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ASSESSING THE PHYSICO-CHEMICAL PROPERTIES OF IRRIGATED SOILS FOR SUSTAINABLE RICE PRODUCTION IN PATIGI KWARA STATE, NIGERIA

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ABSTRACT

This paper examines the physical and chemical properties of irrigated soils of a rice producing area in Kwara State with a view to identify the limiting soil physical and chemical properties whose proper management can enhance and increase rice yield to meet its demand in the country. Forty 100m x100m quadrats were demarcated from the 80hectares of irrigated rice field in Patigi, a total of 80 composite soil samples were randomly collected at 0-15cm (top soil) and 15-30cm (Sub soil). The samples were treated and subjected to standard laboratory analysis using standard procedures. Sixteen physical and chemical soil elements that are essential in rice cultivation were analyzed. Coefficient of Variation (C.V), Analysis of Variance and Factor analysis (FA) were used to summarize the data. Factors with eigenvalues >1 were retained, and the factors after subjected to varimax rotation reduced the 17 analyzed soil properties to Five Factor Components (FCs). The result shows that Available Potassium and Water Holding Capacity fall within the medium group. This implies that their availability in balance proportions is essential to support sustainable rice cultivation. It was also revealed that the contents of sodium, Nitrogen and Bulk density fall within the low group. This implies that these properties limit rice growth in this area. The study recommends that soil parameters in the medium and low groups should be adequately managed for better and sustainable rice production in the study area and similar environment through properly management of irrigation system such that it allows regular water supply to the farmland and adequate and timely application of fertilizer; to prevent the soils from being less suitable for plant growth, either through chemical or physical changes.

Keywords: Cultivation, Sustainability, Irrigated rice, Soil, Physical and chemical properties

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INTRODUCTION

In Nigeria rice (*oryza sativa)* is one of the major staple food that provides the nation with about a minimum 2,400 calories per person per day (F.A.O 2000). International Rice Research Institute (IRRI, 2001) reported that an average Nigerian consume24.8kg of rice per year, representing 9 per cent of annual calorie intake. The Central Bank of Nigeria (CBN, 2010) in one of its report stated that annual demand for rice in the country is estimated at 6 million tonnes, while production is about 3.5 million tonnes of milled rice, resulting in a deficit of 2.5 million tonnes. In order to bridge this production gap, government had to import over 2 million tons of rice in year 2011 and 2012. The country therefore becomes the largest importer of rice in Africa. Due to its contribution to the capital calorie consumption, the demand for rice has been increasing at a faster rate than domestic production since the 70s. But unfortunately, production per hectare has not been able to meet the demand when compared with other African countries in south of Sahara (WADA, 2007).

This crop requires an adequate supply of nutrients to achieve the high yields necessary to feed growing populations. Many of these nutrients come from the soil. On a general note, adequate information about these component parts of agriculture has been observed by Olabode (2012) as a pathway to the scientific research based for sustainable agricultural development. Previous study on rice in this area identified inadequate processing machine, finance, poor access to inputs, pest and diseases (Matanmi *et al.*, 2011) and incidences of pest and quellar birds ravage (Olabode, 2012) as the limiting factors of abundant rice production in Patigi and its environ, these studies did not consider edaphic factor as important in rice growth and development for optimum and sustainable yield. Therefore, for Nigeria to be successful in revolutionizing rice production as contained in the Rice Farmers Associations 10-year rolling plan called, "Target 2012 Grains Revolution" she must not only stop importation of rice and encourage local production but also understand different rice production systems and the chemistry of rice soils. In view of this, the objective of this paper is to examine soil physical and chemical properties that will facilitate increased rice yield and sustain its production to meet the demand in the country.

