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Effect of Different Soil Geological Formations (Parent Materials) on Land Suitability for Maize (*Zea Mays*) Production in Niger State, Nigeria

Daniel Mathew*, Lawal Baba Abubakar, Mohammed Tetengi***, Ibrahim Philip Audu****, Shema Andrew Monday*****, Aliyu Emmannuel John******, Uyokei Uba*******, Lemibe Prince Chisom********

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ABSTRACT

This study evaluated the suitability of some soils developed under two geological formations (that is, basement complex rocks and the sedimentary rocks) in Niger State, for maize (Zea mays) production. Four sites two each under the formations were selected for the study. Gidan Mangoro (GDM) and Mutun Daya (MTD) represented the basement complex while Enagi (ENG) and Ndayako (NDY) represented the sedimentary rocks. In each site, a mini profile pit (1m x 1m x 1m) was dug, described and sampled according to FAO guidelines. The samples were analyzed in the laboratory following the standard analytical procedures. Square root method was used in the suitability evaluation of the soils. The results showed that, the texture of GDM, was loamy sand at topmost horizon (Ap), underlain by sandy clay loam at Bt horizon over sandy loam texture at Btv horizon. The texture of MTD was sandy loam at topmost horizon (Ap), underlain by sandy clay loam at Btv1 and Btv2 horizons. ENG, and NYK were sandy loam all through. The current (actual) status of the sites revealed temporally not suitable (N1) with indices of 21, 20, 22 and 17 for GDM, MTD, ENG and NYK respectively due to soil fertility and nutrient retention limitations. After correcting the limitations, the sites showed potentials for the production of maize with indices of 31 (S3), 28 (S3), 47 (S2) and 43 (S2) for GDM, MTD, ENG and NYK respectively. The soils under the sedimentary rock formation showed more potential for maize production. Key Words: Parent materials; basement complex and sedimentary rocks, Land suitability evaluation, maize production.

1. Introduction

Parent material is the material from which soil is thought to have been derived from (Shakeel, 2020). Productivity of a soil is a function of its physical and chemical propertie, these properties are as a result of the interaction among the soil forming factors and processes, hence, making soil to be heterogeneous (Lawal et al., 2014). Evaluation of soils is increasingly becoming necessary as the need for precision agriculture increases (Adeyolanu et al., 2020). Land is an essential natural resource, comprises of physical component of the Earth, which is permanently not covered with water, and vital both for the

*, ****, *****, ******, *******, ********National Cereals Research Institute, Badeggi, Niger State, Nigeria Research Outreach Department, Nigeria, **, ***Federal University Technology, Department of soil science and land management, Minna, Niger State, Nigeria
Email addresses: mathewdaniel1930@gmail.com (Corresponding author - M. Daniel), lawalba63@futminna.edu.ng (B.A Lawal), mohammedtetengi56@gmail.com (T. Mohammed), iaphilip004@yahoo.com (P.A Ibrahim), shemaadrew82@gmail.com (A. M. Shema), aliyujohnemmmanuel@gmail.com (J.E Aliyu), uyokeiuba@gmail.com (U. Uyokei), lemibechisom@gmail.com (P.C Lemibe).

survival and prosperity of humanity (FAO/UNEP, 1999). It is important that agricultural land be used according to its capacity for optimal and sustainable production (Adeboye, 1994, Afolabi et al., 2014).

Land suitability evaluation is the process of assessment and classification of land units according to their suitability for a particular use (Nguyen et al. 2020). Therefore, the objectives of this study were to characterize the soils derived from different parent materials in Niger State, Nigeria and to evaluate their suitability for maize production.

