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Suitability Evaluation of a Typic Plinthustalf in Southern Guinea Savanna Zone of Nigeria, for the production of Quality Protein Maize (*Zea mays L.)*

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Abstract

The need to optimize and produce maize of quality protein content in a Typic plinthustalfs calls for potential suitability evaluation. Hence, three mapping units were established along the toposequence and three profile pits were dug at each per mapping unit. The pits were described and sampled following FAO guidelines. Soil samples were taken from the pedogenic horizons for morphological, physical and chemical data analyses. Linear parametric and square root models were used for assessing the suitability of the soils for maize production. Land qualities considered in the study were climate, topography, wetness, soil fertility and soil physical properties. Except for the fertility status of the land, other qualities were not a constraint to the production of maize at the study site. All the pedons were classified as currently not suitable by both linear and square root models with index of current productivity (IPc) ranging between 1.08 and 2.05. Potentially, using the linear model, the index of potential productivity (IPp) ranged between 63 and 90 thus rated pedon 1 and 2 as highly suitable and pedon 3 as moderately suitable while the square root model indicated all pedons as highly suitable, for both local and quality protein maize production. The limiting factors were mainly low levels of available macro-nutrients (N, P, K, Mg), low organic carbon (0.82 %), and low cation exchange capacity (< 16 cmol/Kg) in all three pedons studied. In conclusion, all the pedons were classified as Typic plinthustalfs were currently not suitable (N1) for Maize Production both by the linear and square root models. Hence, it is therefore recommended that good soil management practices such as integrated soil fertilizer application, effective tillage practices and cover cropping should be adopted to ensure sustainable land use for maize production at the studied site.

Keywords: Quality Protein Maize, Soil suitability, Southern Guinea Savanna, Typic plinthustalf.

Introduction

Land evaluation is the assessment of the capacity of the land for producing a specified crop or combination of crops under specified management practices. It is an applied classification system that assesses the capacity of the soil for its optimal use, that is, to derive maximum benefits with minimum degradation. This has been defined by Van Diepen *et al.* (2011) which use explain or predict the use potential of land. The evaluation of land is normally carried out to determine their suitability for specific uses. The information obtained can be used for a more realistic land use recommendation and present their constraints (Abdulkadir, 2008). It also enables management guidelines in order to promote a more sustainable use of the soil and environmental resources (Maniyunda*etal.,* 2007). Soil evaluation according to Eleweanya *et al*, (2005) involves determining the pattern of the soil cover and dividing this pattern into homogeneous units, and then mapping their distribution and characterizing them. It enables better predictions about specific uses of the land and allows useful statements to be made with respect to land use potential and behaviour towards different management practices.

The pressing demand for food and space from a growing population has created a competition for land. In many developing countries, fuel-wood, cash crops, timber for construction and grazing for livestock compete with food crops for space, not only on the better quality land but also the marginal areas (Verheye, 2000 cited in Sharu *et al*., 2013). In addition, modern agriculture requires that farmers have some direct or indirect knowledge of the capability and nutrient status of the soils to be utilized. Such information enables the farmer to make informed choices on crops and/livestock to be raised that are technically feasible.

This has given rise to soil evaluation studies prior to crop production and other agricultural land uses. The need for land evaluation arose from the fact that soil classification, soil map and the accompanying legends do not meet the needs of farmers and other land users (Ogunkunle, 2003). The importance of land evaluation should be seen in the context of land becoming a scarce and non-renewable natural resource which is highly desired, for which there is a growing competition and which, obviously holds a proper exchange value (Verheye, 2000).

The determination of the suitability of a piece of land for a specified use, involves the matching of land qualities/land characteristics with the requirements of envisaged land use (Ogunkunle, 2003). Land evaluation, according to the FAO framework, can be qualitative or quantitative (FAO, 1976). A qualitative evaluation assesses the suitability of land in general physical terms (e.g. Soil, topography, climate etc), while the quantitative system specifies the input (e.g. fertilizer seeds etc) and the output (e.g. crop yield) in addition to the physical parameters.

There are two methods commonly used for land suitability evaluation. These are: the parametric (Ogunkunle, 1993; Sys *etal*., 1993) and non-parametric methods (FAO, 1976). The non-parametric evaluation was first proposed by FAO (1976), and in this method, pedons were placed in suitability classes by matching their characteristics with the established requirements whereas in parametric linear model, each limiting characteristics is rated. However, most evaluation was based on the parametric method. There are several models of the parametric land evaluation method. However, the most common are the linear model of stories and the square root models (Ogunkunle, 2003).