STUDY AREA

Duku-Lade Rice Irrigation Scheme in Lade, Patigi Local Government Area of Kwara State is selected as the study site (see Figure 1). This area is geographically located within $8^{0}50^{1}$ N and $5^{0}25^{1}$E of the equator. The Local Government Area shares common boundaries with Niger State, Kogi State as well as Edu and Irepodun Local Government Areas (Figure 1). In addition, the Length of Growing Period (LGP) in the area is short; thus the soil requires some forms of supplementary irrigation to ameliorate drought condition during critical stages of rice growth and development. The area falls within sub humid climate with distinct wet and dry seasons lasting between April and October and November to March respectively. The rainfall ranges between 50.8mm in driest month and 2413.3mm in wettest month of the year. The average minimum temperature ranges between 21.1^{0}c and 25.0^{0}c while the maximum is between 30^{0}c and 35^{0}c. Typical of the study area is Feralsols and Hydromorphic soils. They are deeply weathered red and yellowish brown soils with abundant free iron oxides but generally without a lateritic iron pan layer. The soils belong to the order of OXISOLS in American system of soil classification. The soil parent materials are in form of sedimentary rocks formed on sandstone and developed into Mineral hydromorphic soil according to Areola (1982). The hydromorphic soils are seasonally waterlogged soils. They are whitish or grayish in colour, an evidence of poor drainage, which reduces oxides in the soil. They are found in the valleys of most rivers and streams in the study area but widespread along the Niger River. The climax vegetation was tropical deciduous forest but the influence of man, especially farming activities has turned it into dry woodland savanna, which characterized with scattered trees and tall grasses. Because of topographic changes, rainfall differences and edaphic factors, some pockets of other distinct vegetation types found within the study area. Various vegetation species contained here are; Raphia Palm (*Raphia Sardomical*), *eiba Pentandra*, and *Lannea Acida* among others.

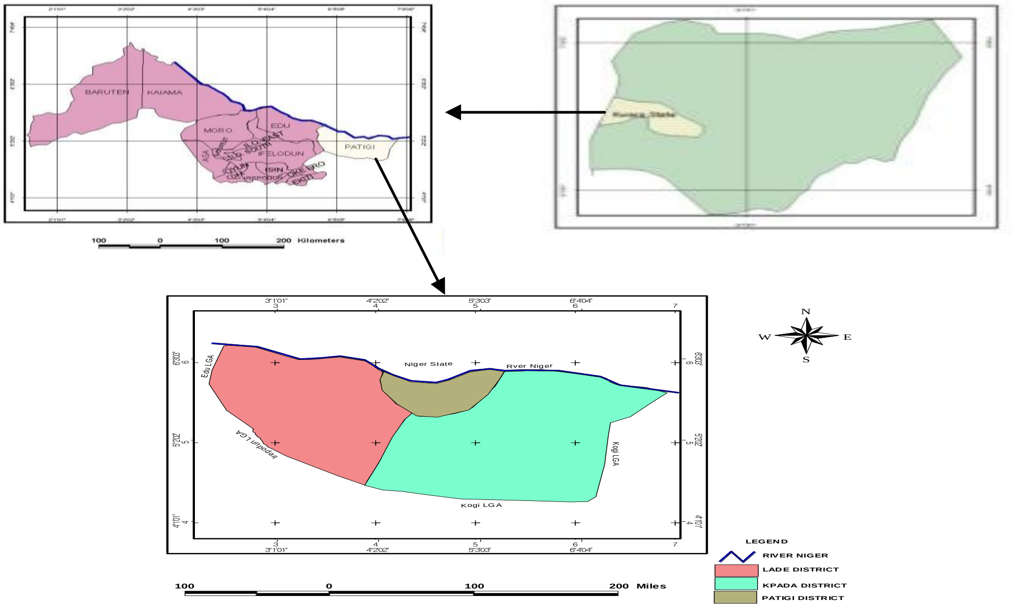

Figure 1: Map of the study area

MATERIALS AND METHODS

The Irrigated Rice Field is composed of eighty (80) plots of cultivable land which is presently under intensive irrigation rice cropping by 50 participating farmers. This scheme was commissioned in 1960 to supplement rain water which hitherto was not sufficient for rice production in the area. This was neglected until after forty-five years when it was revisited and enhanced. Since then, the effort has been yielding fruits towards ensuring double harvest of rice twice in a year. The selection of this field is based on availability of data, accessibility, and ecology of rice plantation and the progress of development in the project site. Soil samples were taken from

Duku-Lade Irrigated Rice Field - the dominant rice systems of the study site. Samplings from predetermined depth of 0-10cm for the topsoil and 10-30cm for the subsoil were considered in order to establish comparability between samples collected from various sample quadrants. This is because the roots of plants are usually concentrated in the top 30cm of the profile where the bulk of plant nutrients are harboured. For example, rice roots concentrate in this zone. From each of the two soil classes, a total number of 40 soil samples were taken from the demarcated 40 quadrants each measuring 100m x 100m on the Irrigated Rice Field. In each of these quadrants, five samples were randomly located and a composite sample was collected at a predetermined depth; 0 – 15cm and 15 – 30cm representing top soil and sub-soil respectively. In view of this, a total of 80 soil samples were collected and later air-dried in the laboratory for further analysis.

