Available online at www.elixirpublishers.com (Elixir International Journal)

Agriculture

Elixir Agriculture 61 (2013) 17033-17039

Elixir ISSN: 2229-712X

Fuzzy and Parametric Methods for Land Evaluation along Katsina-Ala Flood Plains in Central Region of Nigeria: Application to Rice Production

Peter I. Ezeaku* and Charles Tyav

Department of Soil Science, University of Nigeria, Nsukka, Nigeria.

ARTICLE INFO

Article history:
Received: 28 May 2013;
Received in revised form:
24 July 2013;
Accepted: 6 August 2013;

Keywords
Model application,
Land suitability index,
Rice production,
Central Nigeria

ABSTRACT

Rice is an important crop that plays a vital role in diets and economy of farmers in Katsina-Ala in northcentral Nigeria. In this study, Fuzzy set theory, parametric and limitation models were applied to determine the suitability of Katsina-Ala flood plains for rice production. Soils of two pedons were analyzed and the characteristics used as inputs in the model application. The result showed variability of suitability of the land qualities. Climate, soil depth and flood duration were highly suitable (S_1= 95). Texture was moderate (S_2). Soil pH and available P ratings showed currently not suitable (N_1=20) for both pedons. Soil organic carbon was moderately suitable (S_2) but most critical in the normalized pairwise comparison matrix. Salinity (EC) and CEC suitability was moderately suitable (S_2). Parametric and non-parametric aggregate suitability showed moderate suitability (S_2=63.8) for current index with fertility limitations (S_2f). The potential index was high suitability (S_2) for both pedons. Fuzzy regression between land index and observed rice yield was high (R^2 = 0.90). The use of the three models could serve as spatially based decision-making parameters in agricultural land use planning but fuzzy method was recommended based on its relative advantage to other predictors.

Introduction

Appropriate land use decisions are vital in determining of suitability of land for a specific use such as irrigated or rainfed agriculture, referred as land utilization types (FAO, 1985), and to achieve optimum productivity of the land. Land suitability evaluation is one of the effective tools for an effective management of land information on which such decisions should be based. Land suitability evaluation, commonly known as 'land evaluation', was defined as 'the process of assessment of land performance when the land is used for specified purpose'. FAO distinguished two general kinds of land suitability evaluation approaches: qualitative and quantitative. A qualitative approach is used to assess land potential at a broad scale, or employed as a preliminary to more detailed investigations. The results of classification are generally given in qualitative terms only, such as highly suitable (S_1), moderately suitable (S_2), currently not suitable (N_1) and permanently not suitability (N_2).

The second approach is the parametric-quantitative that involves deductive, inductive or simulation modeling systems (Shields et al., 1996) to quantify the potential of land for specific uses. A deductive approach deals mainly with the estimated yield as an index relative to a standard yield, while an inductive technique utilizes land characteristics as evaluation criteria to establish land unit indices, which usually involves additive (arithmetic), multiplicative, and complex operations (Sys, 1985). Simulation modelling uses a complex of multivariate factors, and makes use of a computer based analysis system such as an expert system (Ezeaku and Agbede, 2005). However, use of a fuzzy set methodology (Burrough *et al*, 1992) has made a significant contribution to the refinement of land suitability analyses.

Land evaluation techniques 'predict land performance, both in terms of the expected benefits from and constraints to productive land use, as well as the expected environmental degradation due to these uses' (Rossiter, 1996). In this case, biophysical parameters and/or socioeconomic conditions of the area are considered. Crucial to the estimation of land suitability is the matching of land characteristics with the requirements of envisaged land utilization types (Ruan, 1990). Thus, land evaluation results from a complex interaction of physical, chemical and bioclimatic processes and reliable evaluation models predict accurately the behavior of land (Sys, 1985).

Physical land suitability evaluation is considered a prerequisite for land-use planning and development (FAO, 1984) as it provides information on the constraints and opportunities for the use of the land and therefore guides decisions on optimal utilization of land resources.

The present study applied spatially based parametric, limiting and fuzzy set models of land suitability analysis in order to evaluate the physical land suitability for rice production along Katsina-Ala flood plains in Central region of Nigeria.

Materials and methods

Site description

The study area is the River Katsina-Ala flood plain in Ugbema, Buruku local Government area of Benue state, Central Nigeria. It is located at latitude 07° 08.610 N, and longitude 009°16.681 E as detected by a hand held Global positioning system (GPS).

