Morphology, Organic Carbon and Dissolved Nutrients in Groundwater Table in Two Benchmark Wetlands Sites in Nigeria

Adesola Olutayo OLALEYE [1(✉)]
Ayoade Olayiwola OGUNKUNLE [2]
Baj Nath SINGH [3]
Gabriel Emiola AKINBOLA [2]
James OBUH [4]

Summary

Wetland soils in two benchmark sites located in the tall/grass land savanna (Edozhigi) and in the Rain Forest (Ibadan) were selected in order to study the soil morphological characteristics, organic carbon contents, and the nutrient dynamics (P, Ca, Mg, Fe, and NH_4-N) in the ground water table when rice was planted. Morphologically these soils are gleyed, mottled, with a hue of 10 YR, and low chroma that reflects poor drainage (i.e. aquic soil moisture regime). The soils are deep; more than 1.20 m in depth. The soil organic carbon was high in the surface soils (between 0.6 and 2.15%) and fluctuated irregularly with depth. In addition, the ground water table fluctuated between 40-80 cm depth within all the soils at both sites. Following soil submergence, water soluble P, Ca, Mg, Fe, and NH_4-H increased in the first week and began to decline as from the 56 – 70 days after transplanting (DAT) which coincided with the tillering stage of rice plants. The Nitrate-N concentration was very low (≤4 mg/l) at both sites. This flooding during the rainy seasons would benefit rice plants and the high organic carbon contents in the soils could be a substantial factor in the maintenance of these soils for the cultivation of arable crops during the dry seasons.

Key words

wetlands, ground water table, nutrient, dynamics & morphology

[1] Department of Soil Science and Resource Conservation,
The National University of Lesotho, PO 180 Roma, Lesotho
✉ e-mail: aoolaleye@nul.ls
[2] Department of Agronomy, University of Ibadan, Oyo, Nigeria
[3] Birsa Agricultural University, Kanke Ranchi, Jharkhand, India
[4] Department of Agricultural Economics and Extension, The National University of Lesotho, PO 180 Roma, Lesotho

Received: July 21, 2008 | Accepted: October 15. 2008

Introduction

Over the years, more emphasis of agriculture has been placed on upland soils than on wetland soils. But experience has shown that upland soils are no longer as available as they were in the past because of competition for them by both the agricultural and non-agricultural land use and also because of their low sustainability. The result is that farmers' attention is now shifting to wetland soils as it now constitutes an important component of rural livelihoods in Africa. Wetlands are defined as "areas that have free water at/or on the surface) for at least the major part of growing season. The water is sufficiently shallow to allow for the growth of a wetland crop (including floating rice) and aquatic vertebrates (i.e. fishes), or of natural vegetation rooted in the soil" (Frenken and Mhapara, 2002; Kirsten, 2005). Wetlands can be categorized as: coastal plains, inland basins, river flood plains and inland valleys (IVs). The first three categories refer to distinct physiographic units identifiable on the FAO soil map of Africa (Kyuma et al., 1986). However, the inland valleys are relatively small and cannot be shown on such maps. The coastal wetlands, on the other hand, comprise deltas, estuaries and tidal flats.

Wetland soils occur in all agro-ecological zones in Nigeria with a total potential of about 2.0 million ha (Imolehin and Wada, 1999). About 700,000 ha occur in the northern Nigeria and 200,000 ha in the humid south (Singh et al., 1997). The balance occurs in the highland areas of central and western Nigeria. The conversion of wetlands for agriculture and urban development leads to major changes in hydrology, vegetation and soil characteristics. Wetland areas are influenced both by on-site factors (e.g. impoundments and drainage) and by off-site or upland areas where clearing may lead to enhanced run-off, erosion, sedimentation, and accumulation of organic and inorganic solutes and particulates. Despite being highly productive (for agriculture), wetlands are hydrologically sensitive environments. With improper agricultural practices they can dry up and be rendered unproductive. They are also prone to erosion, resulting in both soil loss and drainage, ultimately leading to the loss of both agricultural productivity and ecosystem goods and services. Some wetlands are located in the headwaters of catchments. As such, impacts of agricultural activities in the wetlands will extend downstream. The uncertainty in farming in the wetlands is threefold. First, the impact of irrigated crop production on the hydrology and soils of the wetlands is not well understood. Second, there is still a lack of definitive information on the impact of both upland and lowland cropping systems and other water uses on water availability in the wetland. And finally, the sustainable rates of groundwater abstraction from the wetlands that will maintain a healthy ecosystem and the flood attenuation properties of the wetland are unknown.

