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SOIL CHARACTERISTICS OF THREE IRON TOXIC SITES IN NIGERIA

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ABSTRACT

Irrigated and rain-fed land often showed some sort of nutritional constraints to rice growth caused by either nutrient deficiencies or toxicities. However, comprehensive data on soil physicochemical characteristics of most lowland ecosystems used for rice cultivation in Nigeria are scanty, making it a complex problem to identify specific yield constraint. This study determined the soil characteristics of rain-fed experimental sites for the Stress Tolerant Rice for Africa and South Asia (STRASA) at Adike (Benue State), Edozighi (Niger State) and Ndubia (Ebonyi State), Nigeria using standard laboratory methods. The mean concentrations of ferrous iron (Fe^{2+}) within 0-20cm and 20-40cm of the soil layers ranged from 800-1230ppm and 1010-1780ppm respectively. The mean iron toxicity score of the 80 lines of rice tried in the experimental sites varied between 1.75-3.65%. Zinc contents of the soil layers ranged from 1.09-2.29ppm and 3.43-4.44ppm. The Physicochemical analysis of the farm soils revealed low levels of nitrogen, potassium, organic matter, cation exchange capacity and acidic ecology with pH range of 4.15-5.22. However, available phosphorus was quite high in all the project sites. The experimental sites recorded zinc deficiencies while the high soil levels of ferrous iron in all the project sites is indicative of iron toxicity hot spot. The low cation exchange capacity of the soils has implication on the vulnerability of the sites to leaching of nutrient elements. Therefore, proper agronomic management is required to enhance rice productivity in the experimental sites.

Key words: Ferrous Iron, Toxicity, Physicochemical Parameters, STRASA

INTRODUCTION

Iron toxicity is a syndrome of nutrient disorder associated with large concentrations of reductible iron (Fe^{2+}) in the soil solution (Becker and Asch, 2005). It is a major nutritional disorder in rice (*Oryza sativa*) cropping systems established on flooded organic soils that contain reductible iron and hence affects primarily the production of lowland rice. Lowland rice is being cultivated on approximately 128 million hectares of irrigated and rain-fed land (Maclean *et al*., 2002), out of which about 100 million hectares show some sort of nutritional constraints to rice growth caused by either deficiencies or toxicities (Brady, 1982). Among the various toxicities, iron toxicity is recognized as the most widely distributed nutritional disorder in lowland rice production (Dobermann and Fairhurst, 2000). On acid soils, it is one of the most important constraints to rice production, and under zinc deficiency, iron toxicity is the most commonly observed micronutrient disorder in wetland rice (Neue *et al*., 1998). Iron toxicity during the seedling stage widely affects the yield of lowland rice in West Africa and several Asian countries and the problem has contributed significantly to the reduced rice grain yield in many poorly drained swamps. Maschner (1995), stated that iron toxicity is the second most important yield limiting abiotic stress in lowland rice production. Due to excessive uptake of the reductible ferrous iron (Fe^{2+}) by the roots and its translocation to the leaves, toxic oxygen radicals may form and damage cell structural components, thus impairing physiological processes (Becker and Asch, 2005). The typical visual symptom of iron toxicity is the "bronzing" or reddish-browning colouration of rice leaves which affects photosynthetic and other physiological processes. Rice yield losses associated with the appearance of bronzing symptoms commonly range from 15% to 30% and in the case of severe toxicity, complete crop failure can occur (Audebert and Sahrawat, 2000). While iron toxicity may occur in a wide range of soil, general characteristics shared by most iron-toxic soils are high amounts of reductible iron, low levels of pH, cation exchange capacity and exchangeable potassium content (Ottow *et al*., 1982). These may be associated with phosphorus and zinc deficiencies and hydrogen sulphide (H_2S) toxicity (Kirk, 2004). Reductible iron (Fe^{2+}) concentrations of 300 mg/l in soil solution is generally considered the critical limit for the cultivation of lowland rice (Lantin and Neue, 1989). However, depending on the site and the cultivar used, reported critical concentrations can range from 20 to 2500 mg kg–1, indicating that factors other than pH and iron concentration influence the occurrence of iron toxicity symptoms. Further constraints arise from the widespread incidence of problem soils particularly, inland swamps and irrigated lowlands that are characterized by light textured soils with high extractable acidity (Becker and Asch, 2005). The most prominent and easily adoptable strategy to addressing iron toxicity at field level is the development and use of tolerant rice germplasm. However, this may not be successful without having a comprehensive knowledge of the soil characteristics of the ecosystem in which such tolerant rice variety can thrive. This study therefore, determined the soil characteristics of three iron toxic sites used for the trial of 80 entries of Stress Tolerant Rice for Africa and South Asia (STRASA) in Nigeria.