Climate/Vegetation/Soil

Benue State enjoys a tropical climate which manifest into two distinct seasons that begins from April to October and the dry season from November to March. The mean annual rainfall is 1,504 mm and mean temperature of 21°C (Benue River Basin

Tele:
E-mail addresses: ezeakup@yahoo.com

Development Authority katsina-ala Weather Station, 2012). The vegetation of the area lies in the southern Guinea Savannah. Tse (2012) reported the surface soils as granular structures which change to medium blocky and angular structures with depth. The soils have stratified deposit which is in conformity with the alluvial origin.

Field work

The area selected for the study was a flood plain land relatively flat, adjacent to the river Katsina-ala stretching up to 3km northwards in the direction of the river flow.

Three sub-samples were collected each from the upper soil layer (0-20 cm) and sub-surface layer (20-40 cm) during the wet and dry seasons and were then mixed to obtain a homogenous sample. The depths were chosen because most cereal crops are surface feeders and the zone where most changes are expected to occur. Auger and 6 profile samples from two pedon diagnostic horizons were collected for laboratory analysis.

Laboratory analysis

Soil samples were air-dried, sieved with a 2mm aperture and soil particles < 2 mm were used for determination of particle size distribution by the Hydrometer method (Gee and Bauder, 1986); soil bulk density was measured on an oven-dried weight basis (Blake and Hartge, 1986). Saturated soil hydraulic conductivity (Ksat) was determined according to Klute and Dirksen (1986) method. Soil pH was determined using a glass electrode pH meter (Mclean, 1982). Soil organic carbon (SOC) was obtained by the wet dichromate acid oxidation method (Nelson and Sommers, 1982). Cation exchange capacity (CEC) was determined titrimetically using 0.01 N NaOH (Rhoades, 1982). Available phosphorus (AP) was obtained using Bray 1 extraction method (Olsen and Sommers (1982).

Establishing land use requirements and suitabilities for rice

Land characteristics are diagnostic variables, considered critical values, which influence the outputs from or the required inputs to, a specific use and serves as a basis for assessing physical suitability of a given area of land for that use (FAO, 1976). The rice requirements were determined using FAO framework for land evaluation (Sys, 1985; FAO, 1976) (Table 1) to serve as standard reference.

In the present study, land characteristics considered for rice production include:- (1) Climate (c): mean annual rainfall (mm) (2006-2011); (2) Wetness (w): drainage (flood duration in months); (3) Physical soil properties (s): soil depth (cm), texture and (4) Fertility properties (f): pH, organic carbon (g.kg^{-1}), CEC (cmolkg^{-1}), electrical conductivity (EC, dSm^{-1}) and available P (mg.kg^{-1}). All of these soil properties were used in establishing current (actual) suitability and in calculating aggregate current and potential index of productivity (IPp).

Land evaluation methods employed in the present study

The three methods of land evaluation that were used to calculate land suitabilities for rice production include: Parametric, Limitation (Non-parametric) and Fuzzy set theory.

2.6.1. *The Parametric method* was applied as an additive model to calculate land suitability index (Li):

$$\mathbf{Li} = A + \frac{B}{\mathbf{100}} + \frac{C}{\mathbf{100}} + \frac{\mathbf{D}}{\mathbf{100}} + \cdots + \frac{\mathbf{F}}{\mathbf{100}} \quad \text{………… (Eq. 1)}$$

Where, Li is the specified land index, A is the overall lowest characteristic rating and B, C...F are different ratings for each property. Here, the characteristic with the lowest value is added to the sum of the ratio of B, C…F to 100.

***The limiting (Non-parametric) method* takes the form of the Square root method to calculate land index (Li):**

$$\frac{\mathbf{Li = R}\min\sqrt{\mathbf{A\,X\,B\,X\,...\,F}}}{\mathbf{100}} \quad \text{………..(Eq. 2)}$$

Where, Rmin is the minimum (lowest) characteristic rank.

The limiting and parametric methods were used in calculating aggregate current (actual) and potential suitabilities of the pedons. The aggregates were calculated using the mean current and potential suitability of climate (c), soil physical properties (s) and chemical (fertility) (f) properties (Table 6) as input variables in Eq. 1 & 2. Aggregate current suitability rating was based on the actual values obtained in Table 6. With added improvement measures envisaged to have improved the fertility (f) deficiencies, additional value of 100 % was added to the equations (1& 2) to calculate aggregate potential suitability.