One major characteristic of the inland valleys is shallow ground water-table (GWT) which is often flooded during the rainy season and high inherent fertility compared to the upland soils. These lands are cultivated all year round. In Nigeria, and other West African countries, during the rainy seasons, they are cultivated to rice and /or sugarcane and during dry season when the water level has receded, they are cultivated to arable crops (e.g. cowpea, *Vignia unguiculata* L Walp; cassava, *Manihot esculentus* and vegetables). Thus, the objective of this paper is to evaluate status of stable soil properties (texture and organic carbon contents) of two benchmark wetland soils in Nigeria and its water and nutrient dynamics. The ultimate aim is to be able to formulate plausible management practices for them in order to reduce soil degradation.

Materials and methods

This study took place in two benchmark wetland soils located in two agro-ecological zones in Nigeria namely: (i) Guinea savanna zone characterized by woodland/tall grass savanna (NGS) (Edozhigi village (ED)), and (ii) Dry Rain Forest zone (RF) (Ibadan (IB)) (Fig 1). The former site is located at points Latitude 9°03'N and Longitude 6°00'E, while the latter (Ibadan) at Latitude 7° 30'N and Longitude 3° 54'E. About one hectare each of a plot of land was mapped using rigid-grid survey and similar points were grouped into mapping units. Profile pits (1.20 m) were dug and, horizons demarcated, as described in the FAO/UNESCO guideline (FAO, 2006), and soil samples were collected for laboratory analysis. Organic carbon contents from each of these soil types were determined after Black (1965). Details of other physical and chemical data are reported elsewhere (Olaleye,et al., 2001) and their suitability for wetland rice cultivation are presented in Olaleye et al. (2002). After mapping from each of these benchmark sites, twelve extractors made of polyvinyl (PVC) pipes (θ =12 cm) perforated (about θ = 1cm) from the bottom up to 1m were randomly placed at the rate of four per mapping units. These PVC pipes were installed at points where they would not interfere with the normal rice cropping. Flexible Teflon tubes (FTT) with 4 mm inner diameters were placed inside these PVC pipes at 1.20 m depth. Bottom of each flexible Teflon tubes were wrapped with nylon cloth. Rainfall

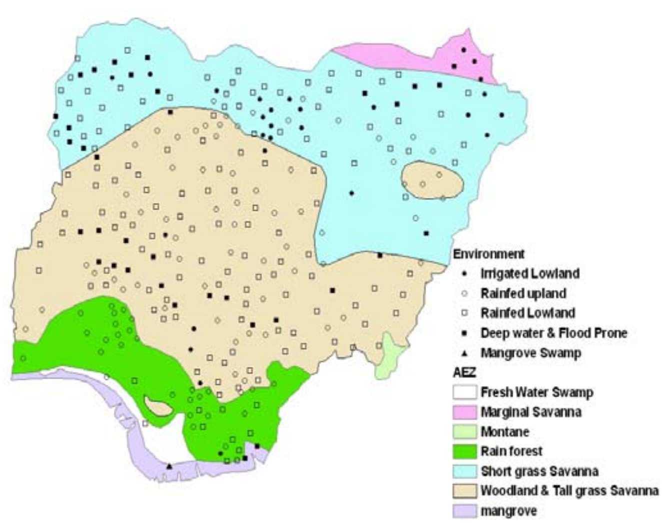

Figure 1.
Rice growing ecology in Nigeria and agro-ecological zones

Table 1. Mean monthly climatic data for Edozhigi and IITA (Ibadan) for 1992 – 2005

