SUITABILITY EVALUATION OF SOME PLINCHUSTALFS FOR RAIN-FED RICE PRODUCTION IN SOUTHERN GUINEA SAVANNA OF NIGERIA

***Adeboye, M.K.A., Lawal, B.A., Tsado, P.A., Ezenwa, M.I.S., Afolabi, S.G. and Adekanmbi A.A.**

Department of Soil Science, School of Agriculture and Agricultural Technology, Federal University of Technology, P.M.B. 65, Minna, Niger State, Nigeria

**Corresponding author: m-adeboye.futminna.edu.ng*

ABSTRACT

The plinthustalfs of Minna, Southern Guinea Savanna Zone of Nigeria, have poor physical properties which induce water-logging during wet seasons which may make them suitable for rice production. This study evaluated their suitability for rain-fed rice production using FAO Land Suitability Classification system. Two sites, the Experimental Farm of Federal University of Technology, Minna (EF) and Maizube Farms (MF) representing the soils, were evaluated. Results indicated that both sites had subsurface plinthite horizon, massive structure and poorly drained. Rainfall, temperature and topography of the two site are favourable for rain-fed rice production. The chemical properties, reaction, phosphorus, total N, organic C, and CEC of the surface soils of the two sites were rated suitable for rain-fed rice production. EF was rated not suitable (N) because of soil depth limitation while, MF was rated marginally suitable (S3) with fertility (organic C) limitation which can be corrected by manuring and incorporation of crop residues. The two sites, in the alternative with adequate drainage and ridging, can be put to the cultivation of groundnut, cowpea, soy beans and early season maize.

Keywords: Guinea savanna, land evaluation, Nigeria, plinthustalf, rain-fed rice.

INTRODUCTION

Pisolithic soils refer to soils with gravels, stones or sheets of humus-poor, slag-like iron-oxide, as a result of irreversible hardening of plinthite, mottles or sheets (Sombroek, 1987). They include a wide variety of red, brown, and yellow fine-grained residual soils of light texture, as well as nodular gravels and cemented soils (Bourman and Ollier, 2002). Soils with plinthites occur predominantly in wet tropics, covering 60 million hectares and are more common in savanna zone, with some soils having as much as 80% gravel contents (FAO, 2006).

Some studies have reported the occurrence of sils with plinthites around Minna, with the upland soils described as deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in their upper layers or beneath surface layers (Ojanuga, 2006). Similarly, Alhassan *et al.*, (2012) and Lawal *et al.*, (2012a) noted dominance of Fe and Mn concretions and kaolinite clay mineral in subsurface layers which were found to be responsible for the development of poor structure of massive or structureless in some of these soils. Deneness on massive structure in subsurface do impacts physical drawback to root development and limits water storage (Stombroek, 1987, Adeboye *et al.*, 2009). Such soils, in terms of their physical and nutrients status, were mostly rated poor for agriculture because of their compacted B-horizon which inhibits root penetration with relatively low moisture (Raychaudhuri, 1980). Despite considerable management challenges, soils with plinthites are still planted to food and tree crops even though the crops do suffer from drought in the dry season (FAO, 2006).

Rice is a stable food crop in Nigeria. According to Africa Rice Center (WARDA) Food and Agriculture Organization (FAO) and Sasakawa Africa Association (SAA)'s report, Nigeria is leading in the production of rice in the West Africa sub-region (WARDA/FAO/SAA, 2008). However, that domestic production of rice in Nigeria has been reported to be far below demand due to rapid population growth, reduction in farmlands in terms of size and quality, and poor rice cultivars (Ajiboye *et al.*, 2001). Plinthustalfs of Minna, because of their poor internal drainage characteristics induced by massive structure in subsurface horizons (Lawal *et al.*, 2012a) looks attractive for production of rice because the rice crop thrives under anaerobic conditions. Thus, the need to evaluate the suitability of this group of soils common within the basement complex formation of Minna for rain-fed rice production is necessary to close gap between rice production and consumption in Nigeria. Although no detailed assessment has been conducted, some farmers within the study area do cultivate rice on the Plinthustalfs around Minna. The objective of this study is to evaluate the suitability of the Typic Plinthustalfs of Minna for rain-fed rice production using the FAO framework for land evaluation (FAO, 2007) and guidelines by Sys *et al.*, (1991; 1993).