***Fuzzy sets theory* was applied based on some of the frameworks**

Fuzzy logic is an attempt to extend the concept of continuous variation of soil properties from the geographic space to the attribute space. Hence, the theory was defined as a mathematical method used to characterize and propagate uncertainty and imprecision in data and functional relationships that deals with a class with a continuum of grades of memberships. Hence, Zadeh (1965) defined mathematically a fuzzy set A as follows:

A = {x, mA(x)} x e X ……………………………..Eq. 3

Where X = {x} is a finite set (or space) of objects or phenomena, mA(x) is a membership function of X for subset A. Burrough (1989) wrote that the membership function (MF) of a fuzzy subset determines the degree of membership of x in A. In other words, objects and their membership grades are expressed on a continuous scale as true or false or ranging from 1 to 0, indicating full membership (1) to full non-membership (0).

Burrough *et al. (*1992) showed that the expression of true or false in Eq. 3 assumes two basic functions: symmetric and asymmetric. Symmetric, also called an 'optimum range', uses a single ideal point as shown in Eq. 3. Asymmetric employs a range of ideal points (i.e. uses lower and upper boundary of a class) for computation of criterion membership functions (MF) and is based on equation:

MF(xi) = [1/(1 + {(xi – b)/d}2)] ………………….. Eq.4

Eq. 4 was expanded for calculating optimum range:

MF (xi) = 1 if (b1 + d1) < xi < (b2 – d2) ……………. Eq.5

Where,

MF (xi) represents individual MF values for *i*th land property *x*, b_1 and b_2 are the lower limits, while d_1 and d_2 are transitional zone widths.

Equations 5 was applied to calculate MF of soil property such as soil pH that could range from slightly acid to slightly alkaline and very low, suggesting very high or low pH values are limiting for crop production.

Membership functions (MF) of other soil properties were calculated using two variants (left and right) of asymmetric. Soil properties with the character of 'more is better,' such as soil organic carbon (SOC), cation exchange capacity (CEC) and soil depth were calculated with asymmetric left model:

MF (xi) = [1/(1 + {(xi – b1 –d1)/d1}] if xi< (b1 + d1) ……………. Eq.6

With a similar rule, soil property that is 'less is better' such as electrical conductivity (EC) or salinity, slope, erosion, etc. was rated with an asymmetric right model:

Table 1. Suitability ratings for rice requirements

Land qualities/ characteristics Units	S_1	S_2	S_3	N_1	N_2
	95 – 85	84 – 60	59 – 20	39 – 20	19 – 0
Climate (c)	>1400	1200-1400	950-1100	850-900	<850
Annual rainfall (mm)					
Soil Physical Characteristics (s)					
(a) Soil Depth (cm)	>50	20-50	5-10	<5	-
Texture (class)	V.good	Good	Moderate	Poor	V.poor
Drainage					
Flood Duration months	>4	3-4	2-3	<2;>4	-
Chemical properties					
Soil pH	-	5.5-7.5	5.2-5.5	≤ 5.5	≥5.2
Total N (%)	>0.2	0.1-0.2	0.05-0.1	<0.05	-
Soil organic carbon ($g.kg^{-1}$)	2-3	1-2	3.4	>4	-
**EC (dSm^{-3})	<0.7	0.7-3.0	>3.0	-	-
CEC ($cmol.kg^{-1}$)	>16	10-16	5-10	<5	
Available P($mg.kg^{-1}$)	>20	15-20	10-15	<10	

Source: Sys (1985), ** FAO (1976 on salinity), S_1=highly suitable, S_2=moderately suitable, S_3=marginally suitable, N_1 =currently not suitable, N_2=permanently not suitable, V= very, Total N= total nitrogen, EC= electrical conductivity, CEC= cation exchange capacity, P= phosphorus

Table 2. The Saaty scale of pairwise comparison matrix

Intensity of importance	Definition
1	Definition
2	Equal importance
3	Equal to moderate importance
4	Moderate importance
5	Moderate to strong importance
6	Strong importance
7	Strong to very strong importance
8	Very strong importance
9	Very to extreme strong
	Extreme importance

Source: Saaty (2003)