Months	Rainfall (mm)		Temperature (°C) Maximum		Temperature (°C) Minimum		Relative humidity (%)		Solar Radiation (MJ m^{-2} day^{-1})	
	Edozhigi	Ibadan	Edozhigi	Ibadan	Edozhigi	Ibadan	Edozhigi	Ibadan	Edozhigi	Ibadan
Jan	0.0	0.0	34.0	33.6	14.5	18.7	56.0	48.0	18.6	13.4
Feb	0.0	59.0	36.5	34.6	17.5	21.9	43.0	63.0	21.8	15.1
Mar	11.5	17.5	39.5	33.5	24.0	21.8	68.5	67.0	20.9	15.5
April	41.4	49.3	37.5	33.3	25.5	22.7	69.0	75.0	23.8	15.5
May	132.1	158.2	34.5	31.8	24.0	21.8	77.5	80.0	22.5	15.1
Jun	140.1	185.1	32.5	30.2	23.5	21.4	81.0	82.0	23.8	13.8
Jul	156.3	132.3	32.0	28.2	23.0	20.8	84.0	84.0	21.0	10.8
Aug	366.6	118.6	31.0	28.3	23.0	21.1	87.0	86.0	19.2	11.7
Sept	173.1	219.4	31.5	29.9	23.0	20.8	85.0	82.0	20.6	13.3
Oct	103.9	156.7	33.0	30.7	23.0	22.2	81.0	81.0	21.2	13.5
Nov	6.2	50.0	34.5	32.1	19.0	23.7	68.0	77.0	20.3	14.1
Dec	0.0	0.0	34.5	32.2	16.0	20.5	61.0	71.0	22.0	14.8
Total	1131.2	1306.1	411.0	378.4	256.0	257.4	861.0	896.0	255.7	166.6
Mean	94.3	108.8	34.3	31.5	21.3	21.5	71.8	74.7	21.3	13.9

To convert MJ m^{-2} day^{-1} to Cal cm^{-2} day^{-1} multiply by a factor of 23.92; Sources: National Crop Research Institute, Badeggi and Agroclimatological Laboratory, IITA, Ibadan

data were monitored weekly during the period of the experiment (Fig 2) from 14 days after transplanting (DAT) of rice to 112 DAT. Mean monthly climatic data during the experiment is presented in Table 1. In addition, the ground water table (GWT) depths were also monitored between these periods. After estimation of the GWT depths, peristaltic pump connected to FTT were used to collect about 20 ml of water samples into well labelled plastic vials of the same volume. Afterwards, the pH was determined using a hand held digital pH meter. Subsequently, water samples were acidified with 0.1N HCl and then placed in ice packs for onward transmission to the laboratory. Water soluble concentrations of these parameters were determined: Ca, Mg, K, P, Fe, NH_4-N and Nitrate-N. These were determined following the method of analysis of the International Institute of Tropical Agriculture (IITA, 1992).

Results and discussion

The main morphological features for the two sites are summarized in Tables 2 and 3. From the data, both sites had impeded drainage conditions. However, main differences between the two sites were in texture -the ED profiles were sandy clay to loam, while the CH plots were sand to loamy sand. In addition, there were abundance of quartz/Fe-Mn concretions in the CH-pedons compared to the ED-pedons. The organic carbon contents in each of these soils are summarized in Figs 2 and 3. Generally the OC contents fluctuated irregularly with depths and were generally higher in the surface soils compared to the sub-soils. In addition, these soils are deep when the water table allows deep digging (Table 2 and 3). Most of the soils were mottled (e.g. the ED-1, ED-2 and ED-3 as well as CH-1, CH-2 and CH-3), and /or gleyed,

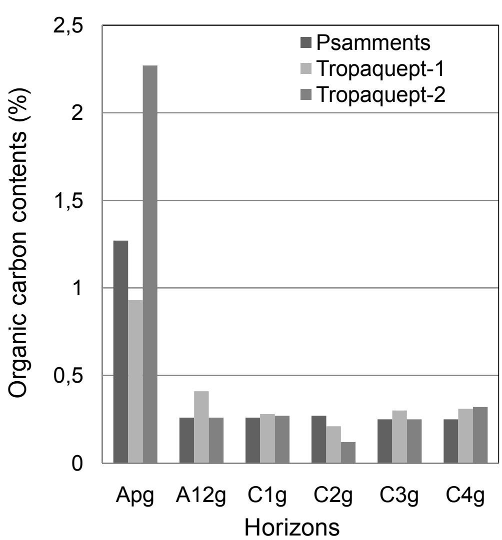

Figure 2. Organic carbon contents in the three wetland types located in the Wood/Tall grass land savanna Agro-Ecological zone

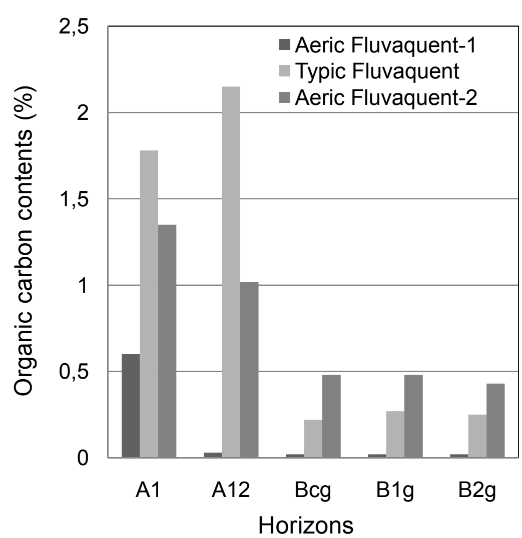

Figure 3. Organic carbon contents in the three wetland types located in the Rain Forest Agro-ecological zone