MATERIALS AND METHODS

The Study Area

The study area is located within suburb of Minna and lies between latitudes 09° 25′N and 9° 31′N and longitudes 06° 22′E and 6° 30′E on altitudes ranging from 177.1 to 229.7 m above mean sea level. Minna lies within the southern Guinea Savanna Vegetation belt of Nigeria. The physical features around Minna consist of gently undulating high plains developed on basement complex rocks made up of granites, migmatites, gneisses and schists. Inselbergs of "Older Granites" and low hills of schists rise conspicuously above the plains. Beneath the plains, bedrock is deeply weathered and constitutes the major soil parent material (Saprolites) (Ojanuga, 2006). Climate of Minna is sub-humid with mean annual rainfall of 1284 mm and a distrinct dry season of about 5 months duration occurring from November to March. The mean maximum temperature remains high throughout, about 33.5 °C, particularly in March and June (Ojanuga, 2006).

Field Study

Sequel to the present study, a semi-detailed soil survey was conducted on the same area using rigid-grid method (100 m x 100 m) from which the plinthustalfs under evaluation was identified. Two modal profile pits, one each at the Experimental Field of the School of

Agriculture and Agricultural Technology of the Federal University of Technology (EF) and Maizube Farms (MF) all in Minna were dug and characterized following the guidelines outlined in FAO (2006). Genetic horizons were identified on the basis of observed differences in some morphological characteristics of the soils which included colour, texture, structure, depth of horizons and inclusions. Samples were collected from the identified genetic horizons into labeled polythene bags and taken to the laboratory for analysis.

Soil Analysis

Soil samples were air-dried, gently crushed and passed through 2 mm-sieves to obtain fine earth separates. Processed soil samples were analysed for some physico-chemical properties following the procedures outlined by the International Soil Reference and Information Centre and Food and Agricultural Organization (ISRIC and FAO, 2002). Briefly, particle size analysis was determined by Bouyoucos hydrometer method. Soil pH was measured in 1:2.5 soil/$CaCl_2$ suspensions with glass electrode pH meter and organic carbon (OC) by Walkley-Black method. Total nitrogen (TN) was determined by micro-Kjeldahl digestion procedure. Available phosphorus (P) was extracted by Bray-1 P method. Phosphorus concentration in the extract was determined colorimetrically using spectrophotometer. Exchangeable bases, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were extracted with 1N NH_4OAc. Ca^{2+} and Mg^{2+} in the extract was determined using atomic absorption spectrophotometer, while K^{+} and Na^{+} were determined by flame photometry. Cation exchange capacity (CEC) was by the use of neutral Ammonium acetate method and base saturation by calculation.

Land Evaluation

Land suitability evaluation for rice was carried out using guidelines of the framework for land evaluation (FAO, 2007) and Sys *et al.*, (1991; 1993). Climatic (annual rainfall, temperature), topography (slope) and soils (soil depth, texture, drainage, pH, available P, organic C, CEC and base saturation) were key factors considered in the evaluation (Fasina and Adeyemi, 2006; Ritung *et al.*, 2007; Ajiboye *et al.*, 2011). Soils of the sites evaluated were placed in suitability classes, using the simple limitation method, i.e. by matching their characteristics with the requirements of rice. Most limiting factor dictated overall suitability for each study site. Suitability of each factor was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) or not suitable (N).