Table 3. Triangular norm T and triangular conorm T*

Triangular norm T	Triangular conorm T^*
Minimum	*Maximum*
T(a,b) = min (a,b)	T^*(a,b) = max (a,b)
Product	*Probablistic sum*
T(a,b) = a.b	T^*(a,b) = a + b - a.b
Bounded product	*Bounded sum*
T (a,b) = max (0, a + b -1)	T^*(a,b) = min (a +b, 1)

Table 4. Mean soil physical properties of the profile diagnostic horizons

Pedon	Depth (cm)	% Clay	% Silt	%FS	%CS	TS%	TX	BD $g.kg^{-1}$	Ksat $cm.hr^{-1}$
1	0-24	9	35	34	22	56	SL	1.30	6.86
	24-51	10	21	37	32	69	SL	1.48	6.40
	51-73	21	19	33	27	60	SCL	1.56	4.83
2	0-27	11	37	40	12	52	SL	1.32	7.20
	27-60	21	27	33	19	52	SCL	1.44	5.90
	60-92	25	24	26	22	48	SC	1.62	4.18

Note: FS = fine sand, CS = coarse sand, TS = total sand, TX = textural class, SL = sandy loam, SCL = sandy clay loam, SC= sandy clay, BD= bulk density, Ksat= soil saturated hydraulic conductivty

Table 5: Mean chemical characteristics of the pedons

Pedon/Hz	Depth (cm)	pH (H_2O)	SOC $g.kg^{-1}$	EC dSm^{-3}	CEC $Cmol.kg^{-1}$	AP $mg.kg^{-1}$
1						
(Ap)	0-34	5.1	1.80	3.2	10.4	1.87
Bt	34-51	4.7	1.65	3.3	14.4	1.87
Bc	51-73	4.5	1.55	2.6	14.0	2.80
2						
Ap	0-27	4.7	1.90	3.2	18.0	2.80
Bt	27-60	4.6	1.55	3.0	14.4	3.73
Bc	60-92	4.6	1.40	2.9	13.4	5.60

Note: SOC = soil organic carbon, EC = electrical conductivity, CEC = cation exchange capacity, AP = available phosphorus

Table 6: Land qualities/Characteristics and their suitability ratings in the study area

Land qualities/ characteristics Units	Pedon 1 Land qualities	Current (actual) Suitability score	Potential Suitability score	Pedon 2 Land qualities	Current (actual) Suitability score	Potential Suitability score
Climate (c) *Annual rainfall (mm)	1,504	S_1 (95)	S_1 (95)	1,504	S_1 (95)	S_1 (95)
	Soil Physical Characteristics (s)					
(a) Soil Depth (cm)	73	S_1 (95)	S_1 (95)	83	S_1 (95)	S_1 (95)
Texture (class)	SCL	S_2 (84)	S_2 (84)	SCL	S_2 (84)	S_2 (84)
	Wetness					
(a)Flood Duration months	5	S_1 (95)	S_1 (95)	5	S_1 (95)	S_1 (95)
	Chemical properties (f)					
Soil pH	4.8	N_1 (39)	S_2 (76)	4.6	N_1 (39)	S_2 (76)
+Soil organic carbon (%)	1.66	S_2 (82)	S_1 (95)	1.61	S_2 (85)	S_1 (95)
**EC (dSm^{-3})	3.0	S_2 (84)	S_1 (95)	3.0	S_2 (84)	S_1 (95)
CEC ($Cmol.kg^{-1}$)	12.9	S_2 (84)	S_1 (95)	15.2	S_2 (84)	S_1 (95)
Available P ($mg.kg^{-1}$)	2.18	N_1 (19)	S_2 (84)	4.04	N_1 (19)	S_2 (84)

Note: EC = electrical conductivity (salinity), CEC = cation exchange capacity,
P = phosphorus, S_1 = highly suitable, S_2 = moderately suitable, S_3 = marginally suitable, N_1 = currently not suitable

Table 7: Suitability aggregate scores and their classification for rice cultivation

Aggregate suitability				
Pedon	Parametric		Non parametric	
	Current	Potential	Current	Potential
1	S_2 f (63.9)	S_1 (91.8)	S_2 f (63.9)	S_1 (91.8)
2	S_2 f (63.9)	S_1 (91.8)	S_2 f (63.9)	S_1 (91.8)