Table 2. Morphological properties of Edozhigi Soils

Horizons	Depths (cm)	Colour (moist)	Boundary	Texture	Structure	Consistence	Quartz stones	Concretions	Roots	Drainage	Mottles
Pedon ED1 : Typic Psamment (Dystric Fluvisol)											
APg	0-10	7.5YR 4/0	Cw	SCL	SAB	lo	-None	many	m.m	WD	few
A12g	10-35	7.5YR 4/0	Cw	SL	Sg	fr	-	-	f.f	PD	many
C1g	35-65	10YR 5/2	As	S	Sg	non-st	-	-	f.f	ID	many
C2g	65-75	5Y 3/2	W	S	Ma	non-st	-	-	-	ID	many
C3g	75-90	2.5 Y 4/2	Cw	S	Sg	non-st	-	many	-	ID	-
C4g	90+	10YR 4/6	-	SL	Ma	wet-st	-	many	-	ID	-
Pedon ED2 : Aeric Tropaquept (Dystric Fluvisol)											
APg	0-7	5YR 4/1	Cw	SCL	SAB	wet-st	-	-	m	PD	-
A12g	7-23	5YR 4/1	Cw	CL	SAB	wet-st	-	-	m	ID	ma.dis
Cg	23-64	7.5YR 8/2	Cw	SCL	SAB	sl.st	-	-	m.f	ID	-
C1g	64-79	10YR 5/8	Cw	SCL	Ma	st	-	-	-	ID	med.man
C2g	79-94	10YR 5/8	-	CL	Ma	st	-	-	-	ID	med.man
C3g	94-121	10YR 5/3	-	L	Ma	v.st	-	-	-	ID	-
Pedon ED3 : Aeric Tropaquept (Eutric Fluvisol)											
APg	0-6	5Y 4/1	Cs	SCL	Ma	st	-	-	m	WD	med.fw
A12g	6-23	5Y 4/1	Cs	SL	Ma	v.st	-	-	f	WD	-
Cg	23-44	7.5YRN 4/0	Cs	LS	Ma	v.st	-	-	v.f	WD	-
C1g	44-87	10YR 4/4	-	S	Sg	fr	-	-	-	PD	co.med
C2g	87-102	7.5 YR 6/4	-	SL	Ma	st	-	-	-	PD	coa.med
C3g	102-120	10YR 5/6	-	L	Ma	v.st	-	-	-	PD	ma.dis

Boundary: Cw= clear wavy, W= wavy, As= abrupt smooth., Structure: SAB=subangular blocky, Sg= single grain, Ma= massive, Consistence:lo= loose, fr= friable, non-st = non-sticky, wet-st= wet-sticky, st=sticky, v.st=very sticky, sl-st=slightly-sticky, Roots: f.f= few fine,v.f= very fine, f=fine, Mottles: med.fw= medium.few, med.man= medium many, co.med= common medium, coa.med= coarse medium, ma.dis= many distinct, Drainage: ID= impeded drainage, WD= well drained, PD= poorly drained, Textural class= TC: SCL= sandy clay loam, SL= sandy loam, S=sand, CL=clay loam, LS=loamy sand, L= loam.

