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MICRONUTRIENT AVAILABILITY IN SOILS UNDER SAWAH RICE PRODUCTION OF INLAND VALLEYS IN NIGERIA

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ABSTRACT

Despite the vital roles of soil micronutrients in rice production, especially in Nigeria, where efforts are being made to increase rice production, there is little information on micronutrient availability in lowland soils of Nigeria. This study therefore investigated the availability of micronutrients (Zn, Cu, Fe, Ni and Mn) in lowland soils under sawah in Nigeria, in order to provide basic information that can also be used as baseline data for analysis in future investigations. Soil samples for this study were collected from all the sawah sites in Bida, Zaria, Ilorin, Abakaliki and Akure. Zn, Cu, Fe, Ni and Mn were extracted in DTPA-TEA solution at pH 7.3 Topsoil (0–15 cm) Cu ranged between 0.43 and 4.09 mg/kg, with an average of 1.90 mg/kg. Mn values ranged between 9.27 and 99.12 mg/kg, with an average of 52.59 mg/kg. Ni values ranged between 0.08 and 1.56 mg/kg, with an average of 0.57 mg/kg. Fe ranged between 41.41 and 451.03 mg/kg, with an average of 199.09 mg/kg. Zn ranged between 0.07 and 5.83 mg/kg, with an average of 1.02 mg/kg. These results indicate that soils under sawah in Nigeria are deficient in Zn and have moderate level of Cu, Fe, Ni and Mn. Although Fe was generally found to be moderate, Fe toxicity was observed in some sites. While the average Zn value was 1.02 mg/kg, which is above the critical level of 0.83 mg/kg for rice production as recommended, majority (60%) of soils under sawah had Zn values below the critical level. Correlation analysis showed that Zn is significantly and positively correlated with exchangeable Ca, exchangeable Mg, exchangeable Na, P, SiO_2, S, total carbon (TC) and total nitrogen (TN), but no significant correlation was observed with pH. Further study to investigate the roles of redox potential and pH in micronutrient availability in soils under sawah in Nigeria is recommended.

Key words: Micronutrients, *sawah*, inland valleys, soil, Nigeria

INTRODUCTION

Rice is important in the food economy of Nigeria and the sixth major crop cultivated in area after sorghum, millet, cowpea, cassava and yam (Ojehomon *et al.*, 2006). Rice is now a structural component of the Nigerian diet and rice imports make an important share of Nigerian agricultural imports (Ogundele and Okoruwa, 2006). Apart from rice serving as an important component of the Nigerian diet, the role rice played in employment generation cannot be overlooked. Rice production provides employment for more than 80% of the people in various activities along the production/distribution chain from cultivation to consumption (Ogundele and Okoruwa, 2006). The consumption of traditional cereals, mainly sorghum and millet, has fallen by 12kg per capita, and their share in cereals used as food dropped from 61% in the early 1970s to 49% in the early 1990s. In contrast, the share of rice in cereals consumed grew from 15% to 26% over the same period. (Akpokodje *et al.*, 2002; Ogundele and Okoruwa, 2006). Average yield of upland and lowland rainfed rice in Nigeria is 1.8 ton per hectare, while that of the irrigation system is 3.0 ton/ha (PCU, 2002). This is very low when compared with 3.0 ton/ha from upland and lowland systems and 7.0 ton/ha from irrigation systems in places like Côte d'Ivoire and Senegal (WARDA and NISER, 2001; Ogundele and Okoruwa, 2006). An average Nigerian consumes 24.8 kg of rice per year, representing 9 per cent of annual calorie intake (IRRI 2001). Nigeria has experienced rapid growth in per capita rice consumption during the last three decades, from 5 kg in the 1960s to 25 kg in the late 1990s (WARDA 2003) with a potential for increase in years to come.

Nigeria with all ecologies in the country suitable for rice cultivation has the capacity to be self-sufficient in rice production. The comparative resource advantage in terms of favourable climatic, soil and ecological conditions for production of rice also put Nigeria in a better position for self-sufficiency in rice production.

Rice is grown under the upland rain fed, inland shallow swamps, deep water and lowland irrigated production systems (Olayemi 1997; Oladele and Wakatsuki 2010). It is estimated that the potential areas for lowland rice production is between 4.6 and 4.9 million ha, with only 1.7 million ha under cultivation (Imolehin and Wada, 2000). However, there has not been any improvement in the development of the vast area of lowland suitable for rice production in Nigeria. Researchers have conducted researches on effective utilization of the lowlands to improve rice production in Nigeria to a sustainable level. It was reported that the failure to effectively utilise the lowland for rice production was due to lack of understanding of lowland ecosystems. Buri *et al.* (2000) reported that lowlands receive eroded and transported material from adjacent uplands resulting in variations in nature and character with respect to both and total nutrient contents. *Sawah* as a viable option for the development of these lowlands was introduced to Nigeria. *Sawah* refers to a levelled and bounded rice field with inlet and outlet for irrigation and drainage (Wakatsuki *et al.* 1998).