2. Literature Review

The study of soils in the landscape is very important for the understanding of the processes and patterns of soil development and properties. It also helps to account for the role of parent materials and slope positions on soil properties and processes along the hillslope (Elias & Gbadegesin, 2012. In general, parent materials influence soil formation by their different rates of weathering, the nutrients they contain and dominant particle size (Shakeel, 2020). Soils containing hardened iron concretions in form of gravels (pisoliths) either on the surface horizons or beneath are widespread within the basement complex rocks formation of Niger State (Lawal et al., 2023). Predominantly, soils developed on basement complex rocks, have impervious subsurface horizons due to plinthization processes (Lawal et al., 2023). Sedimentary rocks, although much less in volume than igneous or metamorphic rocks in the Earth's crust, are more accessible to study and exploitation as they cover 72% of the land surface and 99% of the ocean floor. They have a special position among life support systems as they hold most of the world reserves of groundwater. Moreover, they host all the world deposits of fossil fuels either formed in situ or entrapped in favorable structures after migration through the rock massive, and the soils formed from sedimentary rocks are very deep and well drained (Einsele, 1992).

3. Materials and Methods

Niger State is underlain by two geological terrains namely the Basement complex rocks and the sedimentary rock formations. The study covered the four sites, two from the basement complex and two from sedimentary rock geological formation. The sites were Gidan Mangoro in Bosso (Longitude: 6^o 29′ 30.570″ E and Latitude: 9^o 34′ 29.652″ N). Mutun Daya in Paikoro (Longitude: 7^o 03′ 03.090″ E and Latitude: 9^o 33′ 34.188″ N), Enagi in Edati (Longitude: 5° 32' 8.220" E and Latitude: 9° 7' 24.630" N) and Ndayako in Mokwa (Longitude: 5^o 00′ 49.440″ E and Latitude: 9^o 22′ 19.002″ N), all within the southern Guinea savanna agroecological zone of Nigeria. Niger State is sub-humid tropical and experiences two distinct wet season and dry seasons. Rainfall is bi-modal with mean total annual rainfall of 1,600 mm in the southern part and decreased to 1,200 mm in the northern part of the state, distributed from the months of May to October. The dry season is about 5 months duration from November to March. The mean annual maximum rainfall is about 1600 mm. The average minimum and maximum temperatures are 20 ℃ and 37 ℃ respectively while the mean annual relative humidity is between 39% to 70%. Geomorphologically, Niger State was characterized by undulating landscape, upland, lowland, plains, flood plains, and rolling dissected plains (Alabi 2011).

Field work and soil sampling

One profile pit measuring 1 m × 1 m × 1 m (or to permissible depth), was dug in each of the locations and were described according to FAO guidelines (FAO, 2006). Soil samples were collected from the identified genetic horizons, from bottom to the top of the profile. The following materials were used for the field study; handheld GPS device, Munsell Colour Chart (2009 version), a plastic bucket, zip-lock bags, digger, shovel, hand-trowel, hand note book, writing pen, permanent marker, stapler, and masking tape. The well-labelled soil samples were taken to the laboratory for processing and routine analysis. Laboratory Analysis.

The air-dried soil samples were passed through a 2 mm mesh and analysed according to standard laboratory procedures (IITA, 2015). Briefly, particle size distribution was determined by Bouyoucos hydrometer method, using sodium hexametaphosphate as the soil dispersing agent. The textural classes of the soils were determined using IUSS soil textural triangle. Soil pH was determined in a 1:2.5 soil / water suspension using a standard pH meter and electrodes. Exchangeable acidity (H^+ and Al^{3+}) was determined by titrimetric method, while organic carbon (C) was determined by Walkley-Black method of wet combustion involving oxidation of organic matter with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4). Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OAc. Calcium and Mg in the soil extract were determined using atomic absorption spectrophotometer while K and Na were determined by flame photometry. Cation exchange capacity (CEC) was determined by the neutral 1N NH_4OAc saturation method. Base saturation was determined by calculation, dividing the sum of exchangeable bases by their CEC and then multiplied by 100.

