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Land Suitability Evaluation of Kubanni Floodplain for Rice Production in Zaria, Kaduna State, Nigeria

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ABSTRACT

Land suitability evaluation analysis is necessary to achieve optimum management and utilization of available land resources for sustainable agricultural crop production. The objective of this study was to determine the suitability of Kubanni floodplain for rice production in Zaria, Kaduna State, Nigeria. Qualitative and quantitative land suitability evaluation of two mapping units in Kubanni floodplain which covers an area of 11.6 ha was carried-out using the detailed soil survey method of classification. Generally, the surface soil texture was sandy loam to loam. The soil reactions were slightly acidic to neutral, organic carbon; available phosphorus and total nitrogen were rated low. The CEC (NH_4OAc) were medium and base saturation was rated high while EC and ESP were low. Qualitatively, soil mapping units (KBI and KBII) were currently not suitable (N1) for rice production due to limitation imposed by soil chemical properties. Quantitatively, soil mapping units (KBI and KBII) was also currently not suitable (N1) while potentially KBII was marginally suitable (S3). With proper soil fertility management, the potential of these soils can be raised to moderately suitable (S2) for rice through an increase in organic matter to improve soil structural development, drainage and aeration thereby improving the fertility of the soils.

Keywords: Qualitative, Quantitative, Suitability, Floodplains, Rice.

INTRODUCTION

Nigeria is the most populous country in Africa, with a population of over 160 million people. Its domestic economy is dominated by agriculture, which accounts for about 40% of the Gross Domestic Product (GDP) and two-thirds of the labour force (Tunji, n.d.). Agriculture supplies food, raw materials and generates household income for the majority of the people. In Nigeria today, the need for increased food production to feed the ever-increasing human population and to diversify the export base crops of the country is more recognized now than ever before. This has turned the attention of both farmer and government to the exploitation of floodplains which are believed to have more agricultural potential than the upland soils (Esu, 1999). Land suitability evaluation is the process of making predictions of land performance over time based on specific types of uses (Rossiter, 1996). This assessment is always carried out separately for each category of land use (Reshmidevi *et al*., 2009). Land evaluation can tell farmers how suitable their land is in terms of soil limitations to specified land use and management practices. Soil suitability classifications are therefore based on knowledge of crop requirements, prevailing soil conditions and defined soil management. In other words, soil suitability classifications specify to what extent soil conditions match crop requirements under defined input and management circumstances (FAO, 1976 cited in Jimoh, 2015). The suitability looks at the limitations imposed by soil properties, landform and other features which do not form a part of the soil but may have a significant influence on using the soil. From the basic soil requirements of crops, a number of soil characteristics are directly related to crop yield performance. The function of land evaluation is to bring about an understanding of the relationships between the condition of the land and the uses to which it is put to and to present planners with comparisons and promising alternative options.

The food sub-sector of Nigerian agriculture parades a large array of staple crops, this includes sorghum, maize, millet, rice, wheat etc. Of all the staple crops, rice has risen to a position of preeminence. Rice (*Oryza sativa)* as a cereal grain is the most important staple foods for a large part of the world's human population. Rice is the grain with the second-highest worldwide production, after maize (FAOSTAT, 2005), rice is the most important grain with regard to human nutrition and caloric intake, providing more than one-fifth of the calories consumed worldwide by the human species (Smith, 1998). Rice which is the most consumed grain is short in supply, and there is growing demand to increase its production in Zaria environ. They are widely regarded as a superior food, which until recently was mainly consumed by city dwellers and middle and higher income earners (Dawam, 2000 cited in Aondoakaa and Agbakwuru, 2012). It is in this direction that a land suitability evaluation study is relevant.