In land evaluation, either the current suitability or potential suitability may be determined. Current suitability measures the land resources to support or otherwise the desired use without any major amendment. Potential suitability on the other hand evaluate the potential of the land resources to support or otherwise the desired use after some minor or major amendment.

The productivity of soils in Nigerian guinea savanna zone is decreasing due to their fragile nature. These lands have been utilized intensively for various purposes at the expense of their suitability resulting in degradation and altering of the natural ecological conservatory balances (Ande, 2011; Senjobi, 2007). Therefore, there is need to use the soils in a sustainable way to avoid their degradation. It is on this premise that this study was carried out to evaluate the suitability of soils for maize (*Zea mays L.)* production.

Furthermore, the information obtained from the study will enable land users and farm managers to make proper decisions on what and how crops should be grown with appropriate management to be adopted for optimum production of maize

Materials and Methods

Description of study area

The study was conducted at Kwara State University Teaching and Research farms, Malete, located at Latitude 8° 30' N, 8° 36' and Longitude 4° 31' , 4°33' E and about 345m above the sea level in the Southern Guinea Savanna Zone of Nigeria (Fig. 1). The digital elevation model and land-use cover classification map of the study area are also produced and included (Figures 2 – 3). The digital elevation model helps to delineate the topographic location of the study area while land-use cover showed the various vegetation types grown in the area.

The area has seven months of rainfall with mean annual rainfall of 1,150 mm and a mean annual temperature that ranges from 25- 28.9 °C. It exhibits a double maximal pattern between April and October of every year. The wet season is between April and October while dry season starts November and ends in March (Olowoake and Ojo, 2014). The crops commonly grown in the area include: soybeans, beeniseed, cowpea, groundnut and maize.

Field Studies

Three mapping units were established and three soil profiles were dug to represent the three mapping units. The profiles were described using the guidelines of FAO (2006) and Soil Survey Staff (2014). Sampling of each profile was carried out according to the pedogenic horizons.

Soil samples were collected from each pedogenic horizons, air-dried at room

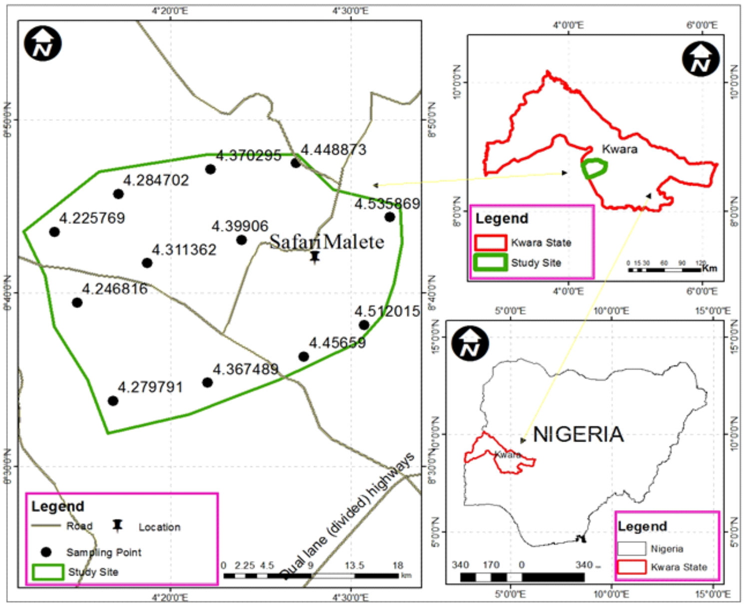

Figure 1: Location Map of the study area.