Land Suitability Evaluation for Maize

Suitability evaluation was performed for production of maize using the square root method (Khiddir, 1986) as expressed in equation (1):

$$Si = Rmin \times \sqrt{\frac{A}{100} X \frac{B}{100} X \frac{C}{100} \ldots\ldots} \qquad (1)$$

where, Si= suitability index, Rmin= connotes the factor that has minimum rating; and A, B, C… are ratings of other factors besides the minimum.

The land suitability evaluation took into consideration the soil characteristics related to land qualities affecting the land use types. Four (4) land quality groups: climate (c), soil physical properties (s), wetness (w) and fertility (f) were used in the evaluation. Final suitability for each crop was defined by applying the computed index values converted to its corresponding land suitability classes. According to suitability ranking of Sys et al. (1991), land suitability index of 0-12.5% connotes permanently not suitable (N2), 12.5-25% is currently not suitable (N1), 25-50% is marginally suitable (S3), 50-75 % is moderately suitable (S2) and 75-100% is highly suitable (S1). The soil and environmental requirements for maize production used in the evaluation are shown in Table 1.

Table 1. Factor Rating of Land Use Requirements for Maize Production (Sys, 1991)

Land Qualities	Unit	Class, degree of limitation and rating scale			
		S1 (100)	S2 (85)	S3 (60)	N (40)
Climate (c)					
Annual rainfall	(mm)	>800	700-800	600-700	<600
Mean temp	(Cº)	24-30	30-32; 20-24	32-35; 15-20	>35; <15,
Soil drainage (w)	Drainage class	Well	Moderately well	Imperfect	Poor, very poor

Land Qualities	Unit	Class, degree of limitation and rating scale			
		S1 (100)	S2 (85)	S3 (60)	N (40)
Soil characteristics (s)					
Effective soil depth	(cm)	>100	75-100	30-75	<30
Soil Texture		CL, L	SL, LS	LCS	CS
N utrient availability (f)					
Soil reaction	pH	6.0-6.5	5.5-6.0;6.5-7.0	5.0-5.5; 7.0-8.2	<5.0; >8.2
Topsoil organic carbon	(g kg-1)	>2.0	1.0-2.0	0.5-1.0	<0.5
Total N content	(g kg-1)	>0.2	0.1-0.2	0.02-0.1	<0.02
Available P content	(mg kg-1)	>40	10-40	3-10	<3
Topsoil K content	(cmol kg-1)	>0.3	0.2-0.3	0.1-0.2	<0.1
Nutrient retention capacity (n)					
Base saturation	(%)	>80	40-80	20-40	<20
Topsoil CEC	cmol kg-1	>25	13-25	6-12	<6
Sodicity ESP	(%)	<10	10-15	>15	-
Soil angle (Erosion hazard)	(%)	<4	4-8	8-16	>16
Soil angle (Erosion hazard)	(%)	<4	4-8	8-16	>16

L=Loamy, SL=sandy loam, CL=clayey loam, SC=sandy clay, LS=loamy sand

Source: Modified by Sys 1991

4. Results and Discussions

Morphological Properties of the Soils

The study showed that the soils from GDM and MTD were moderately-deep to deep, having 70-100 cm effective soil depth, with coarse fragments. The dominant colour spectral of the soils indicated a range of 7.5YR and 10YR hues which impacted the soils with colour variations such as dark yellowish brown, strong brown, brown, pale brown. According to Brady and Weil (1999) and Aki et al. (2014), these group of colours may be indicative of the presence of migmatite, gibbsite, goethite and haematite minerals in the soils. The presence of mottle colouration in the subsoils may be an indication of internal drainage problem due to presence of plinthic layers which restricted free movement of water within the soil body, during the rainy season. This causes the soils to be imperfectly to poorly drained during the rainy season.

The soils from ENG and NDY were deep to very deep effective soil depth of 75-105 cm and were relatively free from course fragments and were well-drained. Similar to soils described under the basement complex, the colour features of soils of ENG and NDY indicated a range of 2.5YR to 10YR which impacted them with red, dark yellowish brown, dark red, dark yellow brown and dark reddish brown.