MATERIALS AND METHOD

Study Area

Three experimental sites known for their incidence of iron toxicity have been selected at Adike (Makurdi), Edozighi and Ndubia (Abakiliki), Nigeria. Their environmental features were as given in Table I.

Sample Collection

The field was radially divided into eight sampling points and composite soil samples were collected at each extremity and median part. 3 samples were randomly collected at 0-20cm and 20-40cm respectively using a soil auger. A total of 24 samples were collected at each soil depth from each site in July, 2009. Then, samples from each horizon were bulked and 3.0kg soil taken into labelled polythene bags and transported to the Central Services Laboratory, National Cereals Research Institute, Badeggi for processing and analyses.

Sample Preparation and Analysis

Bulked and homogenized soil samples from the depth of 0-20cm and 20-40cm respectively were sieved (< 2.00 mm) and laboratory analyses of the soil parameters were carried out on the < 2.00mm particles using standard laboratory procedures. Particle size was determined using the hydrometer method (Gee and Bauder, 1986), pH was measured in 1:2.5 suspension in water and organic matter was determined by dichromate oxidation method (Nelson and Sommers, 1982). Soil Calcium (Ca), magnesium (Mg) and potassium (K) were extracted using 1N ammonium acetate at pH 7.0 (USDA, 2004). Ca and Mg levels were determined using Atomic Absorption Spectrophotometer (AAS) while the level of K was determined with the aid of Flame Photometer. Cation Exchange Capacity (CEC) was determined by summation method following the extraction of exchangeable acidity in 1N KCl (IITA, 1979). Available phosphorus was extracted using dilute HCl/NH_4F (Page *et al*., 1982) while total nitrogen was determined following Kjeldahl digestion method (Bremner and Mulvaney, 1982). Levels of the extractable iron and zinc were determined using Atomic Absorption Spectrophotometer (AAS).

RESULTS AND DISCUSSION

Figure 1 presents the mean concentrations (ppm) of the reductible iron (Fe^{2+}) and zinc of the STRASA's experimental sites at Adike (Makurdi, Benue State), Ndubia (Abakiliki, Ebonyi State) and Edozighi (Niger State) Nigeria. The results of this study revealed that Edozighi's site had the highest mean iron concentration of 1,230ppm within 0-20cm soil layer while Adike and Ndubia recorded 830ppm and 800ppm respectively. However, the deeper soil layer (20-40cm) in Adike and Ndubia sites recorded higher iron contents of 1,780ppm and 1,190ppm respectively while Edozighi recorded 1,010ppm. Generally, the mean soil iron levels of all the experimental sites fell within the reported critical limits of 20-2500mg/kg for iron toxicity (Becker and Asch, 2005). The elevated iron level of the 0-20cm soil depth at Edozighi site may be favoured by the lower zinc content (1.09ppm) of this soil zone. Majerus (2007), observed that the increased availability of certain metals such as iron significantly affects the geo-mobility of the others, such as zinc. The mean zinc concentrations (ppm) within 0-20cm soil depth at Adike and Ndubia experimental sites were 2.26 and 2.29 while the corresponding zinc contents of the 20-40cm soil layer were 3.45ppm and 3.43ppm respectively. Edozighi site recorded 4.44ppm within the 20-40cm soil layer (Figure 1). Generally, all the experimental sites have zinc deficiencies. Available soil zinc concentration of ≤ 20ppm has been reported deficient for rice (Becker and Asch, 2005). These results present the experimental sites with high potential for iron toxicity and the implication on rice's uptake of reductible iron to phytotoxic level. Figure 2 presents the percentage mean flowering, iron toxicity score and the grain yield/plot of the 80 entries of rice lines tried in each of the experimental sites. Different alphabets on the bars indicate that the analysis of variance in the results obtained between sample locations were statistically significant ($p < 0.05$). At Edozighi site, the rice lines recorded very high percentage flowering (96.29) but yielded the lowest grain yield of 1.16kg/plot. This may be due to the high iron toxicity score (3.65%) of the site. Maschner (1995), stated that iron toxicity is the second most important yield limiting abiotic stress in lowland rice production. Ndubia with the lowest percentage mean flowering (75.04) produced the highest grain yield (3.22kg/plot). This may be attributed to the lowest record of iron toxicity score of 1.75%. Ottow *et al*., (1982), reported that iron induced yield reduction is frequently associated with poor nutrient status of the soil enhanced by increasing conditions of phosphorus, potassium and zinc deficiencies, low cation exchange capacity and pH. Using USDA soil triangle classification chart, the particle size distribution of the sites (Table II) showed that the experimental sites at Edozighi, Adike and Ndubia are clay loam in texture. The physicochemical properties study (Table III) revealed that all the sites have low nitrogen contents, low cation exchange capacity and potassium reserves. The soils are also strongly acidic (pH 4.15-5.22). Neue *et al*., (1998), reported that in acid soils, iron toxicity is one of the most commonly observed micronutrient disorder in wetland rice with significant effect on grain yield. Furthermore, Radojevic and Bashkin (1999), reported that a strongly acidic soil has implication on the leaching of toxic aluminium into soil solution which is associated with phytotoxicity in plants and significantly affect nitrogen uptake. Thus, the general low grain yield/plot recorded in this study may be due to the multiple disorder which made the rice highly susceptible to the effect of iron toxicity.