De Detta (1981) as cited in Jimoh (2015) maintained that land data should be made available and understandable to the users by providing interpretative ratings for specific land use. The land qualities and land use requirements should be matched to enable farmers to maximize output in agricultural production by identifying the land qualities and the requirements for various land**s** for effective management. Thus, the land suitability studies will assist in identifying soils for optimum yields for rice in Zaria. Therefore, information is needed on soil qualities and climatic conditions of the area to ascertain the suitability of the soil for rice cultivation. Studies on land evaluation are few in Nigeria as reported by Atofarati *et al*. (2012) that the major factor limiting agricultural productivity in the country is inadequate information on land characteristics. A number of studies have been carried out in the country to enrich our soil databank; this includes Oluwatosin (2005) who assessed suitability of some land in Northwestern Nigeria for rainfed crop production using a qualitative land evaluation method. The study revealed that all the soils were currently not suitable (N1) for cereals but were marginally suitable (S3) for grain legumes. The major limitations were nutrient availability (f) which cut across all the soil while erosion hazard and drainage were a major limitation in the upland and valley bottom respectively. In addition, Lawal *et al*. (2012) evaluated the suitability of soils of lower river Oshin floodplains in Kwara State, Nigeria for rainfed arable crops using the FAO land suitability evaluation method. They reported that all the soil units were moderately suitable (S2) for maize production while for rice production, the area was marginally suitable (S3) with topography, soil texture and soil fertility being the major limitation. Despite the importance of land evaluation on the sustainable management of land and for enhanced crop production, specific soil suitability studies such as suitability assessment for rice production have not been properly documented in literature. This study attempts to contribute to existing knowledge as well as fill the locational gap in knowledge on soil suitability assessment in Zaria.

MATERIALS AND METHODS

Description of the study area

Kubanni floodplains, Zaria, Kaduna State ($11^0$06'50"N - $7^0$40'22"E) is characterized by Northern Guinea Savanna vegetation type. The area is intensively cultivated to an array of crops such as maize, rice, cowpea, onion and tomato. The length of growing period is 150-180 days (Yakubu, 2004). Zaria lies within a region which has a tropical Savanna (Aw) climate type with distinct wet and dry season (Kowal and Knabe, 1972). It is characterized by long dry season from November through March while the wet season from April to October with a mean annual rainfall of 1100mm. The temperature fluctuates within a range from 22^0C during cold nights to over 38^0C during the hot days. The relative humidity during dry season is about 15% and reaches up to 60% during the rainy season (Kowal and Knabe, 1972). Geologically, the area lies within the high plains of Northern Nigeria characterized by landforms which consist of inselbergs and pediment landscape overlying the basement complex which is nearly level to gently undulating plains (Yakubu, 2004).

Soil Sampling

A detailed soil survey using rigid-grid method (100 m × 100 m) on 11.6 ha land was carried out. Soil units were mapped out based on colour, texture, drainage and depth; two modal profile pits were dug and examined according to Soil Survey Staff (2010) procedure. Bulk soil samples were collected from various genetic horizons identified within the profile pits of each soil unit. The samples were air-dried, sieved with a 2mm sieve size and analyzed in the laboratory for physical and chemical properties.

Laboratory analyses

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1979). Soil pH was measured in water using glass electrode pH meter (Agbenin, 1995). Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). The cation exchange capacity (CEC) was determined using the ammonium acetate method (Agbenin, 1995). Base saturation was calculated as the sum of total exchangeable bases divided by cation exchange capacity (NH_4OAc) (Agbenin, 1995). Available P was determined using Bray 1 method (IITA, 1979). Total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Exchangeable bases (calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in the soil were determined using the ammonium acetate extract from the CEC determination. Sodium and K were determined using flame photometer while Ca and Mg was determined using atomic absorption spectrometer. Electrical conductivity was determined using Wheatstone bridge method (Agbenin, 1995) while exchangeable sodium percentage (ESP) was calculated as the percentage sum of total exchangeable sodium divided by cation exchange capacity (NH_4OAc) (Agbenin, 1995).

Land Evaluation

Qualitative land suitability evaluation for rice production

Qualitative or Non-parametric method of land suitability evaluation for rice was carried out using the FAO method (FAO, 1983) (Table 1). Key environmental factors considered in the evaluation were climate (annual rainfall, temperature), topography (slope) and soils. The identified soil units were placed in suitability classes by matching their characteristics with requirements of the test crop. The most limiting characteristic dictate overall suitability for each soil unit using limiting condition procedure. The suitability of each factor for respective soil unit was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) or not suitable (N).

Quantitative land suitability evaluation for rice production

In quantitative (parametric) method of land evaluation, each limiting characteristic was rated as follows: S1 (95), S2 (85), S3 (60), N (40). The index of productivity for each soil mapping units was calculated using Ogunkunle (1993) modified equations:

$$IP= A \times \sqrt{(B/100 \times C/100 \times D/100 \times E/100 \times F/100)}.$$

Where A= overall lowest characteristic rating of all land quality groups (Nutrient availability), B, C, D, and E are lowest characteristic ratings for their respective land quality group. The land characteristic was grouped into the following land qualities; climate (c), soil physical property (p), wetness (w), Nutrient availability (f) and Salinity (S). The suitability classification was done separately for each soil unit identified in the study area.