NB: S_1 = highly suitable, S_2 f = moderately suitable with fertility limitation

Table 8. Pairwise comparison matrix

Criteria						
Soil depth (cm)	1.00					
Texture (class)	0.42	1.00				
SOC (%)	0.45	6.4	1.00			
EC (dSm^{-1})	0.31	4.9	0.48	1.00		
CEC ($cmol.kg^{-1}$)	0.25	3.47	4.00	2.61	1.00	
Climate index	2.12	0.35	0.40	0.28	0.24	1.00

Table 9. Normalized pairwise comparison matrix with criteria weights

Criteria	Soil depth (cm)	Texture (class)	OC (%)	EC (dSm^{-1})	CEC ($cmol.kg^{-1}$)	Climate (index)	Weight
Soil depth (cm)	0.123	0.112	0.141	0.107	0.133	0.099	0.138
Texture (class)	0.047	0.039	0.016	0.021	0.014	0.044	0.034
OC (%)	0.236	0.229	1.116	0.213	0.211	0.242	1.235
EC (dSm^{-1})	0.130	0.054	0.091	0.110	0.089	0.028	0.029
CEC ($cmol.kg^{-1}$)	0.126	0.129	0.112	0.054	0.073	0.066	0.087
Climate (index)	0.042	0.037	0.063	0.022	0.078	0.039	0.052

Note: SOC (%) = soil organic carbon (percent), EC = electrical conductivity, CEC = cation exchange capacity

Table 10. Observed rice yield, land suitability classes and land indices obtained by fuzzy method for the two pedons

Pedon	Observed yield (tha^{-1})	Land suitability classes Fuzzy index
1	3.94	S_1 (86.24)
2	3.66	S_1 (89.50)

Note: S_1 = highly suitable

MF (xi) = [1/(1 + {(xi – b2 –d2)/d2}] if xi< (b2 + d2)………..…. Eq.7

As there are *n* land characteristics to be rated, the MF values of individual land characteristics under consideration were combined using a *convex* combination function to produce a joint membership function (JMF) of all attributes, Y as follows:

$$JMF(Y) = \sum_{i=1} \lambda_i \, MF(x_i) \quad \text{Eq.8}$$

Where, *i=1;* ƛi is a weighting factor for the *i*th land property *x*, and *MF (xi)* denotes a membership grade for the *i*th land property *x*.

The results are put in a matrix R (called characteristic matrix).

The weight of each effective land characteristic in rice yield was calculated and put in weights matrix (W) through Analytical Hierarchy Process (AHP). The AHP is characterized by pairwise comparisons among decision elements for generation of relative matric. In this method, pairwise comparisons were considered as inputs and relative weights were as outputs. The Saaty (2003) scale (Table 2) was used for generation of pairwise comparison matrix which relatively rate priorities for two criteria.

Final land suitability class was determined with a multiple operator (combination). The final matrix of land suitability (E) was then calculated after multiplying the characteristic matrix (R) by weights matrix (W). The components of E indicate the degree of membership of relevant land unit to land suitability classes (Ezeaku, 2005). This matrix was calculated as below:

$$E = W \circ R \quad \text{Eq. 9}$$

Where: o is fuzzy operator created from Triangular norm T (as minimum) and Triangular conorm T* (as maximum) (Ruan, 1990) (Table 2).

According to these norms, the best result for final land suitability matrix was achieved through the formula by Keshavarzi and Samadian (2009):

$$e_j = \min(a_1 + a_2 + \ldots + a_n, 1) \quad \text{Eq.10}$$

$$a_i = \max(0, w_i + r_{ij} - 1), \; i = 1, 2, \ldots, n \quad \text{Eq.11}$$

Where:

r: components of characteristic matrix (R) for land characteristic of i under the land suitability class of j,

w: components of weights matrix (W) for land characteristic of I,

e: components of final land suitability matrix (E) for land suitability classes of S_1 to N,

The final land suitability matrix for Pedon 1 is shown as an example below:

$$\begin{matrix} & S_1 & S_2 & S_3 & N \\ P_1 = & [0.76 & 0.26 & 0.08 & 0] \end{matrix}$$

In order to calculate land index, the sum of components of land suitability matrix (E) was set to one (standardized) and the new components of matrix were multiplied by average of indices of land suitability classes, respectively, based on the following formula (Sarmadian *et al*., 2009):

$$LI = \Sigma [d(E_j) \times A_i] \quad \text{Eq. 12}$$

Where:

LI is land index; d is normalized (standardized) value of land suitability matrix (E), while A is the average of maximum and minimum indices of land suitability classes.

