



SOIL FERTILITY ASSESSMENT AND LAND SUITABILITY EVALUATION FOR WHEAT (*Triticum aestivum* L.) AND RICE (*Oryza sativa* L.) CULTIVATION IN SELECTED FARMLANDS OF KONDUGA LOCAL GOVERNMENT OF SUDAN SAVANNAH ZONE OF NIGERIA

I.B. Buji^{1*}, I. Adamu¹, I.Z. Talha¹, A.L. Ngala¹, D. Samaila², A.A. Turajo¹ and H.B. Musa¹

¹Department of Soil Science, University of Maiduguri, Borno State, Nigeria

²Department of Agricultural Science, Federal Collage of Education Gidan Madi, Sokoto State, Nigeria

ABSTRACT: The fertility and land suitability of Mashamari, Mandarari, and Duwari soils in the Konduga Local Government of Borno State, within the Sudan Savanna climatic zone, were investigated for Wheat (*Triticum aestivum*) and Rice (*Oryza sativa*) cultivation using simple limitation methods. Soil samples were collected from nine sampling points across the study area and analyzed for various parameters. The surface soils in Mashamari and Mandarari were classified as loam, while Duwari exhibited a sandy clay loam texture. Bulk density varied across locations, with moisture content generally below the optimal range of 25–60%. Soil reaction was neutral in Mashamari and moderately acidic in Mandarari and Duwari, falling within the suitable range for both crops. Organic carbon and total nitrogen contents were generally low, and available phosphorus values were uniformly low. Exchangeable bases indicated low calcium, variable magnesium, and low to moderate potassium, with very low to low exchangeable sodium. Land evaluation revealed highly suitable conditions for soil workability, rooting depth, and nutrient availability, with marginal suitability for organic matter, cation exchange capacity, and moisture availability. Climate (temperature) was moderately suitable. The aggregate suitability classification for the current conditions was marginally suitable (S3) due to limitations in nutrient availability and moisture conditions. However, with potential amendments, particularly integrating organic materials and promoting subsurface drainage, the suitability was enhanced to moderately suitable (S2), with only temperature as a limiting factor for wheat and rice production.

Key words: Simple limitation methods, Dutch Auger, Aggregate suitability and limitation

INTRODUCTION

Understanding soil fertility and land suitability is fundamental for improving crop production and ensuring long-term agricultural productivity. This is particularly true in regions like Konduga Town, located in Borno State, Nigeria, where the intersection of environmental factors and agricultural practices plays a crucial role in shaping the success of farming endeavors. The evaluation of soil fertility and land suitability in this region is imperative for guiding farmers towards informed decision-making and implementing efficient agricultural strategies.

Soil fertility, is the capacity of soil to provide essential nutrients to plants, as influenced by various factors such as soil texture, structure, organic matter content, and nutrient levels (Brady and Weil 2008). The intricate relationship between these factors requires a comprehensive analysis to gauge the overall fertility status of farmlands in Konduga Town. Concurrently, land suitability evaluation involves assessing the appropriateness of specific areas for different types of crops, considering factors such as climate, topography, and soil characteristics (FAO 2006). Understanding land suitability is instrumental in determining the most suitable crops for cultivation, thereby maximizing yields and minimizing environmental impact.

This study seeks to delve into the soil fertility and land suitability for dry season wheat and rice cultivation in selected farmlands of Konduga Town, Borno State, Nigeria, with a focus on providing valuable insights for sustainable agricultural practices. By examining the current state of soil fertility and assessing land suitability, the research aims to contribute essential knowledge that can inform agricultural policies, guide land-use planning, and empower local

*Corresponding Author's email: ibrahimbuji84@gmail.com Phone: +2348030988345

farmers in optimizing their agricultural activities. The objectives of the study were to; assess the fertility status of the soils, determine the suitability of the soils for dry season wheat and rice cultivation and to recommend suitable soil management for sustained production.

MATERIALS AND METHODS

General Description of the Soils

The soils of the area generally occur in simple patterns and are not considerably varied over short distances, especially in texture and drainage. During the survey a number of individual soils were recognized, but could not be shown as the purpose of the survey work does not include soil characterization and classification. Instead, the soils were described and mapped in relation to changes in color and land use.