Productivity index

Potential Index of Productivity (IPp)**:** In computing the IPp, properties that are not easily altered like cation exchange capacity, base saturation, pH and organic matter were used as part of the fertility (f) group while the easily altered chemical properties like exchangeable K, Ca, available P, and total N were not part of the calculation.

Current Index of Productivity (IPc): In this case, both the easily altered chemical properties like exchangeable K, Ca, available P and total N, as well as those used for IPp, were used for the calculation of the IPc.

RESULT AND DISCUSSION

Land Characteristics of the Study Area

Two soil units were delineated and denoted as KBI and KBII based on soil colour, texture, drainage and depth. Land qualities of the soils units are shown in Table 2. The soils were rated using the critical limits recommended by Malgwi (2007). Soil units KBI was deep (>145cm), imperfectly drained, yellowish brown (10YR5/4) in colour, texture varied from sandy loam to loam and covered an area of 7.9 ha. Soil units KBII was also deep to very deep (>170cm), imperfectly drained, colour varied from dark yellowish brown (10YR4/6) to brownish yellow (10YR6/6), dominated by loam texture and covered an area of 3.7 ha.

Table 1: Factor **of** suitability rating for rice

Land Characteristic/ diagnostic factor	**S1 95 – 85**	**S2 65 – 60**	**S3 60 – 20**	**N <20**
Climate				
Rainfall (mm)	800-1200	700 – 800	600 – 700	<600
Temperature (^oC)	24 – 28	22 - 24, 30-32	18 - 22, 32-35	<18, >35
Land/soil physical property				
Slope (%)	0 – 1	1 – 2	2 – 4	>4
Soil depth (cm)	>75	50 - 75	25 – 50	<25
Soil Texture	C, SiC, CL	SC, SiC, SiL	SL, L, SCL	S, LS
Volume of coarse fragment	< 15	<35	<55	<55
Drainage	Well	Moderately Well	Imperfect	Poor, very poor
Nutrient availability (topsoil)				
pH	5.0 -6.0	6.0 - 7.0	7.0 - 8.0	> 8
Organic Carbon (gkg^{-1})	20-40	10-20	5-10	< 5
Total Nitrogen (gkg^{-1})	> 2	1 -.2	0.5-1	<0.5
Available P ($mgkg^{-1}$)	> 40	20 – 40	10-20	<10
Exchangeable K ($cmolkg^{-1}$)	> 0.2	0.1- 0.2	< 0.1	< 0.1
CEC ($cmol(+)kg^{-1}$)	> 25	13 – 25	6 – 12	< 6
Base Saturation (%)	> 75	50 – 75	30 – 50	< 30
Salinity and Sodicity				
Salinity EC (dS/m)	< 3	3 – 6	6 – 10	>10
Sodicity ESP (%)	< 15	15- 40	40– 50	>50

SiC=silt clay, L=loam, SCL=sandy clay loam, SC=sandy clay, SL=sandy loam, C= clay, LS= loam sand, S=sand

Adopted from FAO (1983) and Olaleye *et al.,* (2002).

Generally, soil depth of the mapping units would permit crop root proliferation and elongation since water table was deep enough not to constitute hindrance to root development. The brown to gray colour could be attributed to imperfectly drainage condition of the soils, indicating that Fe^{3+} is reduced to Fe^{2+}giving the soil matrix a grayish colour. The imperfect drain condition was as a result of the valley floor position which receives runoff of water and sediments from the upland and high water table of the units (Jimoh, 2015). Atofarati *et al.* (2012) reported similar findings on soils of toposequence in Ile-Oluji, Ondo State, Nigeria. The two soil units were dominated by grain structure which may be as a result of low content of clay in the soils which acted as binding agent.