The soil samples were air dried, crushed and passed through a 2mm sieve with consideration to the specific soil parameters rice require to grow and develop. As noted by, sixteen elements that, which are required in large quantity. The soil parameters considered are the particle size distribution by Bouyoucos, G.H (1951), the bulk density (Black, 1965) and Water holding capacity, Exchangeable cations (Ca^{++}, Mg^{++} , Na^{+} and K^{+})(Juo, 1981), Exchangeable acidity. Soil pH, Available phosphorus (Bray and Kulz 1945), Cation exchangeable capacity, Base saturation, Organic matter content by Walkley and Black Method (1934), modified by Juo (1981) and total nitrogen content by Kjeldahl (Bremmer 1965). They are essential in rice nutrition according Verma and Bhagat (1992) and IRRI (2012). Coefficient of Variation (C.V) was used to examine the degree of variation within the set of variables. Variation only exists when C.V. is greater than 33% (Olubusoye and Olaomi, 2002). The inferential statistics relevant to this study include; Correlation, Principal Component and factor Analysis. Factor analysis (FA) was carried out using correlation (standardized/transformed data) matrix of the statistical software SPSS Windows version 17.0. The factors with eigenvalues >1 were retained; and factors subjected to varimax rotation to reduce soil properties to highly correlated major component groups. The identified factors are rotated to provide a better description of the variable pattern. Therefore, factor loadings were selected in categories as put forward by Gareth and Dennis (1984); such that ± 1.00-0.7 high; ± 0.69-0.50 medium; and ± 0.49-0.30 low.

RESULTS AND DISCUSSION

The mean, standard deviation and coefficients of variation of the physical properties in the top and sub soils are presented in Table 1. It is identified that clay is mostly varied among all other soil physical properties in both topsoil (41.92%) and subsoil (41.17%). This could be as a result of the nature of system of irrigation being practicing in this area. Thus, the results generated from the coefficient of variation statistics show that the soils in the study site are relatively homogenous in view of their textural composition. This was arrived at based on the nature of the parent material that gives rise to such soil physical composition within the study area. Table 2, 3 and 4 presented the rotation of the factors, simplified factor matrix and eigenvalue that indicate new variables from original data, restructuring of the new five factors and both the total and cumulative variance as explained by the factor analysis. Factor analysis reduced 17 measured soil properties into Five Factor Components (FC) groups that explained >63% of the total variability. This is done by separating significant clusters of variables, without altering their relative positions.

Table 1: Variability of soil properties in top and sub soil

Soil Properties	Top Soil			Sub Soil		
	Mean	**S.D**	**C.V**	**Mean**	**S.D**	**C.V**
Physical Properties						
Sand (%)	80.00	5.54	6.93	74.92	6.52	8.70
Silt (%)	9.90	4.15	41.92*	11.78	4.85	41.17*
Clay (%)	10.27	2.53	24.63	14.53	2.54	17.48
Bulk Density	1.88	0.22	11.70	1.94	0.31	15.98
Water Holding Capacity	8.36	2.26	27.03	6.76	3.21	47.49*
Chemical Properties						
Ph	5.74	0.33	5.75	5.23	0.27	5.16
Total Nitrogen (%)	1.48	0.33	22.29	0.86	0.28	32.56
Organic Carbon (%)	0.67	0.14	20.89	0.52	0.16	30.77
Organic Matter (%)	1.17	0.27	23.08	0.93	0.34	36.56*
Exchangeable Na^+ (cmol/kg)	1.23	0.21	17.07	0.77	0.19	24.68
Exchangeable Ca^{++} (cmol/kg)	5.00	1.00	20.04	3.37	1.89	56.08*
Exchangeable Mg^{++} (cmol/kg)	2.46	0.98	39.84*	3.18	0.21	6.60
Exchangeable K^+ (cmol/kg)	1.24	0.19	15.32	0.28	0.12	42.86*
Exchange Acidity H^+ (cmol/kg)	0.22	0.24	109.09*	5.36	2.01	37.50*
Available Phosphorus (mg/kg)	7.09	2.12	29.90	8.75	1.39	15.89
Cation Exchangeable Capacity (cmol/kg)	10.06	0.89	8.85	1.29	0.92	71.32*
Base Saturation (%)	99.28	0.42	0.42	99.15	0.51	0.51