Sawah is a multifunctional constructed wetland characterised by geological fertilization process and nitrogen fixation which compensate for nutrients losses. *Sawah* system was introduced through on-farm adaptive research in the two research sites of Gara and Gadza inland valleys, located in Bida, Nigeria in 1986 (Hirose and Wakatsuki 2002). This was followed by on-farm adaptive research and participatory trials between 1986 and 1990 by Japanese researchers. Effectively, the dissemination of the *sawah* technology took off in 2001 from villages previously identified in a diagnostic survey (Oladele and Wakatsuki 2010). To date, *sawah* technology has covered states in all the 6 geopolitical zones of Nigeria.

Various socio-economic studies have been conducted in order to strengthen the adoption and sustainable use of *sawah* technology in Nigeria. These included Oladele Wakatsuki (2008), Oladele Wakatsuki (2010), Fu *et al.*, (2009),Fashola *et al.*, (2006), Ademiluyi *et al.*, (2008) and Alarima *et al.*, (2011a). Till date, not much has been done on the fertility and nutrient management of *sawah*. In a previous study (Alarima *et al.*, 2018), evaluation was made on the basic physico-chemical properties of the *sawah* soils in Nigeria, it was reported that *sawah* soils in Nigeria are low in basic nutrient fertility parameters. However, little information is on *sawah* soils potential in providing the micronutrients required for rice production. This study therefore aims at investigating the micronutrients availability of the soils under *sawah* in Nigeria. This will provide basic information for sustainable management of soils under *sawah* in Nigeria in order to meet up with the desired increase in rice production and to address the rice demand and consumption among Nigerians.

MATERIALS AND METHODS

Study area and soil sampling

This study was carried out in five states in Nigeria where *sawah* rice production is being practiced. The states are Niger, Kaduna, Kwara, Ebonyin and Ondo. Data used in this study were collected in all the *sawah* sites in these states namely: Bida, Zaria, Ilorin, Abakaliki, and Akure. The sites are Ejeti (EJT), Emir (EMR), Etusegi (ETS), Nasarafu (NSF), Shabamaliki (SHB), Sheshibikun (SHE), Etundandan (ETD), Zaria (ZNK), Ilorin (ILA), Ishiagu (ISH) and Akure (AKR) - Fig. 1. Soils of the Bida area are of Mesozoic (Cretaceous) origin, and are generally known as Nupe sandstone. The soils of Zaria are derived from Basement Complex rocks which are essentially granites, gneisses, migmatites, schists and qual1zites that are rich in quartz and low in divalent cations (Wall 1978). The soil of Ilorin is formed from the Precambrian basement complex rocks and it is under the grassland savannah forest cover and belong to the soil group called ferruginous soil. The soils of Abakaliki are derived from Cretaceous black shale and siltstone or shale and limestone (Abe *et al.* 2007). The soil of Akure is made up of ferruginous tropical soils. Crystalline acid rocks constitute the main parent material of these soils. The main features include a sandy surface horizon underlain by a weakly developed clayey, mottled and occasionally concretionary sub-soil. The soil is however sensitive to erosion and occasional water logging as a result of the clay sub-soil. The soils have an exceptional clayey texture, but combine good drainage and aeration with good properties of moisture and nutrient retention.

Laboratory Analysis

Zn, Cu, Fe, Ni and Mn were extracted in DTPA-TEA (diethylene triamine pentaacetic acid – triethanolamine, pH 7.3) solution (Reed and Martens 1996). Zn, Cu, Fe, Ni and Mn were determined using an inductive coupled plasma atomic emission spectrophotometer (Shimadzu ICPE 9000, Kyoto, Japan). Total elements were analysed using X-ray Fluorescence Spectrometry (XRF). Total SiO_2, TiO_2, Al_2O_3, Fe_2O_3 (total iron expressed as Fe_2O_3), MnO, Na_2O, MgO, K_2O, CaO, and P_2O_5 abundance in the samples were determined by X-ray fluorescence (XRF) in the Department of Geoscience, Shimane University, using a RIX-2000 spectrometer (Rigaku Denki Co. Ltd.) equipped with Rh-anode X-ray tube. All samples were made on pressed powder disks, following Ogasawara (1987). Powdered soil samples were ignited at 10500C prior to major element analyses. Loss on Ignition (LOI) of samples was determined before preparing glass beads. A 1.8 g sample of soil was mixed with 3.6 g flux powder (a mixture of Li2B4O7: LiBo2 at ratio of 4:1), placed in a platinum crucible and put in a bead sampler machine (NT-2000, Tokyo Kagaku, Co) for making glass beads. The glass beads of soil samples were thereafter placed in an XRF spectrometer (RIX-2000 spectrometer, Rigaku Denki Co. Ltd.) to determine major elements content. Ten elements (Si, Fe, Al, Ti, Mn, Mg, Ca, Na, K, and P) were analysed. Total content of trace elements including Zn, Cu and Ni were determined.

Statistical analysis

Statistical analysis was performed to determine the relationships between the soil fertility characteristics. Correlation analysis was used to determine the relationships that existed among soil fertility properties using the Statistical Package for Social Science (SPSS).