The soil pH was slightly acidic to neutral (6.4–6.9) which is within the pH requirement for most arable crops (Brady and Weil, 1999). Generally, organic carbon (O.C) (3.5 – 4.9 g/kg), available phosphorus (Ap) (4.47 – 6.22 mg/kg) and total nitrogen (TN) (0.11 – 0.14 g/kg) was rated low while CEC value of (8.4 – 8.15) was rated medium according to Malgwi (2007). The medium level of the CEC might be a reflection of the intensity of weathering of parent material from which the soil evolved. Base saturation (NH_4OAc) of the surface soils were rated medium to high (67-87%) in all the units, similar result was reported by Atofarati *et al.* (2012). FAO (1999) reported that soils with base saturation of >50 % are regarded as fertile soils while soils with less <50 % are infertile. Based on FAO classification, the soils were classified fertile soils. The EC value of soil was rated very low (< 4 dSm^{-1}) which indicates none saline (electrical conductivity class). Exchangeable Soil Percentage (ESP) of soil unit KBI was rated low (< 15) while soil KBII was rated higher (>15) the critical limit for sodicity (Brady and Weil, 2002). This implies that this soil unit is sodic i.e high in Na^+ content and this could significantly affect crop production. Sodic soils are usually more dispersed, less permeable to water and are of poor tilth, usually plastic and sticky when wet and are more prone to form clods and crust on drying (Babalola *et al.*, 2011). For improved crop yields, soil fertility restoration measures which include the use of inorganic and organic manure to improve the soil physical and chemical constraints should be adopted.

Table 2: Characteristics of the soil mapping units

Land Characteristic	**KBI**	**KBII**
Climate		
Mean Annual Rainfall (mm)	1004	1004
Temperature (°C)	26	26
Land/soil physical property		
Slope (%)	0-2	0-2
Soil Depth (cm)	>160	>150
Soil Texture	SL,L/SL	SL
Drainage	Imperfectly Drained	Imperfectly Drained
Nutrient availability (topsoil)		
pH (H_2O)	6.9	6.4
Organic Carbon (gkg^{-1})	3.5	4.9
Total Nitrogen (gkg^{-1})	0.11	0.14
Available P ($mgkg^{-1}$)	4.47	6.22
Exchangeable K (cmol kg^{-1})	0.21	0.27
CEC (cmol(+)kg^{-1})	8.4	8.15
Base Saturation (%)	87	67
Salinity and Sodicity		
Salinity EC (dS/m)	0.07	0.08
Sodicity ESP (%)	18	6

CL = Clay loam, L= loam, SL=sandy loam, LS = loamy sand, LCM= loamy coarse sand, CS=coarse sand
Source: Fieldwork (2014)

Qualitative land suitability classification for rice production

A summary of land qualities/land characteristics of the study area is shown in Table 2. The assessment ratings resulting from matching of land qualities and the requirements for rice is presented in Table 1 using the FAO (1983) suitability ratings. Soil units KBI and KBII have effective soil depth > 100 cm and thus were rated highly suitable (S1) for rice. Mean annual rainfall and temperature were considered highly suitable (S1). On the basis of soil texture, soil units KBI and KBII which were sandy loam to loam, overlaying loam was marginally suitable (S3) for rice. The slope of < 2 % made soil mapping units KBI and KBII soil units moderately suitable (S2). However, slope of < 3 % may favour mechanical operation (Fasina and Adeyanju, 2007). The entire soil units were imperfectly drained hence rated marginally suitable (S3).

Regarding soil reaction (pH), soil mapping units KBI and KBII were moderately suitable (S2). Considering nutrient retention ability (CEC), soil units KBI and KBII were marginally suitable (S3). Soil units KBI and KBII were highly suitable (S1) with regard to exchangeable K. Soil mapping units KBI was highly suitable (S1) while KBII was moderately suitable (S2) with regard to percent base saturation (BS). Soil units KBI was currently not suitable (N1) while KBII was marginally suitable (S3) with respect to organic C content. With regard to total nitrogen and available phosphorus both soil units (KBI and KBII) were currently not suitable (N1). All the soil units were highly suitable (S1) with regards to salinity and sodicity status (Table 3). Soil mapping units KBI and KBII were currently not suitable (N) (Table 3) for rice production due to low organic carbon, total nitrogen and available phosphorus contents. Ogunkule (1993); Olaleye (2002) and Oluwatosin (2005) also reported that soil fertility is the major limitation to the suitability of Nigeria soils. The overall suitability of the Kubanni floodplains for rice production was classified into the order not suitable (N1), class currently not suitable (N1), and subclass f (fertility) while the units were f-1(fertility) (Table 3). Soil mapping unit KBI and KBII were classified as N1f-1 which represents a deficiency of organic carbon, total nitrogen and available P for rice production at the unit level of classification.