S.D=Standard Deviation. C.V= Coefficient of Variation *C.V >33.33%

Factor Component I was directly related to *'textural property'* of soil, it explained 19.2% of the total variance (Table 3) with a positive and negative high loading from Sand and Silt respectively (Table 4) with negative medium and low loading from clay and sodium in the soil structure model(Table 4). This factor is characterized with low rate of nutrient-holding capacity due to reduced level of clay content. In addition, the soil is less sodic and this reduces its rate of being deteriorating because water infiltrates and percolate easily. Component II named as *"soil Organic base nutrient material"* explained 13.9% of the total variance with a positive high loading from organic matter and organic carbon, negative medium loading from Available Phosphorus (AP). The factor played crucial role for nutrient holding in soil pool and responsible for plant vegetative growth; while soil AP showed negative loading due to its present status as assumed by the low organic matter of the entire soil. Component III, called *'soil primary nutrient'* explained 12.3% (table3) of variance with positive and negative high loading from potassium and exchange acidity respectively. There is also positive medium loading from sodium, positive low loading from nitrogen and CEC respectively while pH has low negative loading. The result of this loading structure is expected because the high level of acidity decreases pH, which in return increases the content of potassium in the soil. Component IV is named '*soil secondary nutrient"* with 10.4% of total variance. The factor has positive and negative high loading from Magnesium and Calcium respectively (Table 4). This indicates calcium and magnesium as the two most dominant cations of this nutrient group. Component V is called *'base saturation'* which has positive high loading from Base Saturation, medium negative loading from water holding capacity and positive low loading from Bulk Density (Table 4). This factor has total of 7.8% variance. The factor explained that the soil holds water poorly because of low soil compaction.

Table 2: Rotated factor loadings of a five factor model of soil properties in the irrigated rice

Variables	**Component**				
	I	II	III	IV	V
Sand	.929*	-.115	.151	-.024	-.054
Silt	-.801*	-.038	.001	.019	.057
Clay	-.563	.338	-.296	-.089	.077
Bulk Density	.197	-.152	.224	.120	.493
Water Holding Capacity	.203	-.144	.095	.079	-.573
Ph	.279	.223	-.377	-.473	-.322
Total Nitrogen	.251	.080	.430	.332	-.343
Organic Carbon	.000	.921*	.001	.111	.057
Organic Matter	-.020	.905*	-.054	.074	.211
Sodium	-.308	-.219	.532	.165	-.435
Calcium	.215	-.050	.171	-.873*	-.046
Magnesium	.220	.058	.051	.826*	.046
Potassium	-.003	.155	.733*	-.107	.102
Exchange Acidity	-.312	.104	-.776*	-.087	-.020
Available Phosphorus	.224	-.656*	-.374	.184	.088
Cation Exchangeable Capacity	.266	.111	.372	-.107	-.090
Base Saturation	-.124	.177	-.069	.185	.786*

The study confirmed Sand as the largest particle in the soils of this area with little proportion of silt and clay. This soil is light and typically low in water retention capacity due to very low organic content. This as well affected the pH of this area. The soils are often the first to become acidic because water percolates rapidly, and contain only a small reservoir of bases (buffer capacity) due to low clay and organic matter contents. Soil pH in most of the samples (60%) in the study area is strongly acidic. The level of pH in both soil layers is adequate for the decomposition of organic matter thereby increasing the availability of Phosphorus, Magnesium and Calcium in the soil for rice production. This is also reflected in the low content of the recorded CEC values. The effect of low CEC in most of the soils shows that the soils have a low resistance to changes in soil chemistry caused by continuous farming system.

Table 3: Eigen value, Total and cumulative variance explained by factor analysis

Factors	Eigen Value	% of Total Variation	Cumulative Variation
I	3.26	19.16	19.16
II	2.36	13.91	33.07
III	2.09	12.28	45.35
IV	1.77	10.40	55.75
V	1.33	7.79	63.55