Physical Properties.

The physical properties of the soils of the four sites are presented in Table 2.

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Table 2. Physical properties of the soils

Site	Horizon	Soil Depth	Sand	Silt	Clay	Textural Class	Bulk density	Total porosity
		(cm)	(g kg-1)				(g cm-3)	(%)
GDM	Ap	0 – 30	774	160	66	LS	1.45	45
	Bt	30 – 46	614	140	246	SCL	1.50	43
	Btv	46 – 75	674	200	126	SL	1.67	37
MTD	Ap	0 – 16	681	200	119	SL	1.46	45
	Btv1	16 – 27	601	140	259	SCL	1.63	39
	Btv2	27- 70	641	80	279	SCL	1.57	41
ENG	Ap	0 – 30	679	146	175	SL	1.41	48
	AB	30 – 50	699	146	155	SL	1.51	43
	B1	50 – 66	619	206	175	SL	1.37	48
	B2	66 – 85	599	206	195	SL	1.30	51
	B3	85 – 105	619	206	175	SL	1.48	44
NDY	Ap	0 – 20	721	180	99	SL	1.32	50
	Bt1	20 – 75	761	120	119	SL	1.47	45
	Bt2	75 - 100	721	160	119	SL	1.48	44

LS=loamy sand, SL= sandy loam, SCL= sandy clay loam.

Source; Laboratory Experiment 2023

The soils from GDM and MTD developed from basement complex, which have their textures to be loamy sand in surface horizons while sandy clay loam in sub-surface horizons respectively. The sand content follow the same pattern in all the soils of these sites, it decreased with soil depth. The silt content of these sites increased and decreased with soils depth except for MTD that decreased with depth. The clay content of MTD increased with soil depth while GDM increased and decreased with depth. The high sand fraction in surface horizon was also influenced by the parent material from which the soils are formed (Akpan-Idiok (2012); Peter and Umweni, 2021). The texture of ENG and NDY were sandy loam both in surface and sub-surface horizons. The sand content follow a particular pattern in all the soils, it decreased and increased with depth. Silt fraction from ENG and NDY were less in the topsoils than in the sub soils, while clay content increased with depth except for ENG that increased and decreased with depth. The relative high sand content in the area was the reflection of the effect of parent material such as Nupe sandstones. According to (Akamigbo and Asadu, 1983), the parent materials have been noted to influence the texture of the soils derived from them. The lower silt content in the soils may also be attributed to the effect of parent materials on the soils, as it has been reported by Akamigbo. (1984) that silt content is low in most soils of Guinea savanna of Nigeria.

Chemical properties

The chemical properties of the soils of study areas are presented in Table 3.

Soil reaction was slightly acid to neutral with pH values of the surface soil as 6.3, 6.4, 6.9 and 6.5 for GDM, MTD, ENG and NDY respectively and were classified as slightly acid to neutral.

Organic carbon (OC) in GDM ranged from 1.46 to 2.33 g kg-1 and rated high. OC in MTD ranged from 3.61 to 7.05 g kg-1, and rated very high. OC in ENG ranged from 0.51 to 4.24 g kg-1 and rated low to high. OC in NDY ranged from 6.72 to 9.01 g kg-1 and rated very high. Organic carbon is an essential component of soil chemical parameter for tropical soils, contributing to aggregate stability, permeability, water holding capacity, nutrient retention, and other desirable soil properties. (Ravindra. et al.2017). Total N in the soils of all sites was very low to low. Except in NDY, where available phosphorus was low, other sites had moderate to high values. The cation exchange capacity (CEC) values for all sites were generally low, except for MTD that was moderate. According to (Chude, et al. 2011) rating, the concentration of exchangeable Ca2+ in GDM, MTD, and NDY were rated to be low, and exhibited the pattern of increased and decreased with the profile depth. While it concentration in ENG was rated to be moderate and increased and decreased with soil depth. The concentration of exchangeable Mg in GDM and ENG were rated to be moderate both in surface and sub-surface horizons and exhibited increased and decreased pattern with soil depth.