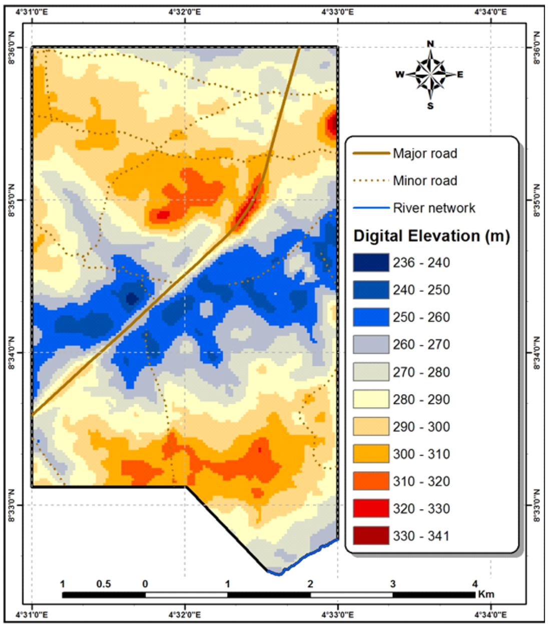

Figure 2: Digital Elevation Model (DEM) of the study area

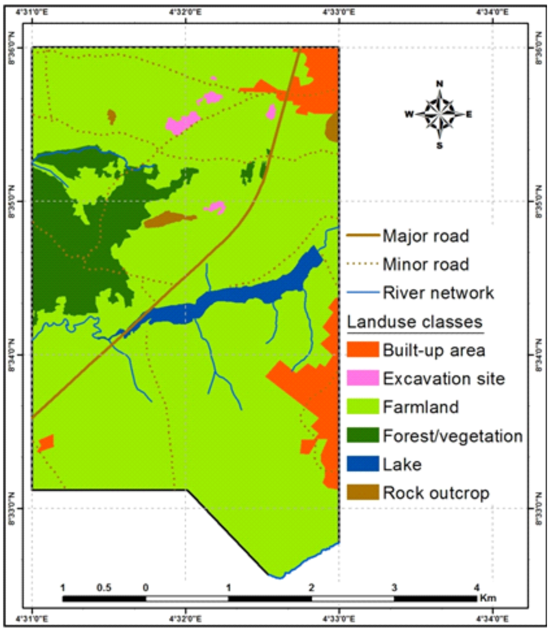

Figure 3: General land-use classification of the study area

temperature for 48 hours, grinded and passed through a 2 mm sieve to remove large particles, debris and stones. The sieved sample was further grinded and passed through 0.5 mm sieve for nitrogen and organic carbon determination. The soil samples were analyzed for soil texture, pH, organic carbon, total N, extractable P, exchangeable bases and exchangeable acidity and micro-nutrients. Particle size was determined by the Bouyoucos hydrometer method (Gee and Or, 2002). Soil pH was measured electrometrically in a 1:1 in H_2O. Organic carbon was determined by Walkley - Black dichromate wet oxidation method (Nelson and Sommer, 1982). Total nitrogen was determined by the Micro- Kjeldahl method (Foth, 2014) and extractable P was determined by Bray-1 method (Bray and Kurtz, 1945). Exchangeable bases were determined by the atomic absorption spectrophotometer following the standard procedures. Micronutrients were extracted with 0.1 Ethylene diaminetetraacetic acids (EDTA) and determined using atomic absorption spectrophotometer.

Land Evaluation Procedure

The pedons were placed in suitability classes by matching their characteristics with the requirements in Table 3 below. The suitability class of a pedon is that indicated by its most limiting characteristic. This follows the well-known “Law of the Minimum” in agriculture, which states that crop yield will be determined by the plant nutrient in lowest supply (FAO, 2005). Secondly, each limiting characteristic was rated for the parametric method. The index of productivity (IP) for each pedon was calculated using the equation below:

General Landuse classes	**Area (Hect.)**
Built-up area	116.7
Excavation site	12.7
Farmland	1669.2
Lake	49
Forest/vegetation	213.4
Rock outcrop	12.9
Total area	**2073.9**

$$IPc = A \times B/100 \times S/100 \times C/100 \times F/100. \text{ (I)}$$

$$IP = A.\sqrt{\frac{B}{100}\cdot\frac{C}{100}\cdots\cdot\frac{F}{100}}\text{.....................(2)}$$

Where, A is the overall lowest characteristic rating, B, C…F are the lowest characteristics rating for each land quality group.

The five land quality groups used in this study are climate (c), topography (t), soil physical properties (s), wetness (w), and chemical fertility (f). Only one member in each group was used due to strong correlations that exist among members of the same land quality. A group (e. g. texture and structure in the group's') (FAO, 2005). Potential index of productivity (IPP) and current (actual) index of productivity (IPC) was calculated without putting the calcium (Ca) mole fraction and available phosphorus (Bray's P1) into the 'f' group, while the IPC would be calculated with the calcium mole fraction (exchangeable Ca^{2+} as a fraction of cation exchange capacity) and available phosphorus (Bray's P1) forming part of the 'f' group (Ajiboye *et al.*, 2011).