RESULTS AND DISCUSSIONS

Morphological and Physicochemical Properties

The morphological and physico-chemical properties of the pedons are shown in Table 1. The two pedons were imperfectly drained and their surface colours were grayish brown (10YR5/2) and dark grayish brown (10YR3/2) in the Experimental Farm of the Federal University of Technology, Minna (EF) and Maizube Farms (MF) respectively with both having had cemented plinthite horizons starting from depth of 24 cm in EF and 39 cm in MF. The plinthic horizons have massive structure which could have developed as a result of strong aggregation by sesquioxides and silica, which served as cementing agents (Alexander and Cady, 1962). Strong aggregation and cementation in the plinthite horizons could have been a major factor responsible for saturation of the studied soils, especially during peak period of rainy season.

According to Bosch *et al.*, (1994), strong aggregation and cementation may restrict vertical water flow and induce horizontal flow of water in soils. Lawal *et al.*, 2012a) classified the soils represented by pedons EF and MF as Typic Plinthustalfs Haplic Plinthosols (Eutric).

Particle size analysis showed dominance of sand fraction over other mineral particles in both pedons. The two pedons had decrease in sand content down the profiles. Clay was next to sand in dominance and unlike sand, clay content increased with soil depth. Schaetzi and Anderson (2005) attributed increase of clay down the soil profile to pedogenic processes involving eluviations and illuviation of clay particles, neo-formation and transformation of primary minerals in subsurface horizons. Texture of the surface soil of pedon EF was sandy loam and changed to gravelly sandy clay loam and sandy clay with increasing soil depth, while pedon MF had sandy clay loam in surface soil and changed to gravelly sandy clay and clay in subsurface.

The interpretation of chemical properties was made according to Chude *et al.*, (2011). Soil reaction (pH) of the surface soil was moderately acidic in EF and neutral in MF. (Organic C was rated very high in surface soil of EF and moderate in MF respectively. Total nitrogen (TN) was rated low in the surface of EF and very low in MF. The available P was rated moderate in the surface soil of both sites which makes application of P fertilizers not necessary for successful cultivation of rain-fed rice.

Suitability Evaluation for Rice

A summary of land qualities/land characteristics of the study sites are shown in Table 2 and the land suitability ratings obtained by matching the land characteristic values of the two pedons (Table 2) with land requirement for rice (Appendix 1) is shown in Table 3. Mean annual temperature is 33.5°C and annual rainfall was 1284 mm (Ojanuga, 2006), and both were rated highly favourable (S1) (Sys *et al.*, 1993). Topography was also considered adequate (S1) for rice with slope at both sites less than 3%. According to Fasina and Adeyanju (2006), a slope of < 3% favours mechanical operations. These soils under evaluation spread across middle and lower slope positions. The presence of plinthite layers in subsurface of both pedons predisposed the study sites to water saturation during the peak period of rainy season, usually from months of July to September. Hence, both sites were rated moderately favourable (S2) for lowland rice. Depth to plinthite horizons was 24 cm and 83 cm respectively for EF and MF and was rated unsuitable (N) in EF and highly suitable (S1) in MF.

Soil reaction was rated favourable (S1) for rice production. The pH range of 5.6 to 6.8 for the horizons above the plinthite layers may not pose problem for uptake of most plant nutrients especially phosphorus. However, according to Ajiboye *et al.*, (2011), a pH value above 6.0 may limit availability of micronutrients such as Fe, Zn, Mn and Cu which form metallic cations that precipitate into low solubility compounds at high soil pH levels. This implies that the pH value for surface soil of MF may be deficient in some micronutrients; however, Lawal *et al.*, (2012b) have reported the adequacy of Zn and Cu in soils around Minna. Total nitrogen was highly adequate (S1) in both sites while phosphorus was moderately (S2) adequate. The organic C was adequate (S1) in EF and marginally adequate (S3) in MF. The difference in organic C status may be attributed to level of management of crop residues and other sources of organic materials by farmers. CEC was moderately adequate (S2) in EF and highly adequate (S1) in MF. Regarding base saturation, both sites are highly suitable (S1).

In terms of aggregate suitability, EF was rated not suitable (N) with soil depth as the most limiting factor. A soil depth of 24 cm was rated as unsuitable for rain-fed rice by Sys *et al.* (1993). MF was generally rated as marginally (S3) suitable for rain-fed rice production with limitations in soil depth which was 39 cm and low level of organic C which can be corrected through management practices that will encourage incorporation of organic residues so as to maintain favourable structure for sustainable rice cultivation.