Table 3. Morphological Properties of Ibadan (IITA*) Soils

Horizons	Depths (cm)	Colour (moist)	Boundary	Texture	Structure	Consistence	Quartz stones	Concretions	Roots	Drainage	Mottles
Pedon CH 1: Aeric Fluvaquent (Eutric Gleysol)											
A11	0-8	10YR 3/4	Cs	LS	v.f. cr	sl.st	-	-	co (5-10 %)	ID	-
A12	8-16	10YR 3/3	Dw	S	Sg	fr	0.10%	-	fi	ID	fine
Bcg	16-60	10YR 3/4	Cw	S	Sg	fr	3-15 %	so.com	fi	PD	coarse (>5mm)
B2g	60-75	2.5Y 4/4	Cw	S	-	fr	3-15 %	so.com	-	PD	coarse (>5mm)
Pedon CH 2: Aeric Fluvaquent (Eutric Gleysol)											
A11	0-20	10YR 2/2	Cw	SL	SAB	fr	0.10 %	-	ma.fi (5-10%)	ID	-
A12	20-26	10YR 4/6	Cw	LS	f.cr	fr	0.10 %	-	co	ID	-
Bc	26-35	2.5YR 4/0	Cs	S	SAB	sl.st	0.10 %	few	fi	ID	few
B1g	35-62	2.5YR 4/0	Cs	S	v.f.gr	non-st	-	few	-	ID	co
B2g	62-80	2.5YR 4/0	Cw	S	v.f.gr	lo	-	-	-	PD	few
Pedon CH 3: Tropic Fluvaquent (Eutric Gleysol)											
A11	0-12	10YR 2/2	Cw	LS	Ma	sl.st	-	-	ma.fi	ID	-
A12	12-28	10YR 2/1	Cw	LS	Sg	sl.st	-	-	ma.fi	ID	-
Bc	28-60	2.5YR 3/2	Wd	LS	C.SAB	fr	-	few	f.fi	Id	-
C1g	60-86	10YR 6/6	Cw	SL	Ma	fr	-	ma	-	PD	-
C2g	86+	10YR 5/8	Cw	SL	Ma	lo	-	v.ma	-	PD	ma (>5mm)

Boundary: Cs=clear smooth, Wd=wavy diffuse, Dw=diffuse wavy, Structure: SAB=sub-angular blocky, v.fcr=very fine crumb, sg=single grain, v.f.gr=very fine granular, Ma= massive, Consistence: sl.st=slightly sticky, fr=friable, lo=loose, Roots= co=common, fi=fine, f.fi=few fine, Mottles: co=common, ma=many, Drainage: ID= impeded drainage, PD=poorly drained, Concretions: so.com=soft common, v.ma= very many, Textural class: S=sand, SL=sandy loam, LS=loamy sand * International Institute of Tropical Agriculture (IITA)

having a hue of 10 YR, and low chroma that reflects poor drainage (aquic soil moisture regime) or seasonal mottling. Often mottles are so faint or fine that Munsell description may be difficult. The morphological features such as grey or low chroma (< 3) colours, mottles, and concretions observed in these pedons are indication of soil wetness brought about by the oxidation-reduction cycles due to groundwater fluctuation. The reduced iron present in these soils impart greyish colour on the soil matrix. Saturation (or soil submergence) either naturally or artificially for at least three to four months a year during rice cultivation may cause soil reduction but the degree of reduction is dependent on the organic matter content. Results of weekly rainfall distribution during the experiment at these two sites are presented in Fig 4. It showed that rainfall at NGS varied 0 mm (112 DAT) to 7.12 mm (70 DAT), and between 5.4 mm (42 DAT) to 35.8 mm (98 DAT) (Fig 1) in the RF.

Results further showed that the GWT fluctuated irregularly following the rainfall distribution at these two sites (Fig 4). The pH of water sampled at both sites ranged between

Table 4. Texture of the wetland soils at the two experimental sites

Soil properties	Soil depth 0-20cm	20-40cm	40-80cm	80-120cm
	Rain Forest (DRF)			
Sand (%)	75.7	76	72	80
Silt (%)	15.1	9.2	13.1	7.3
Clay (%)	9.2	15.1	15.1	13.1
Textural class*	LS	LS	LS	LS
	Wood/Tall grass savanna (NGS)			
Sand (%)	50	49	48	51
Silt (%)	7	5	6	8
Clay (%)	43	46	46	41
Textural class	SC	SC	SC	SC