RESULTS

General Fertility Status

As earlier reported (Alarima *et al.*, 2018), soils under *sawah* in Nigeria are low in fertility. *Sawah* soils in Nigeria are predominantly sandy with mean value of 60.60% (Table 1). Soil pH was low and ranged between 4.6 and 6.8 with a mean value of 5.2 for pH H_2O. The pH was found to be moderately acidic to slightly acidic in the study area. The values of ex. Ca were generally low across all the sampling locations in Nigeria. Ex. K content of the soils under *sawah* was low with mean content of 0.32 cmol kg^{-1}. Observed Ex. Mg in soils under *sawah* was low. Ex. Na was generally low in soils under *sawah* in Nigeria. Topsoil available P in the soils under *sawah* in Nigeria was low. SiO_2 values ranged between 24.65 $mg.kg^{-1}$ and 688.46 $mg.kg^{-1}$ with topsoil average of 130.71 $mg.kg^{-1}$ with majority falling below the recommended level for rice production. Observed S level was generally low in soils under *sawah* across all the sampling locations compared to the critical level of 8 mg kg^{-1}as recommended Yamaguchi (1997). The content of TN was generally low in soils under *sawah* in Nigeria. Following a similar trend, TC in soils under *sawah* in Nigeria can be categorised as low.

Micronutrients

Topsoil (0-15 cm) Cu ranged between 0.43 and 4.09 mg kg^{-1} with a mean value of 1.90 mg kg^{-1} (SD = 1.04)- Table 2. Cu decreased with increasing depth (Fig 2) in most study sites but erratic in some sites. Avail. Cu level was high across all the sawah sites in Nigeria. Zn ranged between 0.07 and 5.83 mg kg^{-1} with a mean of 1.02 mg kg^{-1} (SD = 1.53). Avail. Zn was low with majority of the sites sampled for the study had values lower than the soil critical level of 0.83 necessary for rice production as proposed by Randhawa and Takkar (1975). Avail. Zn decreased with increase in depth but showed increase with depth in ILA 2. Topsoil avail. Fe ranged between 41.41 and 451.03 mg kg^{-1} with a mean of 199.09 mg kg^{-1} (SD = 129.37). Fe mostly decreased with increase in depth but showed erratic distribution in few sites – (Fig 2). Most of the sites had values falling within the range of 70-300 mg kg^{-1} of available Fe with only few sites have values below 70 mg kg^{-1} and values above 300 mg kg^{-1}. Topsoil available Mn values ranged between 9.27 and 99.12 mg kg^{-1} with a mean of 52.59 mg kg^{-1} (SD = 27.80). Available Mn mostly decreased with increase in depth but showed erratic distribution in some sites. There are however few cases of increase in values with increasing depth as were observed in EJT 1 and ILA 2. Available Ni values ranged between 0.08 and 1.56 mg kg^{-1} with a mean of 0.57 mg kg^{-1} (SD = 0.36). Available Ni mostly decreased with increase in depth but showed fluctuated with increase in depth in some sites.

Geochemical properties

Topsoil total Zn ranged between 49.80 and 11.50 ppm with a mean of 21.79 ppm (SD = 9.03). Most of the site sampled had values below the mean level. Topsoil total Cu ranged between 3.40 ppm and 22.50 ppm and had a mean value of 11.93 ppm (SD = 5.87). Fifty per cent of the study locations had values above the mean value while 50% had values below the mean value. Topsoil total Ni ranged between 3.30 ppm and 39.80 ppm and had a mean value of 16.46 ppm (SD = 9.76) Table 2. Most of the site sampled had topsoil total Ni values below the mean value. Topsoil SiO_2 ranged between 67.57% and 94.47% in soils under *sawah* in Nigeria. The mean topsoil $SiO_2$is 85.96%. Majority of the locations sampled had values above the mean. TiO_2ranged between 0.60% and 6.39% with a mean of 1.77%. Majority of the locations sampled had values above the mean TiO_2 value. Al_2O_3 values ranged between 2.60 % and 13.63% with a mean of 7.61%. Fe_2O_3 ranged between 0.49% and 9.18% with a mean of 2.59%. The mean value of MnO is 0.06% and ranged between 0.02% and 0.27%. MgO ranged between 0.06% and 0.70% with a mean of 0.18%. CaO values ranged between 0.08% and 1.83% with a mean of 0.33%. Na_2O ranged between 0.17% and 1.24%

with a mean of 0.42%. K_2O ranged between 0.29% and 3.96% in soils under *sawah* in Nigeria a mean of 1.05%. P_2O_5 values on the other hand ranged between 0.01% and 0.23% with a mean of 0.04%. SiO_2, Al_2O_3 and Fe_2O_3 dominated, accounting for a cumulative average of 96.16%. Except TiO_2 and K_2O which showed mean values of >1%, MnO, MgO, CaO, Na_2O and P_2O_5 showed meanvalues of < 1%.