Table 4: Factor Labels and Structure for Soil Properties

Factors	**High**		**Medium**		**Low**	
FCI	Properties	Values in Soil	Properties	Values in Soil	Properties	Values in Soil
Positive	Sand	> 80(%)	None	-	None	-
Negative	Silt	< 30 (%)	Clay	<15 (%)	Sodium	< 2 (%)
FCII Positive	Organic Carbon	< 1 (%)	None	-	None	-
	Organic Matter	< 2 (%)	None	-	None	-
Negative	None	-	A Phosphorus	< 12 (mg/kg)	None	-
FCIII Positive	Potassium	< 2 (%)	None	-	Nitrogen CEC	< 2.5 (%) < 12
Negative	Exchange Acidity	1 (%)	None		pH	< = 6.5 (1:1)
FCIV Positive	Magnesium	< 5.0 (cmol/kg)	None	-	None	-
Negative	Calcium	< 7 (cmol/kg)	None	-	None	-
FCV Positive	Base Saturation	> 90 (%)	None	-	None	-
Negative	None	-	WHC	< 14 (%)	Bulk Density	< 3 (g/cm^2)

Key to categories: ± 1.00-0.7 high; ± 0.69-0.50 medium; and ± 0.49-0.30 low (first order approach)

Generally, the concentration of nutrient cations is higher in the topsoil but lower in the subsoil. This is because of low leaching activities in this type of soil and the environment. This allows for largest proportion of cation at the topsoil layer to be retained. This trend of the nutrient cations as observed in this study is in conformity with the ideal situation for rice cultivation. This clearly described the effectiveness of the Gravity Irrigation method adopted at the rice field. This type of irrigation does not encourage leaching but allows water to flow through a drainage channel along and in between the farmland as observed and recommended by Chambers (1988), as a major and perhaps the best irrigation system that distributes water through the command area, allowing it to seep and to provide water for rice cropping system. The mean values of Total Nitrogen for topsoil (1.48) and sub soil (0.86) is adequate in the soil of this area, being higher than the 0.05% critical limit for most crops (Gbadegesin, 1984) and this is required in the greatest amount for maximizing rice yields. The existing relationship between total nitrogen and other soil elements such as clay content and exchange acidity is such that proper application of N fertilizers will be necessary so as to facilitate improved crop growth and grain yields, especially on intensive irrigation fields.

The C.V. values of the Available Phosphorus contents for both topsoil (29.9%) and subsoil (15.9%) is the reflection of Potassium trend in the soil whereby the soils nutrients are both homogenous. This shows that, these two crucial elements are needed equally in the area of study for effective crop yield, because of Available Phosphorous stimulates young root development and early fruiting. Though available Potassium levels below 0.2cmol/kg according to Hazelton and Murphy (2007) suggests that crop response to the application of potassium fertilizer is possible, particularly where heavy removal of potassium by harvesting or grazing occurs as revealed by this study. The observed case of Soil Organic Matter (SOM) revealed that this soil element is homogenous in the topsoil but varied in sub layer considered this soil element to create negative effects on crop productivity; therefore improving its level was a prerequisite to ensuring soil quality; and future agricultural productivity and sustainability as reported by Katyal *et al*. (2001). It is therefore mandatory to respond to nutrient management with consistent application of mineral fertilizers, manure or the practice of green manuring to influence this soil nutrient.

Finally, the soil simplified factor model (Table 4) for the irrigated rice system is presented by identifying Sand (> 80), Silt (< 30), organic carbon (< 1), organic matter (< 2), exchange acidity (< 2), potassium (1%), magnesium (< 5.0 cmol/kg), calcium (< 7 cmol/kg) and base saturation (>90) as leading soil elements of this area. Although some elements like clay, P and WHC fall within the medium group. These soil elements are expected to be available continuously and in balance proportions to support sustainable rice cultivation. Meanwhile, the content of other soil properties that appeared in low group could reduce yield, being the most limiting of the essential rice growth factors. In this case, intensive soil management should be adopted to improve the low group soil properties with minimum requirement for rice yield maximization.

CONCLUDING REMARKS AND RECOMMENDTIONS

The study has assessed the physical and chemical contents of soils within irrigated field in Patigi area. Irrigation system is found to be essential for rice cultivation in the study area based on the nature and character of the soil of this environment. It is also evidently clear that not all the soil properties have adequate content that can support appreciable rice yield that will meet the demand. It is therefore mandatory to respond to nutrient management with consistent application of mineral fertilizers, manure or the practice of green manuring to influence this soil nutrient. The study recommends that rice farmers and farm managers should develop management strategies to increase rice production in their various capacities. In other words, proper and effective management of irrigation system such that it allows regular water supply to the farmland and adequate and timely application of fertilizer; to prevent the soils from being in less suitable and of medium status for plant growth, through chemical or physical changes. This will not only sustain rice production but also increased food supply.

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