* LS= loamy sand; SC= sandy clay

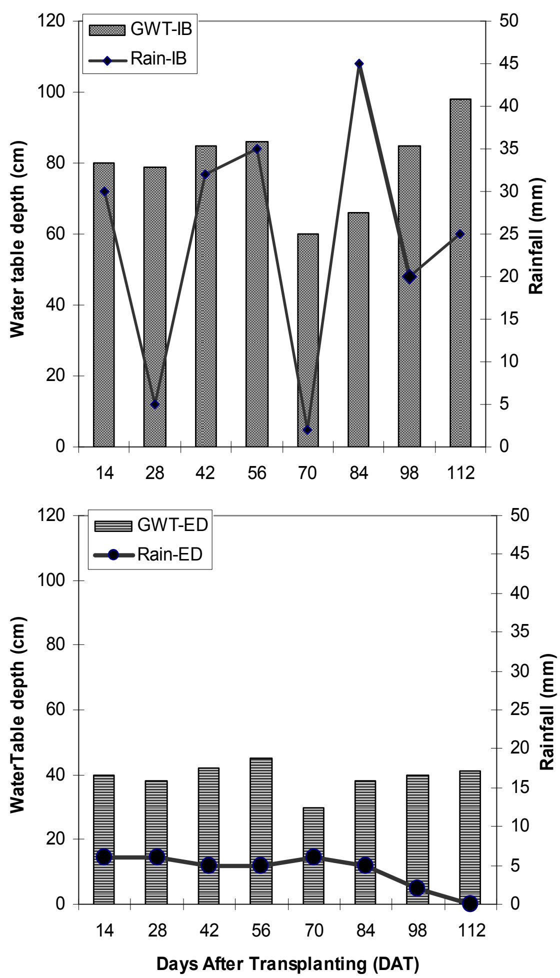

Figure 4. Weekly rainfall and groundwater table depth in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

6.0 – 6.8 throughout the whole duration of the experiment. Dynamics of water soluble Mg, K, P, Ca Fe and NH_4-N are presented in Figs 5-10. It showed that following flooding, the concentrations of these nutrient elements increased and generally declined between 56 and 70 DAT which coincided with the active tillering stage of rice plants. Nitrate-N oc-

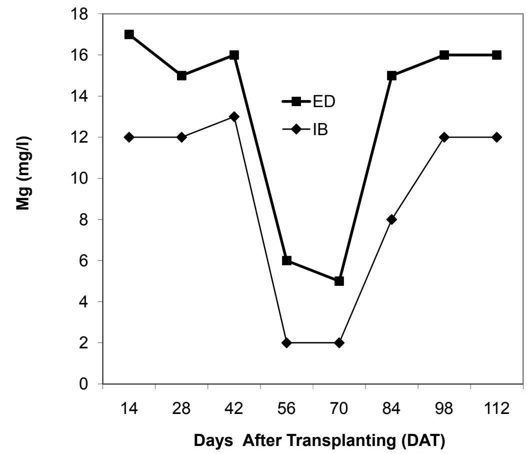

Figure 5. Concentration of water soluble Mg in the GWT in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

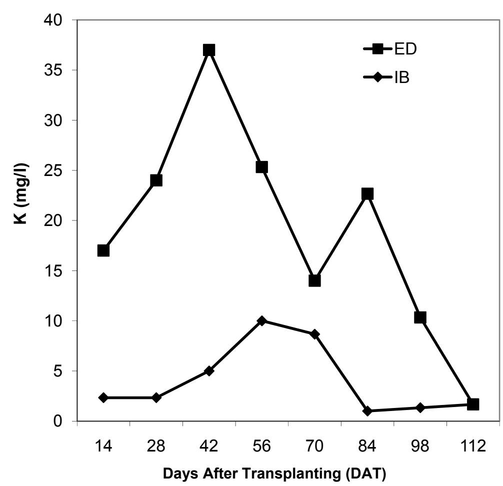

Figure 6. Concentration of water soluble K in the GWT in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

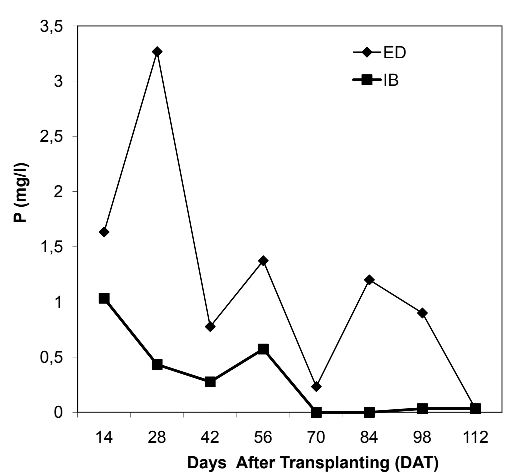

Figure 7. Concentration of water soluble P in the GWT in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