CONCLUSION

Biophysical characteristics such as rainfall, temperature and topography of the studied sites are all favourable for rain-fed rice production. CEC, an index of the potential of soil to retain and release plant nutrients, with moderately to highly adequate in both sites. Low organic C especially in MF can be improved through adoption of management practices that may encourage returns of organic residues into the soil such as planting and incorporation of legumes and application of farm yard manures. Near level topography at both sites and presence of plinthite horizons favoured seasonal water saturation of the soils, a condition required for lowland rice production. While MF rated S3 can be used for rain-fed rice production provided soil organic matter content can be managed. The major factor which limited the suitability of EF for rice was soil depth. For both sites, ploughing and ridging are recommended for optimum and sustainable production of rain-fed rice. In the alternative, the sites can be put to the cultivation of groundnut, cowpea, soy beans and early season maize with adequate drainage provided.

Table 1: Some morphological, physical and chemical properties of the study sites

Pedon	Horizon	Depth (cm)	Colour (moist)	Sand	Silt	Clay	Txtr*	pH ($CaCl_2$)	Av. P (mg/kg^{-1})	TN	Org. C	Ca	Mg	K	Na	CEC	BS (%)
				←	(g/kg^{-1})	→				(g/kg^{-1})		←		($cmol\ kg^{-1}$)		→	
EF	Ap	0-24	10YR5/2	794	90	116	SL	6.0	9	0.65	22.05	2.76	0.38	0.05	0.27	6.53	80
	Btv	24-54	10YR4/6	629	85	276	GSCL	5.6	14	0.61	22.05	3.68	0.98	0.04	0.26	8.58	87
	Btcv	54-120	7.5YR5/6	569	55	376	GSC	5.5	10	0.37	15.44	3.90	1.76	0.05	0.27	10.04	89
	BCt1	120-157	10YR6/3	509	105	386	SC	6.4	10	0.19	15.44	3.84	1.06	0.03	0.12	8.55	89
	BCt2	157-206	10YR7/3	529	90	381	SC	6.5	13	0.05	8.82	4.06	1.48	0.02	0.11	9.47	90
MF	Ap	0-19	10YR3/2	597	134	269	SCL	6.8	10	0.20	10.30	5.60	3.00	0.46	0.92	17.07	88
	Bt	19.39	10YR4/4	527	104	369	SC	5.7	9	0.18	10.30	4.80	2.21	0.15	0.60	13.14	89
	Btv	39-83	10YR5/4	487	114	399	GSC	5.8	8	0.27	14.30	5.20	2.30	0.10	0.49	13.58	89
	Btcv	83-122	10YR5/4	437	124	439	GC	5.4	6	0.10	7.80	6.40	3.12	0.09	0.54	17.03	89
	BCt1	122-150	10YR6/4	427	124	449	C	5.2	6	0.10	ND+	8.00	4.50	0.05	0.48	21.44	91
	BCt2	150-207	10YR6/2	417	154	428	C	5.2	6	0.17	ND	12.00	6.00	0.09	0.42	29.79	94

*Txtr. = Textural class; SL – sandy loam, GSCL – gravelly sandy clay loam; GSC = gravelly sandy clay; SCL = sandy clay, loam; SC = sandy clay; GC = gravelly clay; C = clay
+ND = Not Determined.

Table 2: Land qualities/characteristics of the study sites

Parameters	Location	
	EF	MF
Mean annual rainfall (mm)	1284	1284
Average length of dry season (days)	190	190
Temperature (°C)	33.5	33.5
Slope (%)	<3	<2
Drainage	Imperfectly drained	Imperfectly drained
Soil depth to indurated layer (cm)	24	83
*Texture	SL/GSCL/GSC/SC	SCL/SC/GSC/GC/C
pH (H_2O)	5.5	5.9
TN (g/kg^{-1})	0.37	0.17
Available P (mg/kg^{-1})	11	8
Organic C (g/kg^{-1})	16.76	10.68
CEC ($cmol\ kg^{-1}$)	8.63	18.68
% base saturation	87	90

*SL = sandy loam; GSCL = gravelly sandy clay loam; GSC = gravelly sandy clay; SCL = sandy clay loam; SC = sandy clay; GC = gravelly clay; C = clay.