Results and Discussion

Soil properties and classification

The soil morphological, physical and chemical characteristics obtained from the land units are presented in Tables 1and 2. The first profile was located in the upper slope of the toposequence. The profile was deep and had a loamy sand epipedon (Horizon A) overlying a sandy loam to sandy clay loam subsoil. This pedon had high sand content, moderate silt content and clay content increases with depth which shows the evidence of argilluviation in the second, third and fourth horizons of this pedon. The iron- manganese concretions were identified in the subsurface horizon between depth 35- 86cm and 86- 147 cm. The soil was well drained at the time of sampling, but few, distinct dark reddish grey mottles (10 R ¾) were observed at a depth 35 -86 cm. With increase in depth, the mottles became many, coarse and prominent. The Mottling observed in the soils may be attributed to the reducing condition of iron in the soil due to alternating wetting and drying conditions over a long period of time (Eswaram *et al.,*2003).The pedon had medium sub angular blocky structure in both surface and sub surface soils. The second pedon was located on the middle slope of the toposequence. The Pedon had loamy sand texture on the surface horizon and loamy sand, sandy loam in the sub surface soils. The epipedon was fairly stony and free of concretion while iron- manganese concretions were encountered at depth 41-61 cm and 61-156 cm. The soil was deep and well drained at the time of sampling. However, dark gray (5 YR 4/1), fine, medium and distinct to dark reddish brown (5 YR 3/2), many, common, coarse and

Table 1: Physical and Morphological Characteristics of the soil of the study area

SS/TOPO	Horizon Depth (cm)	% Sand (g/Kg)	% Clay (g/Kg)	% Silt (g/Kg)	Soil Texture	Soil Structure	Consistence	Soil Colour (Moist)	Mottles ++	Concretion +++
UPP	0 – 19	846	60	94	LS	MSAB	Fr, s	Reddish brown (5YR 4/3)	Absent	Absent
	19 – 35	766	120	114	SL	MSAB	Fr, shd	Reddish brown (5YR 5/4)	Absent	Absent
	35 – 86	506	340	154	SCL	MSAB	Hd	Red (10R 4/6)	10R 3/4; f,fi,fn	Present
	86 - 147	596	260	144	SCL	MSAB	Hd	Yellowish red (5YR 5/8)	5 YR 2/1, m,c,pr	Fe- Mn, f, r
MDD	0 – 21	846	60	94	LS	FSAB	Fr, shd	Dark brown (7.5YR 4/2)	Absent	Absent
	21 – 41	826	80	94	LS	SG	Hd	Dark brown (7.5YR 4/4)	Absent	Absent
	41 – 61	786	80	134	LS	CSAB	Hd	Yellowish red (5YR 4/6)	5YR 4/1 m,c,pr	Fe- Mn, c, r
	61 - 156	706	140	154	SL	SAB	Hd	Yellowish red (5R 5/8)	5YR 3/2 m,c,pr	Fe - Mn, m, r
LS	0 – 40	806	60	134	LS	MSAB	Fr, l	Dark brown (7.5YR 4/2)	Absent	Absent
	40 – 61	806	100	94	LS	SG	Fr, l	Reddish brown (5YR 5/4)	Absent	Absent
	61 – 91	646	200	154	SCL	SG	Hd	Red (2.5YR 5/6)	5YR 2/1, m,c,pr	Fe – Mn, f, r
	91 - 156	706	180	114	SL	SG	Hd	Yellowish red (5YR 5/8)	5YR2/1	Fe-Mn,c,r