Fuzzy set was used to establish relationship between land index and observed crop yield.

Results and discussion

Results of physical and chemical properties of the soil pedons are shown in Tables 4 and 5.

Effective soil depth was limited at 73 and 83 cm for Pedon 1 and 2, respectively (Table 4). Following Table 1, soil depth is not a limiting factor to rice cultivation. Textures varied in both pedons but predominantly ranged from sandy loam to sandy clay loam. On the average, the textural class for both pedons was sandy clay loam (SCL).

Mean soil bulk density values ranged from 1.30 to 1.62 $g.kg^{-1}$ and are exponential to the mean values of Ksat (Table 4). Low soil bulk density in the upper horizons implies greater pore space and improved aeration. These qualities reflect the sandy loam characteristic of the soil, suggesting that the upper soils are loosened and could have contributed to high Ksat values obtained in the surface soils. Low to high soil Ksat with profile depth (range: 7.20 to 4.18 $cm.hr^{-1}$) may be due to pedogenesis processes of clay illuviation that filled large pores of the subsoil and cause low water transmission through the soil column.

The soil pH values ranged from 4.5 to 5.1 (Table 5) and could be classified as high given rice requirement (pH: 5.5 – 7.5) in Table 1. Soil organic carbon values ranged from 1.40 to 1.90 $g.kg^{-1}$, while CEC values ranged from 10.4 to 18.0 $cmol.kg^{-1}$. The two land characteristic values in relation to Table 1 are moderate for rice production.

The results presented in Table 6 are current (actual) and potential suitabilities of the soil properties for rice cultivation. Current (actual) suitability was derived by matching the mean soil properties of each pedon in Tables 4 and 5 as well as mean climate data with rice reference requirements in Table 1 to obtain land qualities and their suitabilities.

Total annual rainfall data for five years (2006-2011) was 1,542 mm, 1,370 mm, 1,603 mm, 1,496 mm, and 1,510 mm, respectively, with annual average of 1,504 mm. Results of actual (current) suitability show that mean climate rate was highly suitable (S_1 = 95) (Table 1), indicating that rainfall was not a limitation for the rice cultivation in the area. Soil depth rated high suitability (S_1), suggesting that rice roots could grow freely to absorb nutrients. The root room for rice root development was not limiting. Soil wetness in terms of duration was 5 months (Table 6) and rated highly suitable (S_1), an evidence that the soils are constantly inundated.

The result of soil pH and available P showed serious constraints to rice cultivation as they rated currently not suitable (N1) (Table 6). Soil organic carbon was moderately suitable (S2) but was the most critical among the soil characteristics in the normalized pairwise comparison matrix (Table 7). Electrical conductivity (EC) was equally moderate (S2) in both pedons. Following Table 1, the mean CEC obtained in this study (14.05 cmol.kg-1) (Table 6) was moderately suitable (S2) and accord to medium range that may not limit rice cultivation.

From the result of current suitability of the soils (Table 6), it could be inferred that climate and soil physical properties were optimally suitable (S1) for rice cultivation, while those of soil chemical properties reflect fertility problems ranging from moderate (S2) to currently not suitable (N1), an indication that fertility improvement measures are required to obliterate the nutrient deficiencies and upscale the soil from current suitability to potential suitability.

Potential suitability of the soils (Table 6) were derived on the premise that improved soil management practices such as addition of organic matter, lime materials e.g. oxides and carbonates of Ca and Mg, as well as rock phosphate fertilizers were applied to increase organic carbon and CEC for structural stabilization of the soil aggregates, reduce acidity and ameliorate phosphorus deficiency, respectively. Thus, the potential suitability rating of the soil properties (Table 6) showed an upgrade of soil pH and available P to moderate suitability (S2), while SOC, EC and CEC became highly suitable (S1). Climate and soil physical properties remain currently and potentially highly suitable (S1).

Aggregate suitability ratings for the two pedons obtained with parametric and non parametric models (Table 7) showed current index as moderately suitable with fertility as limitation (S2f) for optimum rice cultivation. The potential index was high suitability (S1) due to applied improvement measures. These results are consistent with Ezeaku and Anikwe (2004) report that soil fertility constitutes a major limitation to maize production in southeast Nigeria as was found for rice cultivation in this study. Thus, paradigm approach which positively lay emphasis on sustainable biological soil systems management is desired.

