-30cm), Ikpe Ikot Nkon (0-15cm), Ikpe Ikon Nkon (15 - 30cm), Ogu-Itumbonuso (0-15cm) and Ogu-Itumbonuso (15-30cm) had available Fe concentration of 125.95, 106.66, 154.25, 130.43 and 122.53mgkg$^{-1}$, total Fe concentrations of 178.89, 213.15, 195.33, 179.33, 184.08 and 192,06mgkg$^{-1}$, and organically bound concentrations of 116.142, 34, 125.38, 149.01,72.65 and mgkg$^{-1}$ respectively. All the three forms of Fe were significantly higher in 15-30cm of the locations than at 0-15cm soil depth.

*Relationship among Soil Properties Studied*

Table 4presents correlation among soil properties studied. Available P had significant negative relationship with organically-bound Fe (r = -0.558; p ≤0.05) and total N (r = -0.477; r≤; p0.05) but its correlation with pH (KCl) was positively significant (r = 0.503; r≤p0.05?).

Soil pH($H_2O$) had significantly negative correlation with organic carbon (r = -0.681; r≤p0.01), total N (r = -.561; r≤p0.05), exchangeable acidity (r = -.534; p≤0.05), exchangeable Al (r = -.534; r≤ p0.05) while the correlations with base saturation (r = .499; r≤ p0.05) and clay (r = .559; r≤P0.05) were significantly positive. Soil pH (KCl) correlated significantly negatively with organic carbon(r = -.686; r≤ p0.01), and total N (r = -.488; r≤P0.05), while correlation with silt was positive (r = 473; r≤P0.05).

Electrical conductivity correlated significantly with exchangeable K (r = 0.544; r≤P0.05). The correlation of organic carbon with total N (r = .696; r≤P0.01), exchangeable K (r = .558; r≤P0.05), exchangeable acidity (r = 0.562; r≤P0.05), exchangeable Al (r = .474; r≤P0.05), ECEC (r = 0.559; r≤P0.05), sand (r = 0.669; r≤P0.01) and clay (r = -.542; r≤P0.05?)were significantly correlated.

Available P correlated with exchangeable Mg (r = 0.522; r≤P0.05) and with exchangeable K (r = -0.576; r≤P0.05).

Exchangeable Ca correlated significantly positively with exchangeable Mg (r = 0.812; r≤P0.01), ECEC (r = 0.786; r≤P0.01), base saturation (r = 0.610; r≤P0.01?), and sand content (r = 0.603; r≤P0.01) while its correlation with Na (r = -.0.525; r≤P0.05) and silt (r = -.479; r≤P0.05) were significantly negative.

Exchangeable Mg correlated significantly positively with ECEC (r = -.0.676; r≤P0.01) and bases saturation (r = -.0.717; r≤P0.01). Exchangeable acidity correlated significantly positively with exchangeable Al (r = 0.876; r≤P0.01), ECEC (r = 0.588; r≤P0.05) and sand (r = .483; r≤P0.05) but significantly negative with base saturation (r = -.757; r≤P0.01). Exchangeable Al correlated significantly negatively with base saturation (r = -.0.762; r≤P0.01). Sand had negative correlations with silt (r = -.0.825; r≤P0.01) and clay (r = -.0.517; r≤P0.05).

## Conclusion

The result of this study has revealed that the soils of the study area were sandy loam and sandy clay loam, hence generally dominated with sand owing to the quartz parent materials from which the soils were formed, to resists further weathering. The result obtained show that the soils were non-saline due to low electrical conductivity. The lighter soil texture of soils of Nna Enin is both at the surface and subsurface helped in better vegetative bloom to result in the highest contents of organic carbon, total nitrogen and effective cation exchange capacity. The concentrations of available, organically bound and total Fe were generally very high in all locations and depths of the studied soils, primarily because of the parent material form to the soils were formed. According to Chude *et al* (2011), the critical limits for iron is >8.0mgkg$^{-1}$. Finally, the result of this study underscores the strong need for test and analysis in soils for understanding of iron and toxicity contents for proper agricultural and uses.

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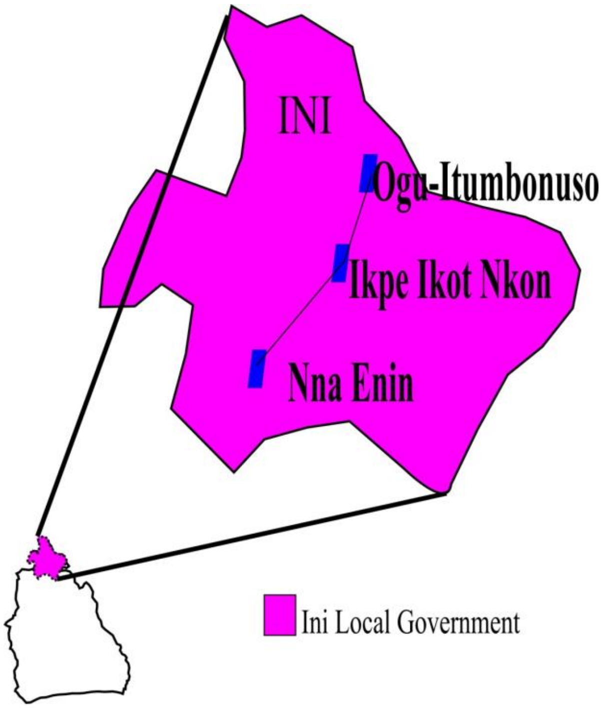