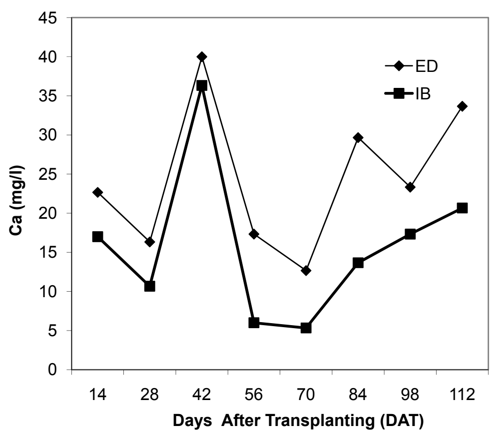

Figure 8. Concentration of water soluble Ca in the GWT in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

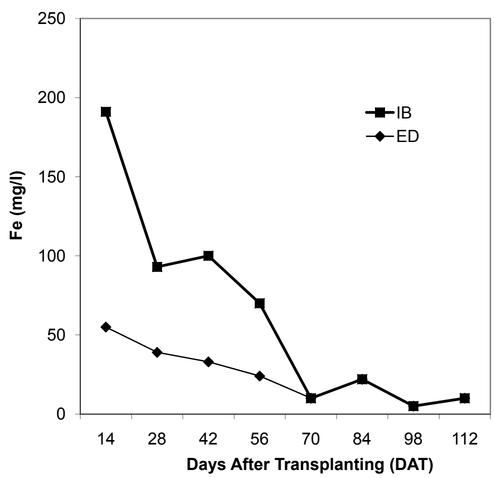

Figure 9. Concentration of water soluble Fe in the GWT in the Guinea savanna (ED) and Dry Rain Forest (IB) in Nigeria

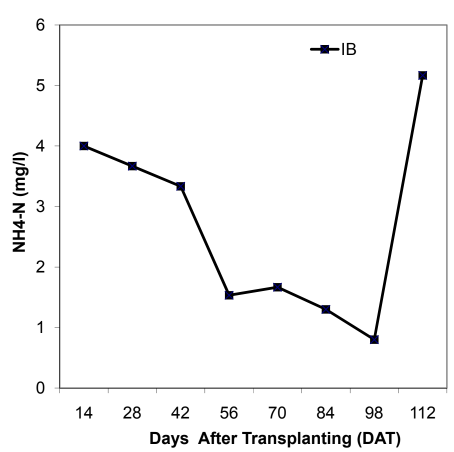

Figure 10. Concentration of water soluble NH_4-N in the GWT at Ibadan, Dry Rain Forest (IB). (Results from the Guinea savanna not presented)

curring in the rooting zone is used for metabolic purposes in the plant. This was agreement with the findings of Seth et al. (2005) and Sahrawat (1998).

The inherent fertility of West African soils, like other soils of tropical Africa, is closely related to the parent material (Ahn, 1970; Kang, 1973; Olaleye et al., 2005). The inland valley soils and associated valley bottom and alluvial soils used for rice cultivation receive regular inputs of nutrients with run-off water and irrigation water, hence the natural soil fertility is maintained. Morphology is the most distinct and diagnostic characteristic of the hydromorphic soils (Vepraskas and Guertal, 1992). Under submergence, the concentrations of Ca, Mg, and K have been reported to increase in the soil solution (Sahrawat, 1998). Irrigation water has also been reported to contain substantial concentration of these nutrients (Kang, 1973). The knowledge of the dynamics of these nutrients and the soil physico-chemical properties have been used to ameliorate these soils (Olaleye and Ogunkunle., 2008) so it is now possible to know the exact planting and when to apply fertilizers to these soils. These knowledge have been transferred by the Hirose project, based within the International Institute of Tropical Agriculture (IITA), to some Nupe farmers in the middle belt (Guinea savanna agro-ecological zone) of Nigeria (Fashola et al., 2006).

Conclusions

In the wetlands of Nigeria, the fertility of the soil and the groundwater table could be used to predict the fertility status of such soils as flooding regime automatically confer much stability and productivity for its use especially during the rainy seasons when used for rice cultivation. This flooding during the rainy seasons would benefit rice plants and the high organic carbon contents in the soils could be a substantial factor in the maintenance of these soils for the cultivation of arable crops during the dry seasons. In addition, it is observed that in most of these soils, Fe-toxicity (excessive Fe-uptake) one of the factors that hinders rice production in these soils, along with deficiencies in P, K, Mg and Ca that resulted in bronzing or yellowing symptoms of rice. Results of this study showed that the contents of the aforementioned cations and P may be increased via fertilization and appropriate water management practices between 56 and 70 DAT.

References

Ahn, P.M. (1970): West African Soils. Oxford University Press, Oxford, 232P.