While it concentration in MTD and NDY were rated to be low, both in surface and sub-surface horizons and exhibited increased and decreased with soil depth. The concentration of exchangeable K in GDM, MTD, and NDY were rated to be very low both in surface and sub-surface horizons and exhibited increased and decreased pattern with soil depth.

Table 3. Chemical properties of soils

Areas	Soil Depth	pH	OC	N	P	Ca	Mg	K	Na	EA	CEC	BS
	(cm)	(H2O)	(g kg-1)		(mg kg-1)	←		(cmol kg-1)			→	(%)
Gidan Mangoro	0 – 30	6.3	1.46	0.46	12.65	2.88	0.96	0.07	0.83	0.04	8.40	56.43
	30 – 46	6.1	2.33	0.48	7.19	3.20	2.08	0.08	0.67	0.03	9.01	66.93
	46 – 75	6.2	1.46	0.36	9.51	2.40	1.12	0.07	0.58	0.04	7.11	58.65
Mutun Daya	0 – 16	6.4	7.05	0.74	14.39	2.08	0.80	0.14	0.45	0.14	14.41	24.08
	16 – 27	6.3	3.61	0.50	20.25	2.40	0.80	0.09	0.51	0.13	17.41	21.83
	27 -70	6.4	3.93	0.52	21.41	2.40	1.44	0.09	0.61	0.10	18.85	24.08
Enagi	0 – 30	6.9	1.87	0.34	26	5.04	0.72	0.14	0.20	0.05	7.40	82.43
	30 – 50	6.5	0.85	0.56	43	5.70	1.04	0.11	0.22	0.08	8.60	82.21
	50 – 66	6.9	4.24	0.46	28	6.64	1.28	0.14	0.23	0.04	11.08	78.82
	66 – 85	6.6	1.19	0.56	21	5.20	1.52	0.12	0.26	0.05	8.40	84.52
	85 – 105	6.4	0.51	0.23	30	5.60	0.40	0.07	0.20	0.05	7.20	87.08
Ndayako												
	0 – 20	6.5	6.72	0.36	9.33	1.60	0.96	0.05	0.50	0.11	10.40	29.90
	20 – 75	6.5	7.70	0.46	7.24	2.08	0.80	0.09	0.56	0.13	13.86	25.47

Source: Laboratory Experiment 2023.

The concentration of exchangeable Na in GDM, MTD, and NDY were rated to be moderate in both surface and sub-surface horizons and exhibited increased and decreased with soil depth. While the concentration of Na in ENG was rated to be low, both in the surface and sub-surface horizons, and also exhibited the pattern of increased and decreased with soil depth.

Land Characteristics/Quality Attributes of the Soils

Results of land characteristics and soil quality attributes of GDM, MTD, ENG, and NDY essential for suitability evaluation are presented in Table 4.

The sites characteristics were based on particle size distribution (texture), effective soil depth, topography, drainage formed, fertility status and nutrient retention status for maize production respectively.