Table 3: Suitability assessment of the Study sites for rice

Land qualities/Land Characteristics	Suitability rating for the sites	
	EF	MF
Climate ©:		
Rainfall	S1	S1
Temperature	S1	S1
Soil physical characteristics (s):		
Soil depth	N	S1
Soil texture	S2	S1
Topography (slope (t):	S1	S1
Wetness (w):		
Drainage	S1	S1
Fertility Status (f):		
Soil reaction (pH)	S1	S1
Total nitrogen	S1	S1
Available Phosphorus	S2	S2
Organic Carbon	S1	S3
Cation Exchange Capacity	S2	S1
Base Saturation	S1	S1
Aggregate Suitability:	NS	S3f

*S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. Limitations (restrictive features): f = fertility limitation; w = wetness/oxygen availability limitation; s = soil physical characteristics limitation; 1 = topography.

Appendix 1: Land requirements for suitability classes for rice

Land Qualities	Factor suitability rating Highly suitable (S1)	Moderate suitability (S2)	Marginal suitability (S3)	Not suitable (N)
Climate (c):				
Rainfall (mm)	>900	800-900	600-800	<600
Temperature (°C)	24-28	22-24	18-22	<18
		30-32	32-35	>35
Soil Physical Characteristics (s):				
Soil depth (cm)	> 75	50-75	25-50	<25
Soil texture	C,SiC,CL	SC,SiC,SiL	SL,L,SCL	S,LS
Topography (t):				
Slope (%)	<3	4-6	7-8	>8
Wetness (w):				
Drainage	Imperfectly drained	Moderately drained	Well drained	Well drained
Fertility Status (topsoil) (f):				
Soil reaction (pH)	5.0-6.5	4.5-5.0	4.0-4.5	<4.0
		6.6-7.0	7.0-8.0	>8.0
Total nitrogen (g/kg^{-1})	> 1.5	1.0-1.5	0.5-1.0	<0.5
Available Phosphorus (mg/kg^{-1})	> 15	8-15	5-8	<5
Organic Carbon (g/kg^{-1})	2.0-4.0	1.0-0.2	0.5-1.0	<0.5
				>5.0
Cation Exchange Capacity ($cmol/kg^{-1}$)	> 12	8-12	5-8	<5
Base Saturation (%)	> 75	50-75	30.50	<30

Source Sys *et al.*, (1991; 1993)

C= clay; SiC = silty clay; CL = clay loam; SC = sandy clay; SCL = sandy clay loam; S= sand; L= loam; SL = sandy loam; LS = loamy sand; SiL = silty loam.

REFERENCES

Adeboye, M.K.A., Osunde, A.O., Ezenwa, M.I.S., Odefin, A.J. and Bala, A. (2009). Evaluation of the fertility status and suitability of some soils for arable cropping in the Southern Guinea Savanna of Nigeria. *Nigerian Journal of Soil Science*, 19 (2): 115-120.

Ajiboye, G.A., Alabi, K.O. Aiboni, V.U., Okeleye, K.A. and Adesodun, J.K. (2011). Classification and suitability evaluation of the soils of a toposequence at Odeda, Ogun State for the production of rice. *Nigerian Journal of Soil Science*. 21 (2): 142-155.

Alhassan, M., Mesaiyete, E. and Mustapha, A.M. (2012). Clay Mineralogy of lateritic soils derived from granite basement: A case study of Minna lateritiec soils. *Journal of Geotechnical Engineering*, 17: 1897-1903.