Correlation analysis between study parameters

There is positive significant relationship between Cu and total Cu (r = 0.82), total Ni (r = 0.73), total Zn (r = 0.44), CIA (r = 0.70) and clay (r = 0.71)- Table 3. There is however a negative significant relationship between avail Cu and pH (r = -0.56) and sand (r = -0.57). The study also revealed that there is a significant relationship between available Fe and CIA (r = 0.48) and pH (r = -0.51). A positive significant relationship exists between available Mn and CIA (r = 0.62) while a negative relationship exist with K2O (r = -0.46) and pH (r = -0.65). Available Ni is significant related to total Ni (r = 0.75), ex. Ca, (r = 0.46) ex. Mg (r = 0.51) and Ex. Na (r = 0.48). Available Ni also has a significant relationship with available P, (r = 0.56) TC, (r = 0.68) TN (r = 0.69) and clay (r = 0.49). Available Zn is significantly related with total Zn (r = 0.87), ex. Ca, (r = 0.71) ex. Mg (r = 0.78) and Ex. Na (r = 0.71). Available Zn also has a significant relationship with available P, (r = 0.76) TC, (r = 0.76) TN (r = 0.77) and clay (r = 0.44) -Table 2.

DISCUSSION

Micronutrients availability in soils under *sawah* in Nigeria varied from deficient, moderate, high and in few cases toxic. The results of our chemical analyses indicated that both total Cu and available Cu concentrations varied throughout the study area. Available Cu level was generally high across all the *sawah* sites in Nigeria with all the sites having topsoil values higher than the critical level of 0.2mg Cu kg^{-1} as recommended by Ponnamperuma *et al* (1981). The high available Cu in this study is related to the abundance of Cu in the parent material of the soil. A significant correlation exists between available Cu and total Cu. The result of this study is in accord with a previous report of Buri *et al*., (2000) who reported that available Cu is not yet a limiting factor for lowland rice production in West Africa. Available Zn was generally low across all the soils under *sawah* in Nigeria. The low content of Zn may be due to prevalence of parent material with low Zn content. Low level of Zn may also be due to low content of TC and TN in the study sites. The contribution of soil organic matter content towards Zn was higher as compared to soil pH in this present study. There was a significant correlation between organic matter (TC: r = 0.68; TN: r = 0.69) and available Zn.

Increased levels of organic matter, increase exchangeable and organic fractions of Zn and decrease oxide fractions of Zn in soil because of reducing conditions to enhance Zn availability (Behera *et al*, 2011). Positive and significant correlation between soil organic matter and total Zn indicates that the total Zn content in soil increases with the increase in soil organic matter. The low content of available Zn may also be due to the sandy nature of the soils. A significant relationship exists between clay content and Zn. Rautaray *et al*. (2003) reported that problem of Zn deficiency is more acute in sandy acid soils having low organic matter content and low level of plant nutrients. Available Fe content was moderate to high across all the sites in this study with most of the sites having values falling within the range of 70-300 mg kg^{-1} of available Fe required for normal rice growth as proposed by Tanaka and Yoshida (1970). Although few sites show deficiency of available Fe with values below 70 mg kg^{-1} and few site had values above 300 mg kg^{-1} which mayresult in toxicity. There is a negative significant correlation between pH and available Fe which means that the lower the pH, the higher the content of available Fe. Available Fe has no significant relationship with other fertility parameters except pH. The high content of Fe may also be due to leaching experience as a result of high rainfall and the sandy nature of the soils. With high rainfall, basic nutrients such as calcium and magnesium in the soil are leached from the soil and are replaced by acidic elements such as aluminum and iron which results in high Fe content. Buri *et al.* (2000) reported high available Fe in highly leached and sandy soils of West Africa. Mn is moderate across all *sawah* sites in Nigeria. Although there is no significant relationship between available Mn and total elemental MnO, Mn availability as reported by other authors may be influenced basically by the redox potential of the *sawah* soils under submergence condition. Buri *et al* (2000) reported that under submerged conditions, soil solution Mn increases and slight increase in pH with flooding condition enhancing further increase in the concentration of Mn in soil solution. *Sawah* soils in Nigeria showed moderate level of available Ni. Available Ni had significant relationships with total Ni, exchangeable cations, TC, TN, available P and clay which show the importance of other fertility parameters on micronutrients.

CONCLUSION

The result of this study has provided basic information on micronutrients availability and a baseline study for further investigations that could contribute to the desired increase in rice production. The study concluded that soils under *sawah* in Nigeria are deficient in Zinc. Although, average Zn value was above the critical level for rice production, majority of the soils under *sawah* in Nigeria had Zn value below the critical level. In addition, the study concluded that soils under *sawah* are moderate in Cu, Ni and Mn. Also, availability of micronutrients has been found to be influenced by total micronutrient and organic matter content.

The roles of other factors such as redox potential and pH influencing micronutrient availability in submerged soil condition could not be ascertained in this study. A further study to investigate the roles of redox potential and pH on the micronutrient availability in soils under *sawah* in Nigeria is recommended.