Quantitative land suitability classification for rice production

In the parametric method of land evaluation, the soils of all the soil units were classified as currently not suitable (N1) with suitability aggregate score of less than 24, based on current productivity index and currently not suitable (N1) in KB I and marginally suitable (S3) in KB II base on the potential productivity index (Table 4). The result of the current parametric and current non-parametric suitability evaluation shows mutual relationship. Thus, this indicates that both evaluation methods were correlated as their suitability classes were similar except for potential suitability of soil unit KBII.

Overall Qualitative and Qualitative Suitability of all the soil units

The crop requirement (Table 1) and the soil qualities (Table 2) in the study area were matched with rating of land use requirement for rice. Soils of all the soil units were rated low with respect to organic carbon, total nitrogen and available phosphorus which could significantly reduce productivity. Based on the climatic condition, all the units were highly suitable and based on soil factor, KBI and KBII were classified into order N, class N1 (currently not suitable), subclass f (fertility) while units were f-1(fertility). Qualitatively, both parametric and non-parametric method of evaluation of floodplain soil of Kubanni showed that soil unit KB1was ranked N1 (22.80) and N1f-1 (Table 4) for both current and potential productivity. Fertility status (organic carbon, total nitrogen and available P) was the factor limiting the suitability of the soil for rice production. Soil unit KBII was evaluated as being marginally suitable (S3) with aggregate suitability score of greater than 25 and less than 45 (Table 4) for floodplain (wetland) rice production.

Table 3: Matching land use requirement with floodplain quality for rice

Land Characteristic / diagnostic factor	Unit	Soil Mapping Units KBI	KBII
Climate (c)			
Rainfall ®	(mm)	S1 (95)	S1 (95)
Temperature (t)	(^oC)	S1 (95)	S1 (95)
Land/soil physical property (p)			
slope (s)	(%)	S2 (85)	S2 (85)
Soil depth (d)	(cm)	S1 (95)	S1 (95)
Soil Texture (a)		S3 (60)	S3 (60)
Soil wetness (w)			
Drainage (m)		S3 (60)	S3 (60)
Nutrient availability (topsoil) (f)			
pH	(H_2O)	S2 (85)	S2 (85)
Organic Carbon (o)	(gkg^{-1})	N (40)	S3 (60)
Total Nitrogen (n)	(gkg^{-1})	N (40)	N (40)
Available P (p)	($mgkg^{-1}$)	N (40)	N (40)
Exchangeable K (k)	($cmolkg^{-1}$)	S1 (95)	S1 (95)
CEC (c)	($cmolkg^{-1}$)	S3 (60)	S3 (60)
Base Saturation (n)	(%)	S1 (95)	S2 (85)
Salinity and Sodicity (s)			
Salinity EC (e)	dS/m	S1 (95)	S1 (95)
Sodicity ESP (e)	(%)	S1 (95)	S1 (95)

Table 4. Suitability aggregate score and classification of the soil units

Soil unit	Parametric		Non-parametric	
	Current	Potential	Current	Potential
KB1	N1 (22.80)	N1 (22.80)	N1f-1	N1f-1
KB11	N1 (22.80)	S3 (34.30)	N1f-1	S3f-1

Aggregate Suitability Class Score: 100-75 = S1, 74-50 =S2, 49-25 = S3, 24-15 = N1 and < 14 = N2 Subclass indicator: Nutrient availability (f).

CONCLUSION

Climate, soil depth, salinity and sodicity factors were highly suitable for rice cultivation, slope and soil reaction (pH) were moderately suitable. However, soil organic carbon, total nitrogen and available phosphorus rendered all the soil units currently unsuitable (N1) for the cultivation of rice by non-parametric method of evaluation using the current productivity method. KBII was evaluated as marginally suitable (S3) for rice production using the parametric method of investigation (potential productivity). Low levels of organic matter, total nitrogen and available phosphorus are the major constraints of these soils and these can be improved by increasing the organic matter level through the incorporation of organic residues such as farmyard manure, plant residues, and household refuse. The organic matter can improve soil structural development, drainage and aeration thereby improving the fertility of the soils for sustainable rice production.

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