Fuzzy results of the pairwise comparison matrix and normalized pairwise comparison matrix with criteria weights are presented in Tables 8 and 9, respectively. The most significant characteristic (criteria) is soil organic carbon among all effective criteria in the rice yield. Electrical conductivity was the least significant criteria. By the determined land characteristic weights, the weight matrix (W) was generated as the matrix below:

W = [1.235 0.138 0.087 0.052 0.034 0.029]

The weight matrix (W) multiplied by characteristic matrix (R) for each land unit based on fuzzy operator (combination) resulted in the final land suitability matrix (E). Then, land indices were calculated based on final E matrix in each land unit. Table 8 shows the observed rice yield, land suitability classes and land indices obtained by fuzzy method for different pedons. Maximum and minimum observed yield were 3.94 and 3.66 (tha-1) for P1 and P2 areas, respectively. The calculated linear regression between land suitability index and observed rice yield using fuzzy method was 0.90.

The regression result accords to a land suitability classification study conducted by Ezeaku (2005) who found the degree of relationship between land index (Li) and observed yield for maize cultivation, using fuzzy set method, to be higher relative to parametric and non-parametric methods. From this result, Fuzzy set method was a better predictor.

Other investigators (Sys et al., 1991; Tang et al, 1991; Burrough et al., 1992, 1997; Sarmadian et al., 2009; Keshavarzi and Samadian, 2009) attributed reasons for choice of Fuzzy set method against other methods to include:

(1) Fuzzy set method consider the continual land changes and is more efficient in reflecting spatial variability of soil characteristic rather than parametric and non-parametric methods that overlook a considerable section of useful information during land evaluation processing. However, parametric and limiting methods were found as simple tools and methods that could be easily applied to evaluating suitability of soils for agricultural crops (Ezeaku, 2003; Ezeaku and Anikwe, 2004).

(2) It allows the environment to be inherently vague and does not try to limit soil continual system to the data measured by soil science researchers.

(3) Fuzzy method helps in making decision under uncertain, complex and difficult situations, thus achieving a suitable and optimum choice demands in compliance with rules, values and different description aspects of decision process. The problem with Fuzzy set is the extensive calculations requiring high volume of data. Also determination of membership functional class requires expertise knowledge but also subjective.

Conclusion

The study revealed the contents of soil organic carbon and other fertility parameters as low and could limit optimization of rice production in the soils of Katsina-Ala flood plain. Adoption of effective management practices that conserve organic matter and enhance nutrient and water holding capacity of the soil is recommended. This would improve the cation exchange capacity content and poorly aggregated sandy nature of the soils and subsequently improve yield.

The use of spatially based models in the study is a proof that they can provide information about the current and potential suitabilities of the soils for rice cultivation. The study result could serve as input for effective management of the flood plains; provide an idea in making effective decisions regarding land suitability problems, and for planning the optimization of land productivity. Fuzzy set theory is recommended for suitability evaluation of soils to crop production in central and other regions in Nigeria given its relative advantages over other soil suitability predictors.

References

Benue River Basin Development Authority Katsina-Ala Weather Station (2012) data

Blake GR, Hartge KH. Particle density. In A. Klute (Eds.), Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA, Madison, WI. 1986, pp 377–382.

Burrough PA. 1989. Fuzzy mathematical methods for soil survey and land evaluation. Journal of Soil Science, 40, 477492.

Burrough PA, MacMillan RA, Van Denrsen W. Fuzzy classification methods for determining land suitability from soil profile observations and topography. Journal of Soil Science, 1992, 43:193-210.

Burrough PA, Van Gaans PFM, Hootsmans R. Continuous classification in soil survey: spatial correlation, confusion and boundaries. Geoderma, 1997. 77: 115–135.

Bray RH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soils. Journal of Soil Science. 1945, 59: 45 – 49.

EzeakuEzeaku PI. Determination of efficacy of parametric and limitation methods of land evaluation for suitability classification of some soils of Southeastern Nigeria. Savannah Journal of Science and Agriculture. 2003, 2: 91-102.

Ezeaku PI, Anikwe MAN. 2004. Physical land evaluation using parametric and limitation methods: An application to maize cultivation in a typic Haplustult soil in southeastern Nigeria. International Journal of Science and Technology, 2004, 10:58-64.