Table 1. Topsoil properties of *Sawah* in Nigeria

Site	Clay	Silt	Sand	pH	pH	TC	TN	C/N	EC	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Na	Blay2-P	Avail. Si	Avail. S
		(%)		(H_2O)	(KCl)	(g kg^{-1})			(dS m^{-1})		(cmolc kg^{-1})			(mg P_2O_5 kg^{-1})	(mg SiO_2 kg^{-1})	(mg kg^{-1})
AKR 1	23.9	12.9	63.2	5.1	4.3	15.04	1.36	11.1	0.03	7.11	2.74	0.40	0.75	90.2	136	28.67
AKR 2	34.6	20.3	45.1	6.4	5.8	29.10	3.01	9.7	0.07	21.22	5.63	0.48	1.49	323.4	688	31.25
EJT 1	22.8	52.9	24.3	4.9	4.3	17.86	1.49	12.0	0.02	3.56	0.77	0.49	0.22	49.2	106	10.88
EJT 2	5.4	14.8	79.9	5.4	4.8	4.70	0.36	13.1	0.01	1.72	0.37	0.12	0.37	21.9	81	5.07
EMR 1	22.8	29.5	47.8	4.9	4.0	5.47	0.45	12.1	0.01	1.77	0.54	0.48	0.40	8.3	108	7.18
EMR 2	25.6	13.9	60.5	4.8	3.7	4.38	0.43	10.2	0.01	2.09	0.63	0.36	0.42	13.0	145	6.84
ETS 1	15.0	27.3	57.7	5.0	4.2	6.55	0.56	11.7	0.01	2.29	0.41	0.31	0.29	12.8	89	6.95
ETS 2	36.4	28.4	35.3	4.9	3.9	6.25	0.57	11.0	0.01	2.75	0.54	0.36	0.26	10.8	130	7.78
ILA 1	16.9	14.6	68.4	4.6	3.8	9.81	0.87	11.3	0.01	3.54	1.12	0.37	0.49	29.3	260	9.45
ILA 2	21.0	24.4	54.6	4.8	4.0	3.05	0.29	10.5	0.01	2.74	0.79	0.58	0.41	4.4	174	5.85
ILA 3	29.5	15.4	55.1	4.6	3.9	14.94	1.27	11.8	0.01	1.47	0.62	0.27	0.16	55.0	25	9.87
NSF 1	13.1	11.0	76.0	6.1	4.6	3.85	0.24	16.0	0.01	2.34	1.19	0.13	0.28	6.9	28	3.56
SHB 1	16.1	19.1	64.7	5.0	4.7	7.37	0.60	12.3	0.02	1.83	0.89	0.19	0.16	32.6	63	6.71
ZNK 1	13.4	9.2	77.4	6.8	4.2	7.20	0.57	12.6	0.01	5.79	1.73	0.60	0.56	15.9	53	6.33
ZNK 2	6.0	12.0	82.0	5.1	4.4	9.38	0.71	13.2	0.02	0.58	0.13	0.13	0.09	19.0	40	10.44
ISH 1	18.9	13.2	67.8	4.8	4.1	10.37	0.94	11.0	0.02	1.37	0.35	0.50	0.27	34.5	55	8.39
ISH 2	20.2	24.4	55.4	4.7	3.7	10.23	0.93	11.0	0.01	0.57	0.11	0.16	0.14	20.6	78	6.75
SHE 1	7.5	19.4	73.1	5.3	4.0	3.66	0.33	11.1	0.01	2.32	0.43	0.15	0.22	5.5	55	5.15
SHE 2	19.4	17.0	63.6	6.0	4.1	2.94	0.29	10.1	0.01	1.50	0.31	0.13	0.16	6.1	74	6.24
ETD 1	16.0	23.9	60.1	4.8	4.0	7.22	0.64	11.3	0.01	3.58	0.54	0.21	0.29	63.3	224	8.06
Mean	19.2	20.2	60.6	5.2	4.2	8.97	0.80	11.6	0.02	3.51	0.99	0.32	0.37	41.1	131	9.57
SD	8.42	9.83	14.72	0.64	0.46	6.33	0.64	1.40	0.01	4.46	1.25	0.16	0.31	70.19	145.48	7.23