Location of the study area

The study was conducted in three farmlands, namely: (i) Mashamari with an average area of 5.13 H hectares, (ii) Mandarari with an area of 20.41 hectares and (iii) Duwari with an area of 16.59 Ha. (Fig. 2.1, 2.2 and 2.3 respectively). Konduga L.G. of Borno state between latitude N11.5290° and N11.67534°, and longitude E13.43188° and E13.39656° (Fig. 1.0)

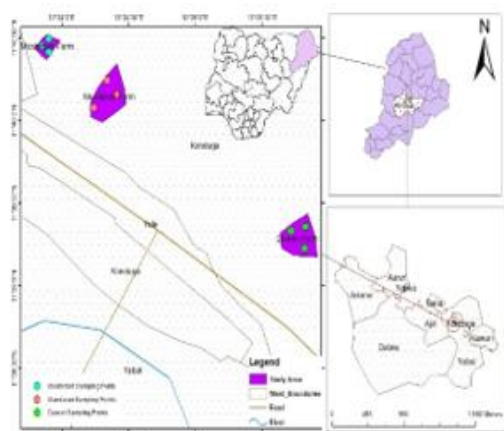


FIG 1.0. GIS Map Showing Nigeria, Borno, Konduga and Study Area/Sampling Sites



Fig 2.1. Google map imagery showing the farm boundary and sampling points for Mashamari (5.13 Ha).

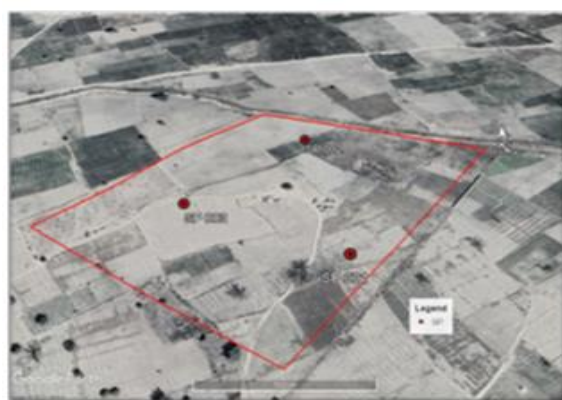


Fig 2.2. Google map imagery showing the farm boundary and sampling points for Mandarari (20.41 Ha).



Fig 2.3. Google map imagery showing the farm boundary and sampling points for Duwari (16.59 Ha)

Description of the Climate

The climate of the project sites is typical of the West African savanna climate. It is divided into distinctly marked by dry and wet seasons, associated with the movement of two dominant air masses over the entire West African sub-

region. From May to October, the sun moves to the northern hemisphere bringing rain bearing south-westerly winds. During this time, the day length is at maximum. The sun moves to the southern hemisphere from November to April, creating low pressure and northeasterly dry winds (harmattan) blow from Sahara, thus there is no rain. The boundary between the two dominating air masses is known as Inter-Tropical Convergence Zone (ITCZ). The ITCZ fluctuates seasonally, but it is furthest south in January when the harmattan blows to the coast and reaches the northern limit in August (Oguntoyinbo, 1982). The dominant wind in the sites and indeed the entire Northeast Nigeria for most of the year is the northerly harmattan. These air movements explain why the wet season is short in the study area, which necessitate dry season farming through irrigation.

Rainfall

Average annual rainfall is around 600 to 800 millimeters (24 to 31 inches) and the length of the rainy season is about 90 - 100 days occurring between late May and early October in the communities of the area. There is little variation in the pattern of wind orientation between the months of November and April while between June and October, the wind direction changes and rain bearing winds blow mainly from the southeast. Keep in mind that specific rainfall patterns can vary from year to year (Grema and Hess, 1994)

Temperature

Temperature is high throughout the year in the area. This is because solar radiation is high and evenly distributed throughout the year. However, a seasonal variation in temperature is experienced. The temperature increases from January to April and drops at the beginning of the rainy season due to the effect of cloudiness, it slightly increases at the end of the rains in October to November, but drops in December due to harmattan. Temperatures ranges from 18 to 40 degrees Celsius (64 to 104 degrees Fahrenheit). The harmattan, a dry and dusty trade wind, can be prevalent during this period (NIMET 2021).

Sunshine

Daily sunshine hours are highest during the months of October to December, slightly decrease during the months of January to April and are lowest between the months of May to September due to cloudiness all over the area. The number of sunshine hours may have an inverse relationship with the mean annual rainfall and number of days or length of the rainy season (NIMET 2021).

Potential evapotranspiration

Potential evapotranspiration is generally high and certainly greater than rainfall. Rainfall exceeds evapotranspiration only during three months of the year; July, August and September. Potential evapotranspiration is relatively low in January because of the cool harmattan; the accompanying dust haze reduces the amount of solar radiation reaching the earth's surface (NIMET 2021).