Table 4. Land characteristics/quality attributes of the sites

Parameter	Gidan Mangoro	Mutun Daya	Enagi	Ndayako
Mean Temp (°C) (Growing Season)	26.2	26	26.4	27
Rainfall (mm)	1256	1328	1,226.3	1,259.5
Dry months	5	5	5	5
Slope (%)	3.0	4	3.0	3.0
Soil depth (cm)	75	70	>100	>100
Drainage	Mod.	Imperf.	Well	Well
Soil texture	LS	SL	SL	SL
Soil reaction (pH)	6.3	6.4	6.9	6.5
Organic carbon (g kg-1)	1.46	7.05	1.87	6.72
Total Nitrogen (g kg-1)	0.46	0.74	0.34	0.36
Phosphorus (mg kg-1)	12.65	14.39	26	9.33
Potassium (cmol kg-1)	0.07	0.14	0.14	0.05
CEC (cmol kg-1)	8.40	14.41	7.40	10.40
Base saturation (%)	56.43	24.08	82.43	29.90
Flooding	F1	F1	F0	F0
Exchangeable Sodic percentage (%)	2.70	12.35	9.88	9.99
Gravel (%)	4	4	2	2

F0 = non-flooding, F1 = moderately flooding, F1= Flooding, F3= highly flooding

Source: Laboratory and Weather Experiment 2023

Land Suitability Evaluation for Maize

The assessment of the fitness of the study sites for maize production followed the suitability criteria laid down by the Sys et al. (1993), for both actual and potential suitability.

The actual suitability evaluation involved the assessment of the land in its status, while the potential suitability evaluation was carried out after imposing corrective management measure to correct the limitation (especially fertility related). The outcome of matching the land and environmental requirement (Table 1) with the land characteristics/ soil quality of the sites (Table 4) for each site covered both the actual (current) and potential suitability of the sites after correcting the limitations) and results are presented in Table 5.

The actual suitability indices were 21, 20, 22 and 17% for GDM, MTD, ENG and NDY respectively, suggesting that all the sites were not suitable (N1) for maize production in their status due to limitations of soil fertility (particularly P and K) and nutrient retention (low organic matter and CEC).

Low K content in GDM, ENG and NDY and moderate in MTD was the major fertility limitation. NDY also had moderate P content in the soil. In addition to fertility limitation, the soils of MTD had limitation of wetness (imperfectively drained subsurface) as a result of presence of plinthic horizon which induced perched water-table. The index suitability for MTD was 20% for actual and 28% for potential which translated to currently not suitable (N1) and marginally suitable (S3) respectively.

Table 5. Suitability Assessment of the study sites for maize production

	Gidan Mangoro	Mutun Daya	Enagi	Ndayako
Climate				
Annual Rainfall	100	100	100	100
Mean temp (growing season)	100	100	100	100
Soil drainage (w)	85	60	100	100
Soil characteristics (s)				
Effective soil depth	85	60	100	100
Soil Texture	85	85	85	85
Slope	100	85	100	100
Nutrient availability (f)				
Soil reaction (pH)	100	100	85	100
Topsoil organic carbon	85	100	85	100
Total N	100	100	100	100
Available phosphorus	85	85	85	60
Potassium	40	60	40	40
Nutrient retention (n)				
Base Saturation	85	60	100	60
Topsoil CEC	60	85	60	60
ESP	100	100	100	100
Aggregate Suitability				
Actual	N1fn (21)	N1wfn (20)	N1fn (22)	N1fn (17)
Potential	S3n (31)	S3wn (28)	S3n (47)	S3n (43)

S3= Marginally Suitable, N1= currently not Suitable, fn=fertility limitations, wfn=wetness and fertility limitations, wn=wetness limitation, n=no limitations.

Source: Land suitability Assessment from land characteristics/quality of study sites 2023

After imposing corrective measures to correct the fertility limitation through application of mineral fertilizer, the index of suitability upgraded to 31, 28, 47 and 43 for GDM, MTD, ENG and NDY respectively. These values corresponded to marginally suitable (S3) for maize production.

5. Conclusion and recommendations

From the results of this study, it can be concluded that climate was not a constraint for the production of maize in the study sites. The low organic matter, phosphorus and potassium content in all the site can be amended by adopting management practices that can encourage return of plant/crop residues into the soil as well as application of mineral fertilizers to improve phosphorus and potassium. Also planting on ridges is recommended for improving rooting condition in Gidan Mangoro and Mutun Daya.

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