Table 2. Topsoil Micronutrients of *Sawah* soils in Nigeria

Site	Micronitrients (mg kg-1)					Total elements (ppm)			Total Elemental Oxides (%)								CIA
	Cu	Fe	Mn	Ni	Zn	Zn	Cu	Ni	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	
AKR 1	2.82	275.60	49.33	1.56	5.83	38.80	16.10	27.00	8.96	8.03	0.10	0.45	1.09	0.58	0.56	0.07	80.07
AKR 2	1.88	84.84	31.84	1.11	4.68	49.80	22.50	39.80	13.61	9.18	0.27	0.70	1.83	0.62	0.93	0.23	80.09
EJT 1	1.82	425.05	51.09	0.57	1.20	22.40	11.50	20.10	8.87	1.48	0.03	0.13	0.19	0.21	0.99	0.05	86.45
EJT 2	0.49	94.24	66.31	0.32	0.23	13.30	6.30	6.60	2.60	1.05	0.04	0.07	0.12	0.18	0.42	0.01	78.40
EMR 1	2.36	186.08	88.56	0.36	0.28	18.40	12.40	11.40	7.72	1.74	0.04	0.12	0.25	0.33	1.31	0.02	80.39
EMR 2	2.67	186.30	62.03	0.37	0.53	18.60	12.40	14.40	7.85	2.58	0.03	0.12	0.21	0.26	0.84	0.02	85.66
ETS 1	2.84	106.77	71.04	0.78	0.26	17.00	13.30	17.70	6.40	0.96	0.04	0.11	0.15	0.21	1.14	0.02	81.13
ETS 2	3.27	79.51	80.74	0.52	0.15	23.10	21.50	32.70	13.63	2.07	0.04	0.17	0.20	0.26	1.63	0.03	86.71
ILA 1	2.99	451.03	97.52	0.89	1.09	25.70	15.20	22.70	6.10	3.13	0.05	0.13	0.17	0.22	0.29	0.04	90.03
ILA 2	2.40	63.05	24.61	0.46	0.26	22.10	20.60	18.30	7.87	4.21	0.07	0.19	0.20	0.23	0.51	0.04	89.26
ILA 3	4.09	358.08	61.44	0.93	1.32	25.30	20.50	27.90	6.91	1.85	0.04	0.14	0.20	0.24	0.32	0.03	90.09
NSF 1	0.43	41.41	9.27	0.08	0.07	11.50	5.90	3.30	2.89	0.49	0.02	0.06	0.09	0.19	0.81	0.01	72.58
SHB 1	1.06	270.58	27.87	0.52	1.32	16.40	5.50	8.70	5.34	0.90	0.02	0.08	0.08	0.18	0.82	0.02	83.10
ZNK 1	0.54	175.52	12.39	0.18	0.07	17.00	3.40	8.30	10.38	1.77	0.03	0.16	0.34	0.71	3.96	0.01	67.45
ZNK 2	0.69	141.13	15.76	0.29	0.21	16.20	6.30	4.90	8.37	1.37	0.03	0.14	0.42	0.73	2.76	0.01	68.18
ISH 1	1.25	285.94	67.93	0.71	0.62	22.50	6.90	12.80	6.58	2.34	0.03	0.21	0.22	1.22	0.40	0.04	78.24
ISH 2	2.39	283.08	62.18	0.80	1.07	27.40	12.00	19.10	9.11	3.15	0.02	0.28	0.22	1.24	0.67	0.04	81.00
SHE 1	1.07	76.32	45.83	0.26	0.08	13.20	9.20	6.40	4.96	1.56	0.18	0.08	0.26	0.31	1.17	0.01	74.08
SHE 2	1.41	51.97	27.00	0.24	0.07	16.30	7.30	12.60	7.32	1.41	0.03	0.11	0.29	0.31	1.18	0.01	80.53
ETD 1	1.53	345.41	99.12	0.54	1.09	19.60	9.80	14.40	6.74	2.50	0.04	0.11	0.10	0.17	0.36	0.04	91.50
Mean	1.90	199.09	52.59	0.57	1.02	21.73	11.93	16.46	7.61	2.59	0.06	0.18	0.33	0.42	1.05	0.04	81.25
Std Devt	1.04	129.37	27.80	0.36	1.53	9.03	5.87	9.76	2.83	2.25	0.06	0.15	0.41	0.33	0.89	0.05	6.93

Table 3. Correlation Coefficient between Micronutrients and other Fertility Parameters

	Avail. Cu	Avail. Fe	Avail. Mn	Avail. Ni	Avail. Zn
Total Zn	0.44	0.21	0.08	0.83	0.87
Total Cu	0.82	0.04	0.30	0.60	0.44
Total Ni	0.73	0.21	0.29	0.75	0.63
Al_2O_3	0.37	-0.02	-0.02	0.35	0.38
Fe_2O_3	0.30	0.04	-0.03	0.75	0.88
MnO	0.03	-0.29	-0.13	0.36	0.56
MgO	0.21	-0.04	-0.12	0.70	0.84
CaO	0.07	-0.15	-0.24	0.58	0.83
Na_2O	-0.14	0.10	-0.12	0.24	0.18
K_2O	-0.37	-0.30	-0.46	-0.42	-0.26
P_2O_5	0.16	-0.01	-0.06	0.59	0.74
CIA	0.70	0.48	0.62	0.38	0.13
PH H2O	-0.56	-0.51	-0.65	-0.26	0.11
Ex. Ca	0.02	-0.12	-0.17	0.46	0.71
Ex. K	0.27	0.17	0.05	0.25	0.22
Ex. Mg	0.03	-0.10	-0.25	0.51	0.78
Ex. Na	0.08	-0.13	-0.09	0.48	0.71
Avail. P2O5	0.08	0.02	-0.08	0.56	0.76
TN	0.24	0.28	-0.02	0.69	0.77
TC	0.23	0.35	-0.03	0.68	0.76
Clay	0.71	0.12	0.22	0.49	0.44
Silt	0.25	0.25	0.29	0.05	-0.05
Sand	-0.57	-0.23	-0.32	-0.31	-0.22