Alexander, L.T. and Cady, J.G. (1962). Genesis and hardening of laterite in soils. USDA Tech. Bull. 1282. 90pp.

Bosch, D.D., Habbard, R.K., West, L.T. and Lawrence, R.R. (1994). Subsurface flow patterns in a rapriaus buffer system. Trans-ASAE. St. Joseph, Mich: Am, Soc. Agric. Eng., 1958-37: 1783-1790.

Bourman, R.P. and Ollier, C.D. (2002). A critique of the Schellmann definition and classification of laterite. *Catena*, 47 (2): 117-131.

Chude, V.O., Olayiwola, S.O., Osho, A.O. and Daudu, C.K. (2011). Fertilizer Use and Management Practices for Crops in Nigeria. Fourth edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. 215 pp.

FAO (2006). Guidelines for soil description. Fourth edition. Food and Agriculture Organization of the United Nations. 97 pp.

FAO (2007). Land Evaluation: Towards a Revised Framework. Land and Water Discussion Paper-6, FAO, Rome, Italy. 107 pp.

Fasina, A.S. and Adeyanju, A. (2006). Suitability classification of some granitic soils of humid southwest Nigeria for rain-fed maize, cassava and swamp rice production. *Nigeria Journal of Soil Science*, 16:1-9.

ISRIC and FAO (2002). Procedures for Soil Analysis. Sixth edition. L.P. van Reeuwijk (ed). International Soil Reference and Information Centre Food and Agricultural Organisation. 119 pp.

ISRIC and FAO (2006). World Reference Base For Soil Resources.Second edition. World Soil Resources Reports No. 103, FAO, Rome. 145 pp.

Lawal, B.A. Adeboye, M.K.A., Tsado, P.A., Elebiyo, M.G. and Nwajoka, C.R. (2012a). Properties, classification and agricultural potentials of lateritic soils of Minna in sub-humid agroecological zone, Nigeria . *International Journal for Development and Sustainability*, Vol. 1 No. 3. (In press).

Lawal, B.A., Adeboye, M.K.A., Tsado, P.A., Ezenwa, M.I.S. and Bayode, O. (2012b). Extractable zinc and copper in hydromorphic soils developed on basement complex rocks and sedimentary rocks in Niger State, Nigeria. *Savannah Journal of Agriculture*, 7(1): 130-136.

Ojanuga, A.G. (2006). Agroecological Zones of Nigeria Manual. FAO/NSPFS, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. 124 pp.

Raychaudhuri, S.P. (1980). The occurrence, distribution, classification and management of laterite and lateritic soils, *Coh. O.R.S.T.O. M., ser. PMol*, 18 (304): 249-252.

Ritung S., Wahyunto, Agus, F. and Hidayat, H. (2007). Land Suitability Evaluation with a Case Map of Aceh Barat District. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia. 33 pp.

Schaetzi, R.J. and Anderson, S. (2005). Soils: Genesis and Geomorphology. Cambridge University Press, Cambridge, U.K. pp. 353-365.

Sombroek, W.G. (1987). Variations in contents and forms of sesquioxides in lateritic soils. A paper presented at "Eurolat" meeting. Freising-Waihenstephan, Fed Rap. Of Germany. March, 1987. International Soil Reference and Information centre (ISRIC), S12-22 9 pp.

Sys, C., Ranst, V. and Debaveye, J. (1991). Land Evaluation I: Prnciples in Land Evaluation and Crop Production Calculations. Agricultural Publication, No. 7, General Administration for Development Cooperation, Belgium. 274 pp.

Sys C., Ranst, V., Debaveye, J. and Beermaert, F. (1993). Land Evaluation III, Crops Requirements. Agricultural Publication No. 7, ITC Ghents, 199 pp.

WARDA/FAO/SAA (2008). NERICA®: the New Rice for Africa – A Compendium, E.A. Somado, R.G. Guei and S.O. Keya (eds.). Cotonou. Benin: Africa Rice Center (WARDA): Rome, Italy: FAO; Tokyo, Japan: Sasakawa Africa Association, 210 pp.