Black, C.A. (1965) Methods of Soil Analysis Agronomy No. 9. Amer. Soc. Agronomy, Madison, Wiscosin.

Fashola, O, Oladele, O., J Aliyu and Wakatsuki, T. (2006). "Practice change for sustainable communities: Exploring footprint, pathways and possibilities". Proceedings of the 2006 APEN International Conference, 3 - 6 March 2006, Beechworth, Victoria.

FAO (Food and Agriculture Organisation) (2006). Guidelines for description. 4th EDITION. Food and Agriculture Oraganizations of the United Nations. 97pp.

Frenken, K.; and Mharapara, I. (2002). Wetland development and management in SADC countries. Proceedings of a sub-regional workshop, 19-23 November 2001. Harare, Zimbabwe: FAO Sub-regional Office for Southern and East Africa.

Issaka, R.N., Ishida, F., Daisuke Kubota and T. Wakatsuki. (1997) Geographical distribution of selected fertility parameters of inland valleys in West Africa. Geoderma 75: 99-116.

Imolehin E.D. and Wada, A.C. (1999). Meeting the rice production and consumption demand of Nigeria with improved technology. International Rice Commission Newsletter. Vol. 49. Published online at http://fo.org/docrep/x7164t/x7164101.htm

IITA (International Institute of Tropical Agriculture) (1992): Automated and semi-automated methods for soil and plant Analysis. IITA Agric. Manual Series of IITA, Ibadan, Nigeria.

Kang, B.T. (1973): Soil fertility problems in West Africa in relation to rice production. Paper presented at the seminar on Rice soil fertility and fertilizer use. Jan. 22 - 27, 1973. West Africa Rice Development Association, Monronvia, Liberia.

Kirsten, D.S. (2005): Economic consequences of wetland degradation for local populations in Africa. Ecol. Econ. Vol 53(2): 177-190.

Kyuma K., Kosaki, T. and Juo, A.S.R. (1986) Evaluation of the fertility of the soils, In: A.S.R. Juo and J.A. Lowe (Eds). The Wetlands and Rice in sub-saharan Africa. IITA, Ibadan, Nigeria, pp. 43-58.

Olaleye A.O. , Ogunkunle, A.O. Sahrawat, K.L. Osiname O.A. and Ayanlaja, S.A. (2002): Suitability evaluation of selected wetland soils in Nigeria for rice cultivation. Tropicultura/Agri-Overseas, Belgium.Vol. 20 (3): 97-103.

Olaleye A.O., A.O. Ogunkunle, K.L. Sahrawat & B.N Singh. (2001): Characterization of some benchmark wetland soils in Nigeria for rice cultivation. Comm in Soil Sci & Plant Anal (USA). Vol. 32 (1&2): 189-208.

Olaleye, A.O., O.A. Osiname and O. Cofie. 2005. Soil and water management for rice production in Nigeria, In E.Y.H Bobobee and A. Bart-Plange (Eds). Hunger without Frontiers. Proceedings of the 2nd West Africa Society of Agricultural Engineering/International Conference on Agricultural Engineering. KNUST, Kumasi, Ghana. pp 358-369.

Olaleye, A.O. and A.O. Ogunkunle. 2008. Management of Two Potentially Iron Toxic Benchmark Wetlands Using Integrated Approach for Rice Production in Nigeria. Accepted for publications Journal of Agronomy and Crop Sciences. Doi: 10.111/j1439-037x.2008.0030.x

Sahrawat, K.L. (1998): Flooding soil: a great equalizer of diversity in soil chemical fertility. Oryza, Vol 35 (4):300-305.

Seth, R.R; R.K. Panda & R.B. Singandhupe.(2005): Study of nitrate movement in a sandy loam soil. Archives of Agronomy and Soil Science.

Singh, B.N., Fagade, S., Ukwungwu, M.N., Williarn, C., Jagtap, S.S., Oladimeji, O., Effisue, A. and Okhidievbie, O. (1997) Rice growing environments and biophysical constraints in different agroecological zones of Nigeria. Met. J., 2(1): 35-44

Verpraskas, M.J. and R. Guertal. (1992): Morphological indicators of soil wetness. 307-312.Proc of Eight International soil correlation meeting: 66-74. in: Proc of the Eight Int. Soil Corr. Meeting (VIII ISCOM): Characterization, Classification, and Utilization of Wet soils. Oct 6 - 21. J.M Kimble (Eds.).

acs74_05