CONCLUSION

The results of this study revealed that the soil reductible iron concentrations of all the experimental sites present them with high potentials for iron toxicity. Furthermore, all the sites recorded soil zinc deficiencies. Results of the physicochemical properties indicated that the experimental sites have acidic soils, low levels of nitrogen, potassium and cation exchange capacity. The low cation exchange capacity of the soil suggests the leaching of nutrient elements. Thus, the performance of rice lines tried at the sites might be due to the effect of multi-nutritional disorder of the soils. However, improved grain yield can be achieved by using iron tolerant rice variety in addition to employing efficient agronomic management to mitigate the effect of iron toxicity and nutrient deficiencies.

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Table I. Some Environmental Features of the STRASA Experimental Sites in Nigeria

Features	Ndubia (Abakiliki)	Edozighi	Adike (Makurdi)
Coordinates			
Latitutde	$8^{o}06^{I}$E	$6^{o}20^{I}$E	$8^{o}62^{I}$E
Longitude	$6^{o}19^{I}$N	$11^{o}05^{I}$N	7.68^{o}N
Altitude (m)	120	144	113
Rainfall (mm)	1600	1225	1370
Temperature (^{o}C)	23 -26	26 -30	26 -29
Vegetation	Derived Savanna	Northern Guinea	Southern Guinea
Geology	Micaceous shale	Cretaceous Sandstone	Sedimentary basin
Soil Type (FAO/UNESCO)	Cambisol	Lithic ustothents	Luvisol

Table II. Particle size distribution of the project sites

Lab. No	Sample description		Sand (%)	Silt(%)	Clay(%)	Textural Class
E/09/S3	Edozhigi	**(A)**	17.89	43.10	39.01	clay loam
		(B)	11.70	45.20	43.10	
M/09/S1	Makurdi	**(A)**	27.64	41.33	31.03	clay loam
		(B)	13.39	39.50	47.11	
A/09/S1	Abakiliki	**(A)**	18.25	35.22	46.53	clay loam
		(B)	16.21	39.35	44.44	

Values presented are mean of replicate data (n = 3). A = 0-20cm, B = 20-40cm,

Table III. Physicochemical Properties of the Soils from the STRASA Experimental Sites in Nigeria