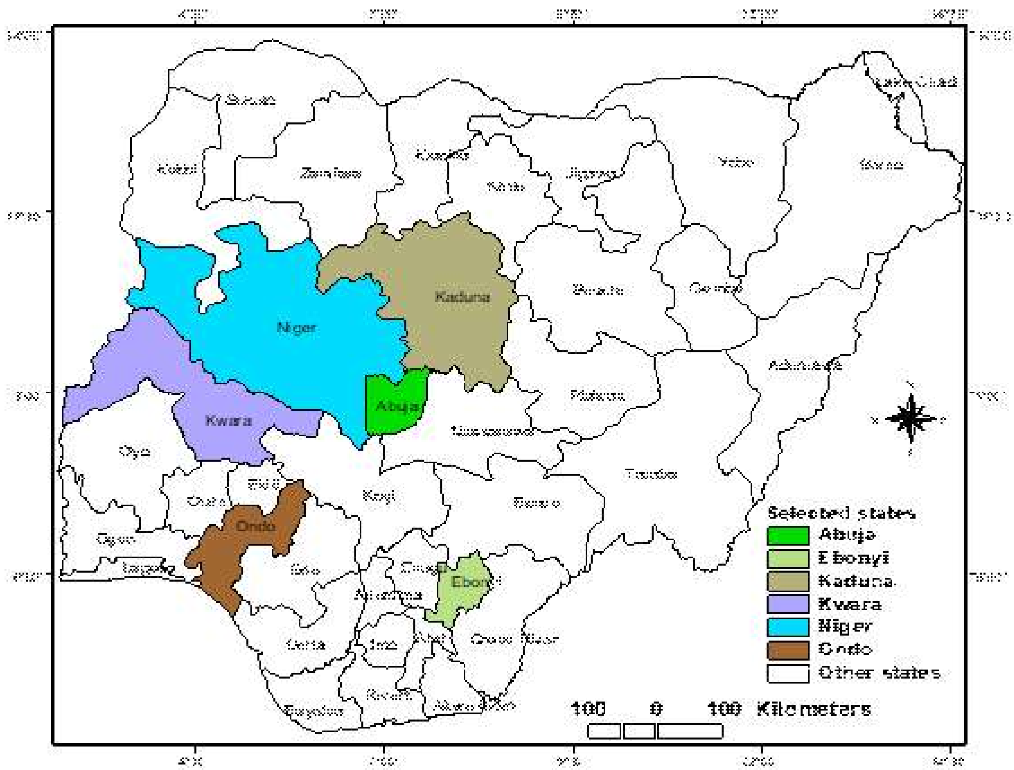

Fig 1: Map of Nigeria showing study locations

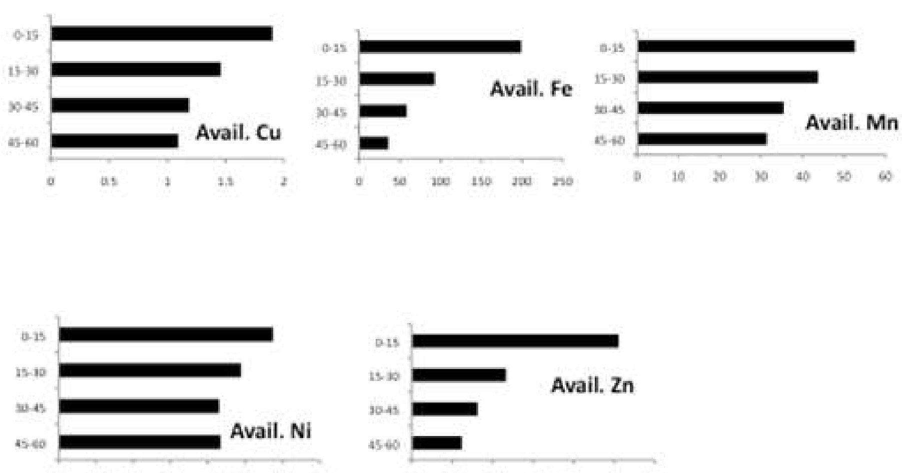

Fig 2: Micronutrients Availability Across Depth

REFERENCES

Abe S. S., Oyediran G.O., Yamamoto S, Masunaga T, Honna T. and Wakatsuki T. 2007. Soil development and fertility characteristics of inland valleys in the rain forest zone of Nigeria: Physicochemical properties and morphological features. *Soil Science and Plant Nutrition* 53: 141–149.

Ademiluyi Y. S., Oladele I. O. and Wakatsuki T. 2008. Socio-economic factors affecting power tiller use among *sawah* farmers in Bida, Nigeria. *Journal of Food, Agriculture and Environment* 6(3 &4):387-390.

Akpokodje G, Lancon F. and Olaf, E. 2002. "Nigeria's rice policy and development: A review". Final draft. West African Rice Development Association, Abidjan, Côte d'Ivoire.

Alarima C.I., Kolawole A, Fabusoro, E, Ajulo A.A., Masunaga T and Wakatsuki T. 2011a. Knowledge and training needs of farmers adopting *sawah* rice production technology in Nigeria. *Journal of Food, Agriculture & Environment* 9 (3&4): 183-188.

Alarima C.I., Matsumoto T, Marquez F. J. D., Siregar A. F., Sato K, Buri M, Wakatsuki T and Masunaga T. 2011b. Silica Availability in lowland soils in Nigeria and Ghana. Paper presented at the Annual meeting of Japanese Society of Soil Science and Plant Nutrition Held at Tottori University, Tottori September 4, 2011.