Ezeaku PI. 2005. Land suitability classification by weight matrix (index) system for rainfed maize assessment in some moist savanna soils, Southeast Nigeria. Production Agriculture and Technology Journal, 1(1):76-86.

Ezeaku PI, Agbede OO. The use of data modeling methods to improve land evaluation and land use planning in Nigerian agro-ecological systems. Production Agriculture and Technology J. 2005, 1(1):43-53.

FAO. A framework for land evaluation. FAO Soils Bulletin 32, Rome.1976.

FAO.. Irrigation and Drainage Paper No. 29, 1976 c

FAO. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bulletin 52, Rome.1984.

FAO. 1985. Guidelines: Land evaluation for Irrigated Agriculture. FAO Soils Bulletin 55, Rome. 1985.

Gee GW, Bauder JW. Particle Size Analysis. In: Klute,A (ed). Methods of Soil Analysis. Part 2, 2nd ed. Agron. Monog. 9. ASA and SSSA, Madison, WI 1986, p.383-411

Klute A, Dirksen J. Hydraulic conductivity and diffusivity. Laboratory methods. In: A klute (ed).Methods of soil analysis part 1 2nd ed. 1986, p.687-734.

Keshavarzi A, Sarmadian F. Investigation of fuzzy set theory`s efficiency in land suitability assessment for irrigated wheat in Qazvin province using Analytic hierarchy process (AHP) and multivariate regression methods. Proc. 'Pedometrics 2009' Conf, August 26-28, Beijing, China. 2009.

Mclean EO. Soil pH and lime requirement. Agron. 9. SSSA. Madison W.I. 1982, p.199-224.

Nelson D, Sommers LE. Total carbon, organic carbon, and organic matter. In A.L. Page, R. H.Miller, & D.R. Keeney (Eds.), Methods of Soil Analysis. Part II, 2nd ed. American Society of Agronomy, Madison, WI, USA. pp. 1982, p.539-580.

Olsen SR, Sommers LE. Phosphorus. In: Page et al (eds) Methods of Soil Analysis. Part 2. Agron 9. ASA, SSSA. Madison, W.I.1982, p. 403-434.

Rhoades JD. Cation exchange capacity. In: Page, A.L. (Ed.), Methods of Soil Analysis Part 2. 2nd Edition Agron. Monogr. 9. ASA, Madison, WI, 1982, pp. 149-157.

Rossiter DG. A theoretical framework for land evaluation. Geoderma 1996, 72 (6): 165-190

Ruan D. A critical study of widely used fuzzy implication operators and their influence in fuzzy expert systems. Doctoral Thesis, State University of Gent, Belgium. 1990, 155 pp

Saaty TL. Decision-making with the AHP: Why is the principal eigenvector necessary? European Journal of Operational Research. 2003, 145: 85-91.

Sarmadian F, Keshavarzi A, Rajabpour B, Rajabpour A. Multi-Criteria Decision Making in Fuzzy Modeling of Land Suitability Evaluation (Case Study: Takestan area of central Iran). Proc.'Pedometrics 2009' Conf, August 26-28, Beijing, China. 2009.

Shields PG, Smith CD, McDonald WS. Agricultural land evaluation in Australia – A Review. ACLEP (Australia Collaborative Land Evaluation Program): Canberra. 1996.

Sys C. Land evaluation, part I, И, Ш. ITC, University of Ghent, Belgium. 1985, Pp343.

Sys C, Van Ranst E, Debaveye J. Land evaluation, Part l, principles in land evaluation and crop production calculations. International Training Centre for Post-graduate Soil Scientists, University Ghent, Belgium. 1991.

Tang H, Debaveye J, Ruan D, Van Ranst E. Land suitability classification based on fuzzy set theory. Pedologie. 1991, 3: 277-290.

Torbert H, Krueger E, Kurtener D. Soil quality assessment using fuzzy modeling. Int.Agrophysics. 2008, 22: 365-370.

Tse AC. Suitability of Flood Plain Deposits for the Production of Burnt Bricks in Parts of Benue State, Central Nigeria. Department of Geology, University of Port Harcourt, Nigeria. 2012, Pp 230.

Zadeh LA. Fuzzy sets. Information and control. 1965, 8: 338-353.