Map of Ini Local Government in Akwa Ibom State
Showing Sampling Locations

**Table 1:Particle size distribution in the study areas**

| **Location (0-15)** | **Sand** | **Silt** | **Clay** | **Texture** |
|---|---|---|---|---|
| | | gkg-1 | | |
| NE | 782.3 | 83.8 | 133.8 | SL |
| IIN | 69.57 | 117.1 | 18.72 | SL |
| OI | 649.0 | 123.8 | 227.2 | SCL |
| **LSD**$_{(0.05)}$ | 4.54 | NS | 9.34 | |
| (15-30cm) | | | | |
| NE | 669.0 | 143.8 | 187.2 | SL |
| IIN | 602.3 | 197.1 | 200.5 | SCL |
| OI | 675.7 | 103.8 | 220.5 | SCL |
| **LSD**$_{(0.05)}$ | 7.36 | 9.33 | 3.33 | |

SL = Sandy loam, SCL = Sandy clay loam, NE = Nna Enin, IIN = IkpeIkotNkon OI = Ogu-Itumbonuso
NS= Not Significant

**Table 2: Soil chemical propertiesinthe study areas**

| **Location (0-15cm)** | **Ph** | **pH** | **EC** | **OC** | **TN** | **Av.P** | **K** | **Mg** | **Ca** | **Na** | **EA** | **ExAl** | **ECEC** | **BS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **($H_2O$)** | **(KCl)** | **$dSm^{-1}$** | **$gkg^{-1}$** | **$gkg^{-1}$** | **$mgkg^{-1}$** | | | | **cmol $kg^{-1}$** | | | | **%** |
| NE | 4.28 | 3.34 | 0.20 | 61.8 | 0.15 | 39.56 | 0.26 | 2.99 | 4.27 | 0.14 | 5.24 | 3.33 | 12.89 | 59.38 |
| IIN | 4.85 | 3.65 | 0.21 | 38.6 | 0.10 | 42.23 | 0.12 | 2.24 | 2.89 | 0.14 | 5.22 | 3.26 | 10.59 | 50.31 |
| OI | 3.44 | 3.65 | 0.22 | 27.5 | 0.07 | 32.01 | 0.24 | 1.50 | 2.60 | 0.15 | 4.00 | 3.20 | 8.49 | 52.76 |
| **$LSD_{(0.05)}$** | NS | 0.34 | NS | 34.3 | 0.07 | 10.22 | NS | 1.49 | 1.67 | NS | NS | NS | 4.4 | 9.07 |
| (15-30cm) NE | 3.98 | 3.62 | 0.23 | 52.9 | 0.22 | 32.89 | 0.25 | 1.30 | 2.20 | 0.16 | 4.52 | 3.29 | 8.42 | 46.32 |
| 11N | 4.83 | 3.90 | 0.17 | 16.0 | 0.04 | 41.78 | 0.10 | 2.48 | 2.67 | 0.17 | 3.50 | 2.15 | 8.32 | 62.03 |
| OI | 5.63 | 3.83 | 0.24 | 27.9 | 0.07 | 29.79 | 0.24 | 2.66 | 3.60 | 0.13 | 2.63 | 1.51 | 9.26 | 71.62 |
| **$LSD_{(0.05)}$** | NS | 0.28 | 0.07 | 36.9 | 0.07 | 11.99 | NS | 1.36 | 0.93 | NS | NS | 0.72 | NS | 25.3 |

EC = Electrical Conductivity, OC = Organic Carbon, TN = Total Nitrogen, AV.P = Available Phosphorus, K = Potassium, Mg = Magnesium, Ca = Calcium, Na = Sodium, EA = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, BS = Base Saturation.
NE = NnaEnin, IIN = IkpeIkotNkon, OI = Ogu-Itumbonuso, ns = not significant

| | | | |
|---|---|---|---|
| NE(15-30cm) | 126.59 | 149.01 | 213.15 |
| 11N | 154.25 | 72.65 | 179.33 |
| OI | 122.53 | 139.41 | 192.06 |
| $LSD_{(0.05)}$ | 31.72 | 76.36 | 33.82 |

Av, Fe – Available iron, O.Fe- Organic iron, Fe- Total iron
NE = NnaEnin, IIN = IkpeIkotNkon, OI = Ogu-Itumbonuso, ns = not significant