Sample Description		pH (H_2O)	Organic Carbon (%)	Organic Matter (%)	Total N (%)	Available P (%)	Exchangeable Cations ($CmolKg^{-1}$)				EA ($CmolKg^{-1}$)	CEC ($CmolKg^{-1}$)
							Na^+	K^+	Ca^{2+}	Mg^{2+}		
Edozhigi	(A)	4.36	1.55	2.67	0.06	8.23	1.11	0.76	3.24	5.13	0.36	10.60
	(B)	5.18	0.81	1.39	0.03	7.75	0.82	0.25	6.23	4.82	0.34	12.46
Adike	(A)	4.30	2.81	4.83	0.05	14.08	1.13	0.67	3.15	9.81	0.35	15.11
	(B)	5.22	2.05	3.53	0.04	11.49	1.00	0.43	8.86	4.46	0.31	15.06
Ndubia	(A)	4.15	1.91	3.28	0.06	15.48	0.87	0.39	5.93	8.86	0.12	16.17
	(B)	4.26	1.22	2.10	0.04	10.13	0.86	0.34	6.23	7.68	0.08	15.19

Data presented are mean of 9 replications. A = 0-20cm, B= 20-40cm soil depth.
EA = Exchangeable Acidity, CEC = Cation Exchange Capacity

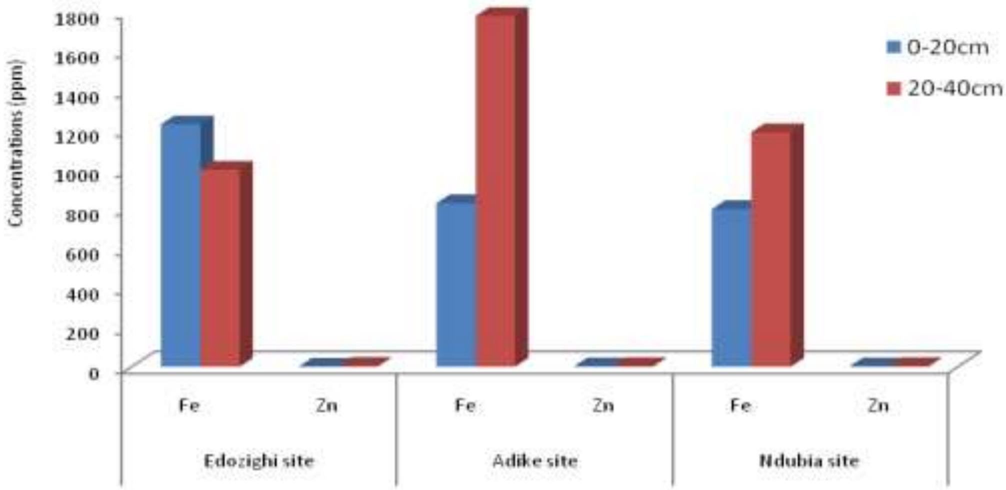

Figure 1. Soil Concentrations (ppm) of Iron and Zinc in STRASA's Lowland Rice Experimental Sites in Nigeria

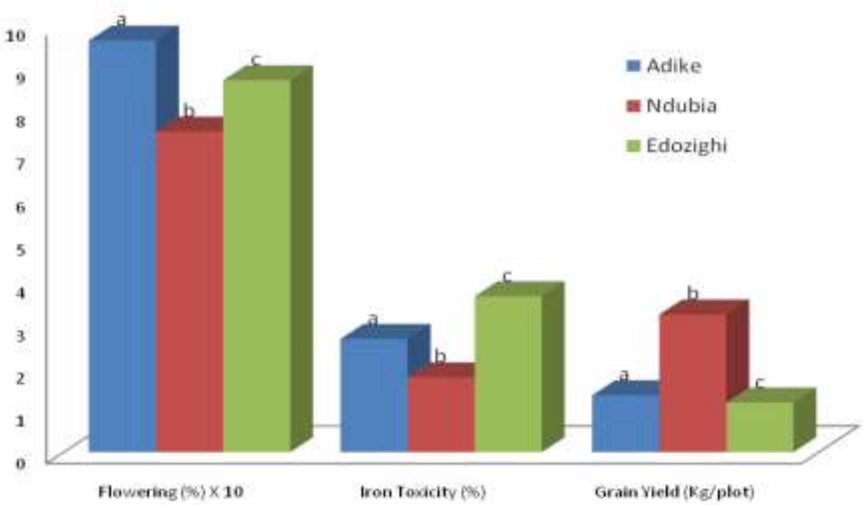

Figure 2. Mean Flowering (%), Iron nToxicity (%) and Grain Yield (Kg/Plot) of the 80 lines of Rice Tried in the Experimental Sites in Nigeria

Key: Different alphabets on the bar indicated the data are statistically significan ($p < 0.05$) between sample locations