Table 2 : Chemical Characteristics of the Soils of the study area

Profile	Horizon Depth (cm)	pH (H_2O)	OC (%)	TN (%)	Av. P (mg/Kg)	K^+ (Cmol/Kg)	Ca^{2+} (Cmol/Kg)	Mg^{2+} (Cmol/Kg)	Na^+ (Cmol/kg)	TEA(cmol/Kg)	CEC (Cmol/Kg)	% B.S	Fe (mg/Kg)	Cu	Zn	Mn
Upper slope	0 - 19	5.96	1.48	0.15	2.55	0.29	3.03	0.89	0.31	0.25	4.77	94.8	104.0	1.67	0.77	181.0
	19 - 35	5.89	1.68	0.17	2.98	0.19	2.79	0.83	0.26	0.35	4.39	92.0	81.7	9.75	0.55	202.0
	35 - 86	5.80	0.82	0.09	2.71	0.57	2.67	0.52	0.43	0.30	4.49	93.3	74.1	10.64	0.71	124.0
	86 - 147	6.01	1.31	0.14	1.02	0.34	2.09	0.66	0.38	0.20	3.67	94.6	55.7	10.61	0.43	110.0
Middle slope	0 - 21	6.17	2.29	0.24	5.11	0.54	3.92	0.99	0.33	0.15	5.93	97.5	95.1	10.24	0.72	124.0
	21 - 41	6.11	1.92	0.20	5.96	0.43	2.23	0.74	0.26	0.15	3.81	96.1	79.6	10.17	0.49	95.0
	41 - 61	5.88	1.35	0.14	1.28	0.76	3.64	0.66	0.29	0.20	5.55	96.4	57.5	10.14	0.39	117.0
	61 - 156	6.08	1.27	0.14	1.42	0.42	2.29	0.57	0.31	0.20	3.79	94.7	22.7	10.29	0.44	110.0
Lower slope	0 - 40	6.16	2.17	0.23	1.70	0.44	5.54	0.81	0.32	0.20	7.31	97.3	138.0	11.05	0.47	186.0
	40 - 61	6.31	1.51	0.16	5.67	0.48	6.47	0.79	0.36	0.25	8.35	97.0	116.0	11.18	0.83	125.0
	61 - 91	5.47	1.28	0.13	0.96	0.54	2.18	0.97	0.41	0.20	4.3	95.3	86.3	11.17	0.88	183.0
	91 - 156	5.66	1.52	0.16	0.77	0.51	2.86	0.79	0.37	0.25	4.78	94.8	87.0	1.55	0.58	171.0

prominent mottles were encountered between 41 cm and 156 cm depth. The structure of the pedon ranged from fine sub angular blocky to single grained on the surface and coarse subangular blocky to subangular blocky in the subsurface soils.

The third pedon (LS) was located on the lower slope of the toposequence. The pedon had loamy sand in the first and second horizons and sandy clay loam to sandy loam in the third and fourth horizons. There was evidence of argilluviation in the subsoils due to increase in clay content (Ojanuga, 1975). The profile was well drained. However, black (5 YR 2/1) fine, coarse distinct, prominent mottles were noticed between 61 cm to 156 cm depth. The profile had medium sub-angular blocky structure in the surface soils to single grained in the subsurface soils (Alabi *et al.*, 2017)

The soils had reactions ranging from moderately acidic to slightly acidic (5.47 - 6.31) in distilled water. The Total exchangeable acidity was moderate for all the pedons ranging from 0.15 -0.35cmolkg^{-1}. The total Nitrogen of all the pedons were generally low (0.09-0.24%), the available Phosphorus were generally low for all pedons (ranging between 0.77-2.96 ppm). The percentage Base saturation of the soils was consistently higher than 90%. This range from 92.0-97 %. The low CEC of these soils coupled with low organic matter, low total Nitrogen and available Phosphorus are indications of low inherent soil fertility status. Several researchers have reported low content of organic carbon in the Nigerian savanna (Raji and Mohammed, 2000; Malgwi*et al.*, 2000; Yaro*et al.*, 2007).

The morphological, physical and chemical characteristics of the soils in this study influenced their classification as Alfisol at Order level. The soils were classified as Typic Plinthustalf at the great group level due to low CEC less than 16cmol$^{(+)}$ kg^{-1} in most of the argillic horizon in the upper and lower slope pedons, greater than 50% base saturated and Plinthic subsurface horizons with mottling which occupied more than half volume of the soils (Soil Survey Staff, 2014).

Suitability assessment

Suitability ratings of the land characteristics (Table 5) was formulated using the rating of limiting characteristics (Table 4) and land requirements for suitability classification for Maize (*Zea mays*) cultivation (Table 3). Suitability ratings of the various land characteristics as well as their aggregate ratings (actual and potential) were computed using the linear parametric models. All the pedons were classified as currently not suitable by both linear and square root models because of index of current productivity (IPc) that ranged between 1.08 and 2.05. Potentially, using the linear model, the index of potential productivity (IPp) ranged between 63 and 90 which rated pedons 1 and 2 as highly suitable and pedon 3 as moderately suitable while the square root model indicated all pedons as highly suitable, for maize production.