**Table 4:Correlation of different forms of Fe and soil properties**

| | Av. Fe | O. Fe | Tot Fe | pH($H_2$O) | pH(kcl) | EC | OC | TN | Av.P | Ca | Mg | K | Na | EA | ExAl | ECEC | BS | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. Fe | 1.000 | | | | | | | | | | | | | | | | | | | |
| O. Fe | -.558$^{*}$ | 1.000 | | | | | | | | | | | | | | | | | | |
| Tot Fe | 0.037 | 0.195 | 1.000 | | | | | | | | | | | | | | | | | |
| pH($H_2$O) | 0.059 | -0.152 | -0.301 | 1.000 | | | | | | | | | | | | | | | | |
| pH(kcl) | .503$^{*}$ | -0.388 | -0.150 | 0.395 | 1.000 | | | | | | | | | | | | | | | |
| EC | -0.429 | 0.418 | 0.201 | 0.147 | 0.018 | 1.000 | | | | | | | | | | | | | | |
| OC | -0.389 | 0.332 | 0.225 | -.681$^{**}$ | -.686$^{**}$ | 0.194 | 1.000 | | | | | | | | | | | | | |
| TN | -.477$^{*}$ | 0.295 | 0.344 | -.561$^{*}$ | -.488$^{*}$ | 0.146 | .696$^{**}$ | 1.000 | | | | | | | | | | | | |
| AV.P | 0.078 | -0.314 | -0.393 | -0.206 | -0.005 | -0.389 | 0.016 | -0.144 | 1.000 | | | | | | | | | | | |
| Ca | -0.065 | -0.071 | -0.240 | 0.129 | -0.302 | 0.031 | 0.367 | -0.005 | 0.155 | 1.000 | | | | | | | | | | |
| Mg | 0.128 | -0.275 | -0.410 | 0.207 | 0.034 | -0.182 | 0.021 | -0.301 | .522$^{*}$ | .812$^{**}$ | 1.000 | | | | | | | | | |
| K | -0.183 | 0.384 | 0.141 | -0.163 | -0.417 | .544$^{*}$ | .558$^{*}$ | 0.405 | -.576$^{*}$ | 0.310 | -0.135 | 1.000 | | | | | | | | |
| Na | 0.461 | -0.460 | 0.128 | -0.315 | 0.256 | -0.407 | -0.283 | 0.023 | 0.240 | -.525$^{*}$ | -0.251 | -0.420 | 1.000 | | | | | | | |
| EA | -0.176 | -0.121 | 0.101 | -.534$^{*}$ | -0.199 | -0.046 | .562$^{*}$ | 0.347 | 0.247 | 0.002 | -0.119 | -0.036 | -0.022 | 1.000 | | | | | | |
| ExAl | -0.082 | -0.117 | 0.117 | -.534$^{*}$ | -0.116 | 0.213 | .474$^{*}$ | 0.259 | 0.148 | -0.101 | -0.276 | 0.133 | 0.064 | .876$^{**}$ | 1.000 | | | | | |
| ECEC | -0.108 | -0.198 | -0.188 | -0.207 | -0.276 | -0.045 | .559$^{*}$ | 0.122 | 0.408 | .786$^{**}$ | .676$^{**}$ | 0.112 | -0.363 | .588$^{*}$ | 0.415 | 1.000 | | | | |
| BS | 0.162 | -0.049 | -0.306 | .499$^{*}$ | 0.062 | -0.049 | -0.289 | -0.377 | 0.089 | .610$^{**}$ | .717$^{**}$ | 0.048 | -0.237 | -.757$^{**}$ | -.762$^{**}$ | 0.078 | 1.000 | | | |
| Sand | -0.101 | 0.164 | 0.014 | -0.324 | -0.452 | 0.092 | .699$^{**}$ | 0.106 | 0.133 | .603$^{**}$ | 0.421 | 0.415 | -.493$^{*}$ | .483$^{*}$ | 0.356 | .763$^{**}$ | 0.001 | 1.000 | | |
| Silt | 0.226 | -0.167 | -0.092 | 0.009 | .473$^{*}$ | -0.241 | -0.458 | 0.013 | 0.109 | -.479$^{*}$ | -0.261 | -0.417 | 0.461 | -0.260 | -0.195 | -.512$^{*}$ | -0.060 | -.825$^{**}$ | 1.000 | |
| Clay | -0.164 | -0.036 | 0.114 | .559$^{*}$ | 0.083 | 0.203 | -.542$^{*}$ | -0.207 | -0.400 | -0.340 | -0.349 | -0.103 | 0.172 | -0.460 | -0.333 | -.574$^{*}$ | 0.089 | -.517$^{*}$ | -0.057 | 1.000 |

EC = Electrical Conductivity, OC = Organic Carbon, TN = Total Nitrogen, AV.P = Available Phosphorus, K = Potassium, Mg = Magnesium, Ca = Calcium, Na = Sodium, EA = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, BS = Base Saturation, NE = NnaEnin, IIN = IkpeIkot Nkon, OI = Ogu-Itumbonuso, Av. Fe= Available Fe, O.Fe= Organic Fe, Tot.Fe= Total Fe, * = 5% and ** = 1%.