Relative humidity

Relative humidity is highest in the pre-rains hot period in March and April, falling to a minimum in October to February. It follows an inverse daily relationship with temperature, reaching maximum values at night and minimum ones at the height of the day (NIMET 2021).

Vegetation

The area is characterized by trees such as *Daniella oliveri*, *Diospyros elioti*, *Ceiba pentandra*, *Nauclea latifolia*, *Bombax costatum*, *Parkia biglobosa*, *Drypetes floibunda*, *Brachystegia eurycoma*, *Brarysocarpus coccineus*, *Zanthoxylum zanthoxyloides*, *Vitox doniana*, *Piliostigma thonningii*, *Azardirtcha indica* and *Entanda abyssinica*. Common grasses are species of *Andropogon*, *Hyparrhenia*, *Penicum* and *Ctenium*.

Land Use

Land use in the communities includes rainfed production of sorghum, maize, cowpea, groundnut and Bambara groundnut and irrigated crops of onion, water melon, rice, and other vegetables. These are grown as intercrops or as sole crops.

Field Sampling Points and Description of Soil Samples

Nine (9) sampling points i.e., three in each site of the three-study area (Fig 2.1, 2.2 and 2.3) were identified. Soil samples were collected from each site using Dutch auger at a depth of 0-15 and 15-30 cm each. The soils were bulked and packed in a nylon bag and properly labeled. The samples were air-dried and sieved through 2 mm sieve for

laboratory analysis. Standard laboratory analysis was followed to determine soil parameters that directly or indirectly influence rice and wheat production. Soil properties considered were physical properties: soil texture, bulk density, porosity, mass wetness and volume wetness. Chemical properties: soil pH & EC, organic carbon, total nitrogen, available phosphorus, exchangeable bases (Ca, Mg, Na, and K), exchangeable acidity, cation exchange capacity and base saturation.

Determination of Soil Physical Properties

Soil Texture

Soil texture was analyzed by hydrometer method (Anderson and Ingram, 1993). Forty gram of soil samples was weighed into a beaker and pretreated with 5ml of 30% hydrogen peroxide to destroy organic matter. This suspension was dispersed with 50ml of 5% sodium hexametaphosphate (calgon) and then transferred to 1litre cylinder and made up to volume. Silt and clay were measured in the suspension by recording hydrometer reading at 40 seconds and clay at 8 hours. Sand was calculated by difference.

Bulk Density

Soil bulk density was determined by the core sampler method after drying the soil samples in an oven at 105 °C to constant weights as described by Jaiswal (2004). The mass of the oven-dried soil was divided by the total soil volume to obtain the bulk density (Black 1965).

Porosity

Soil total porosity was calculated using the following formula; $F = 1 - (\rho_b / \rho_p) \times 100$

Where: F = Total Porosity, ρ_b = Bulk density, and ρ_p = Particle density

Mass Wetness

Soil moisture content was determined using oven drying method which depended on the oven drying temperature as described by Farley *et al.* (2004).

Volume Wetness

This was calculated by multiplying the mass wetness by the bulk density: $\theta_v = \theta_v \times \rho_b$ (Bolsa, 2008).

Determination of Soil Chemical Properties

Soil pH and EC

Soil pH was measured in water (1:2.5 soil-water ratios) after equilibration for 1 hour with a glass/calomel electrode pH meter. The electrical conductivity (EC) was measured in the 1:2.5 soil–water ratios using EC meter (Agbenin, 1995).

Organic carbon

Organic carbon was determined by dichromate oxidation (Walkley and Black, 1934). The organic carbon in the soil was oxidized with 10ml 1N $K_2Cr_2O_7$ and the excess or untreated dichromate was titrated with fresh 0.5N $FeSO_4 \cdot 7H_2O$. The amount of organic carbon oxidized was calculated from the amount of dichromate reduced, corrected for blank.

Total nitrogen

Total nitrogen was determined by Kjeldahl digestion (Bremner, 1965). 5g of soil was digested with 30ml concentrated H_2SO_4 and Kjeldahl tablet. The ammonium in the digest was absorbed into 10ml of 2% boric acid-mixed indicator solution through distillation after making the solution alkaline with 15ml of 40% NaOH and measured titrimetrically with 0.01N H_2SO_4 .

Available phosphorus

Available phosphorus was determined by extraction with dilute acid-fluorides (Bray and Kurtz, 1945). The phosphorus in solution was measured by spectrophotometry after reducing the phosphomolybdate complex formed after adding ammonium molybdate with stannous chloride to a molybdenum blue color.