Conclusion

All the Pedons were classified as Typic Plinthustalfs based on USDA Soil Taxonomy system and evaluated for their suitability for quality protein maize. All the Pedons were currently not suitable (N1) for Maize Production both by the linear and square root models. The limiting factors

Table 3: Land requirements for suitability classes for maize cultivation (modified from Sys*et al*, 1993)

Land qualities	S11	S12	S2	S3	N1	N2
Climate (c):						
Annual rainfall (mm)	850-1250	850-750	750-600	600-500	-	<500
Length growing season (days)	150-220	220-270	270-325	325-345	-	>345
Mean annual temp °C	22-26	22-18	18-16	16-14	-	<14
Relative humidity (%)	50-80	50-42	42-36	36-30	-	>30
Topography (t)						
Slope (%)	0-2	2-4	4-8	8-16	-	>16
Wetness (w)						
Flooding	F0	-	-	F1	-	F2
Drainage (4)	good	Moderate	Imperfect	Poor	Poor	Poor and very poor
(5)	Imperfect	Moderate	Good	aeric	drainable	not drainable
Soil physical properties (s): Texture	SiC,SiCL,CL,SiL,	SC,L,SCL	SL,LfS, LS	LcS,Fs,	-	S,
Coarse fragments (Vol %)						
0 – 10 cm	<3	3-15	15-35	35-55	-	>55
Depth (cm)	>100	75-100	50-75	20-50	-	<20
Fertility (f) :						
Cation exchange capacity (Cmol/Kg)	>24	16-24	<16	<16		
Base saturation (%)	>50	35-50	20-35	<20		
Organic carbon (g/Kg), 0-15cm	>20	12 -20	8- 12	< 8		

Table 4: Rating of the limiting characteristics

Symbol	Definition	Land index
S1	None	95-100
$S1_2$	Very slightly	70.0-94.0
S2	Slightly	55.0-69.0
S3	Moderate	40.0-54.0
N1	Severe	20.0-39.0
N2	Very severe	0.00-19.0

Source; Olaniyan (2003)

Table 5: Suitability ratings of land characteristics for Maize production of *Typic Plinthustalf.*

Land Qualities	(*Zeamays* L.)		
	P1	P2	P3
Climate (c)			
Annual Rainfall (mm)	100 (S_1)	100 (S_1)	100 (S_1)
Mean annual temperature (°C	100 (S_1)	100 (S_1)	100 (S_1)
Relative humidity	100 (S_1)	100 (S_1)	100 (S_1)
Topography (t): Slope (%)	100 (S_1)	100 (S_1)	100 (S_1)
Drainage (w):	100 (S_1)	100 (S_1)	100 (S_1)
Wetness	100 (S_1)	100 (S_1)	70 ($S1_2$)
Flooding	100 (S_1)	100 (S_1)	80 ($S1_2$)
Soil physical properties (v)			
Texture	90 ($S1_2$)	90 ($S1_2$)	90 ($S1_2$)
Structure	90 ($S1_2$)	90 ($S1_2$)	100 (S_1)
Coarse fragments (%) (0-60 cm)	90 (S_1)	100 (S_1)	100 (S_1)
Soil depth	100 (S_1)	100 (S_1)	100 (S_1)
Fertility (f)			
pH	90 ($S1_2$)	90 ($S1_2$)	90 ($S1_2$)
Cation Exchange Capacity (cmol Kg^{-1})	12 (N_2)	12 (N_2)	19 (N1)
Base saturation (%)	90 ($S1_2$)	100 (S_1)	90($S1_2$)
Organic carbon (%) (0-60 cm)	39 (N1)	50 (S_3)	45 (S3)
Macro- nutrients			
Nitrogen	30 (N_1)	30 (N_1)	30 (N_1)
Phosphorus (mg kg^{-1})	19 (N_1)	20 (N_1)	20 (N_1)
Potassium (cmol/kg)	33 (N_1)	40 (S_3)	35 (S_3)
Actual Suitability†	**2.05 (N)**	**1.94(N)**	**1.08(N)**
Potential Suitability†	**81.00 (S1)**	**90.00(S1)**	**63.00(S2)**
Actual Suitability?	**11.4(N)**	**11.4(N)**	**15.08(N)**
Potential Suitability?	**85.38(S1)**	**90.00(S1)**	**75.30(S1)**

† Suitability by linear model; S1= Highly suitable,
S2= Moderately suitable, S3= Marginally suitable, N1= currently not suitable,
N2= permanently not suitable
*Suitability by Square root model

were mainly low levels of available macronutrients (low total Nitrogen, Available Phosphorus, CEC, Organic Carbon and Potentially (without considering soil fertility which is regarded as temporal limitation) by both Models, Pedons are highly suitable (S1) for the production of Maize. However, the productive capacity of the soils of the study area for Maize production can be achieved through the use of soil management strategies such as integrated soil management coupled with a management system that are compatible with diversification of the farming system, like crop rotation, reduced tillage practices, cover cropping, among others. These management practices will upgrade the suitability classes of the soils for higher yield in rainfed sustainable production of maize in the study area.

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