Alarima, C. I., Busari, M. A., Awotunde J. M., Olaniyi, O. O., Masunaga T. and Wakatsuki, T. (2018): Physico-chemical and Geochemical Properties of Soils under Sawah System of Inland Valleys in Nigeria. *Journal of Agricultural Science and Environment*, 18(1 &2), 69-86.

Behera S. K., Singh M. V., Singh K. N. and Todwal S. 2011. Distribution variability of total and extractable zinc in cultivated acid soils of India and their relationship with some selected soil properties *Geoderma* 162: 242–250.

Bur MM, Masunaga T and Wakatsuki T. 2000. Sulfur and zinc levels as limiting factors to rice production in West Africa lowlands Geoderma 94: 23–42.

Fashola O. O., Oladele, O. I., Aliyu J. and Wakatsuki T. 2006. Dissemination of sawah rice technology to farmers cultivating inland valleys in Nigeria. Proceedings of the Asian Pacific Extension Network, 6-8th March 2006, Australia.Http://www.regional.org.au/au/apen/2006/Refereed/5/3223_fashola.html#topofpage (accessed on July 5, 2011).

Fu, R. H. Y., Maruyama, M, Oladele, I. O. and Wakatsuki, T. 2009. Farmers adoption and propensity to abandoned adoption of sawah-based rice farming in inland valley of central Nigeria. Journal of Food, Agriculture and Environment 7(20): 379-382.

Hirose, S and Wakatsuki, T. 2002. Restoration of inland valley ecosystems in West Africa. Norin Tokei Kyokai (Association of Agriculture & Forestry Statistics), Tokyo.

Imolehin, E. D. and Wada, A. C. 2000. Meeting the rice production and consumption demands of Nigeria with improved technologies. International Rice Commission Newsletter FAO 49: 33-41.

International Rice Research Institute (IRRI 2001. RiceWeb http://oryza.com/africa/nigeria/index.shtml

Ogasawara M. 1987. Trace element analysis of rock samples by X-ray fluorescence spectrometry, using Rh anode tube. Bull Geol Sur Jpn 38(2):57–68.

Ogundele, O. O. and Okoruwa, V. O. 2006. Technical efficiency differentials in rice production technologies in Nigeria. AERC Research Paper 154 African Economic Research Consortium, Nairobi April 2006.

Ojehomon, V. E. T., Abo M. E., Ojehomon, O and Ukwungwu, M. N. 2006. Adoption of recommended management practices in the lowland rice ecology of Niger State, Nigeria.TROPICULTURA 24 (2): 82-89.

Oladele, O .I. and Wakatsuki T. 2008. Social factors affecting wetlands utilization for agriculture in Nigeria – A case study of sawah rice production. Rice Science 15(2):150-152.

Oladele, O. I. and Wakatsuki, T. 2010. Missing prerequisites for green revolution in Africa: Lessons and challenges of sawah rice eco-technology development and dissemination in Nigeria and Ghana. Journal of Food, Agriculture and Environment 8 (2): 1014-1018.

Olayemi, J. K. 1997. The Nigerian rice industry: performance, problems and prospects. A research report prepared for FAO, Rome.

Ponnamperuma, F. N, Cayton, M. T. and Lantin R. S. 1981. Dilute hydrochloric acid as extractant for zinc, copper and boron in rice. *Plant Soil* 61: 297–310.

Project Co-ordinating Unit (PCU) 2002. Crop Area Yield Survey (CAY). Federal Ministry of Agriculture and Rural Development, Abuja.
Randhawa NS and Takkar PN. 1975. Micronutrient research in India. *Fertilizer News* 20: 11–19.

Rautaray S. K., Ghosh, B. C. and Mitra, B. N. 2003. Effect of fly ash, organic wastes, and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice-mustard cropping sequence under acid lateritic soil. *Biores. Techn.* 90: 275–283.

Tanaka A and Yoshida S. 1970. Nutritional disorders of the rice plant in Asia. IRRI Tech. Bull. 10, Los Ban˜os, 51 pp.

Wakatsuki, T, Shinmura, Y., Otoo, E. O. 1998. Sawah system for integrated watershed management of small inland valleys in West Africa. In: FAO (Ed.): Water Report No.17, Institutional and Technical Options in the Development and Management of Small Scale Irrigation, FAO, Rome, pp. 45-60.

West Africa Rice Development Association (WARDA) 2003. Strategy for rice sector revitalization in Nigeria. Project Report WARDA, Abidjan, Cote d'Ivoire, 14p.

West Africa Rice Development Association (WARDA) & Nigerian Institute of Social and Economic Research (NISER) 2001. Report of the Stakeholders Workshop. November 8–9,2001. Ibadan, Nigeria.

Yamaguchi, J. 1997. Sulfur status of rice and lowland soils in West Africa. In: Proceedings of the International Symposium on "Plant Nutrition for Sustainable Food production and Environment", Tokyo, Japan. pp. 813–814.

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