Exchangeable bases (Ca, Mg, Na, K)

Exchangeable bases were extracted with 1M NH_4OAc (pH 7.0). Exchangeable potassium and sodium were determined by flame photometer and calcium and magnesium by titration with sodium EDTA using erichrome black T and murexide indicators (Black, 1965).

Exchange acidity

Exchange acidity was determined by shaking 5g soil samples three times with 30ml 1M KCl, first for 1 hour, then for 2×30 minutes and filtered. 50 ml of the filtrate was titrated with 0.05N NaOH using 5 drops of phenolphthalein indicator to a permanent pink end point (Black, 1965).

Cation exchange capacity and base saturation

The cation exchange capacity was calculated by summing up the exchangeable bases and exchangeable acidity ($\text{H} + \text{Al}$). Percentage base saturation was calculated using the following formula: $\% \text{BS} = (\text{A}/\text{B}) \times 100$ Where: $\text{A} = \text{NH}_4\text{OAc}$ (pH 7.0) Extractable Bases ($\text{Ca} + \text{Mg} + \text{Na} + \text{K}$) (cmol (+) kg^{-1}), $\text{B} = \text{CEC}$ (cmol (+) kg^{-1}) (Rhodes, 1982).

Land Evaluation

The principles and methods given in Framework for Land Evaluation, FAO, (2007), using land suitability classification were strictly adhered. The different land units recognized in the three locations were evaluated using simple limitation methods. The rating is determined by five land attributes (Soil workability, rooting condition, Nutrient availability, Moisture availability and Climate which were considered the most relevant for the purpose. Regarding land evaluation, these attributes are referred to as "land qualities".

Land Suitability Classification

The procedure of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined used. According to the terminology given in a Framework for Land Evaluation, FAO (2007), the classification adopted for the surveyed areas is a "qualitative classification", in which the relative suitability of different land units recognized and mapped during the survey are expressed in qualitative terms only, without precise calculations of costs and returns. It is also classed as "current suitability", which refers to the suitability for a defined use of land in its present condition, or with some minor improved management practices only. Four land suitability classes have been recognized. They are described in the sequence of decreasing degree of suitability as; Class S1: Highly suitable land, Class S2: Moderately suitable land. Class S3: Marginally suitable land and Class N: Not suitable land

Non-parametric method

Specifically, the simple limitation approach, soil units were categorized into suitability classes based on their characteristics aligning with established criteria for rice and wheat cultivation (refer to Table 2). The ultimate suitability class, determined through aggregation, highlights the most limiting features of the soil unit (FAO, 1976, and Sys et al., 1993). This classification system entails four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). A designation of S1 is assigned when the soil characteristics satisfy all crop requirements. In cases where one or more characteristics fall short of meeting the crop requirements, the land is categorized as S2, S3, or N. It's noteworthy that improvements in limiting factors may prompt a shift to the next immediate class, such as an upgrade from S3 to S2."

RESULTS AND DISCUSSION**Physical Properties****Soil texture**

The dominant texture of the site is loam in Mashamari and Mandarari, while in Duwari it is sandy clay loam (Table 1). This indicate that the soil required little management because loamy texture is good for most crops and that will lead to sustained production with little management.

Bulk density and total porosity

The result of the bulk density ranged from $1.57 - 1.70 \text{ g/cm}^3$ in Mashamari, $1.65 - 1.75 \text{ g/cm}^3$ in Mandarari and $1.70 - 1.90 \text{ g/cm}^3$ in Duwari. Higher values of bulk density (ρ_b) indicate more compactness of the soil which will impede root growth and water infiltration. The values are within the normal range in Mashamari and Mandarari, but slightly

higher in Duwari in accordance to Arshad *et al.* (1996) soil ratings. Total porosity of all the locations were within the normal range of 30 – 60%. According to Taylor and Eggleton (2001), the pores are ideal for optimum aeration, permeability, drainage and water retention; these also offer most favorable physical condition for optimum plant growth.

Gravimetric and volumetric moisture content

The moisture contents were mostly below the ideal condition of 25 – 60% (Bolsa, 2008). The expression of water content on volumetric basis is more useful and convenient as θ_v is directly involved in calculating water flux, volume of water added to soil by rains/irrigation and the volume of water extracted from the soil by the process of evaporation and transpiration by plants.

Table 1: Physical Properties of Soils of Study Area

Location	Sand (%)	Silt (%)	Clay (%)	Textural Class	Bulk Density (g/cm ³)	Porosity (%)	Mass wetness (mm)	Volume wetness (mm)
Mashamari								
A	46.00	33.20	20.80	Loam	1.70	35.85	27.36	46.51
B	41.00	40.70	18.30	Loam	1.57	40.75	25.20	39.56
C	38.50	43.20	18.30	Loam	1.57	40.75	23.31	36.60
Mandarari								
A	31.00	45.70	23.30	Loam	1.75	33.96	15.01	26.27
B	28.50	50.70	20.80	Silt loam	1.65	37.74	12.08	19.93
C	31.00	48.20	20.80	Loam	1.56	41.13	31.97	49.87
Duwari								
A	56.00	25.70	18.30	Sandy loam	1.70	35.85	19.91	33.85
B	48.50	30.70	20.80	Loam	1.90	28.30	18.35	34.87
C	53.50	25.70	20.80	Sandy clay loam	1.78	32.83	20.05	35.69

Chemical Properties

pH and EC

Soil reaction in the site is generally neutral in Mashamari (ranging from 6.4 – 5.4 with a mean of 7.1) and moderately acidic in Mandarari (ranging from 5.8 – 6.3, with a mean of 6.0) and Duwari (ranging from 5.7 – 6.1, with a mean of 5.9) (Table 2). Soil reaction in the area is within the range for most arable crops (Brady and Weil, 2012). Excessive use of nitrogenous fertilizers in Mandarari and Duwari will acidify the soil. The EC of the soils ranged from 0.04 to 0.11dS/m with a mean of 0.07dS/m. No salinity effect was evidence from the soil samples collected as all the EC levels are less than 4 dS/m and therefore optimum for most crops (Hazelton and Murphy, 2007).

Organic Carbon/Organic Matter

Organic carbon and by extension organic matter contents of the soils were generally very low to low with values ranging between 1.60 and 5.50 gkg⁻¹ in the soils (Hazelton and Murphy, 2007). This is associated with low vegetative cover and high rate of decomposition and mineralization, hence affecting the fertility of the area. Soil organic matter is a term that is usually used in the broadest sense to describe a wide range of organic components in the soil including living and non-living organic materials. The non-living organic matter can be broken down into dissolved organic matter, particulate organic matter, humus and inert organic matter (charcoal and charred plant materials). It is therefore recommended that to increase organic matter, there is need for incorporation of organic matter in the area via crop residues, farmyard manure on cropping, avoid bush burning and increase planting of trees. The use of trees as fuel energy should be replaced by other means for cooking purpose, hence this will reduce erosion and desertification.

Total Nitrogen Content

Total nitrogen contents of the samples were shown in Table 2. According to Hazelton and Murphy soil ratings, the contents of N was moderately low in Mashamari and Mandarari, which ranged from 1.10 to 1.50 g/kg with a mean of 1.30 g/kg and 1.30 – 1.40 with a mean of 1.37 g/kg, respectively. The N content in Duwari was low to high ranging

from 0.40 – 2.80 with a mean of 1.43 g/kg. The authors noted that the low levels of total N could be attributed to the rapid rate of organic matter decomposition, high rate of leaching, volatilization and denitrification among other factors as contained in Ekwoanya and Ojanuga, (2002). The TN contents of the soils in the area fluctuates irregularly which could be attributed to influence of continuous cultivation, a common practice in the area that is accompanied by nearly total crop residue removal.

Table 2: Selected Chemical Properties of Soil Samples from study area (Konduga)

Sample Location	pH	EC	OC	OM	Avail. P	Total N	Exch. Acidity	Exchangeable Bases				CEC	Base Saturation (%)
								Ca	Mg	K	Na		
								(Cmol/kg)					
Mashamari		(dS/m)	(g/kg)	(g/kg)	(mg/kg)	(g/kg)							
A	7.5	0.11	3.90	6.72	6.30	1.10	0.20	2.80	2.40	0.12	0.04	5.36	94.40
B	7.3	0.07	3.70	6.38	4.55	1.30	0.20	3.00	1.60	0.08	0.05	4.73	95.94
C	6.4	0.06	5.90	10.2	6.65	1.50	0.30	2.60	0.80	0.14	0.07	3.61	92.33
Mean	7.1	0.08	4.50	7.77	5.83	1.30	0.23	2.63	1.60	0.11	0.05	4.57	94.22
Mandarari													
A	5.9	0.07	5.30	9.14	5.25	1.40	0.30	2.20	3.80	0.17	0.10	6.27	95.43
B	6.3	0.08	4.30	7.41	1.75	1.30	0.10	2.00	0.60	0.13	0.10	2.83	96.59
C	5.8	0.07	4.50	7.76	3.15	1.40	0.10	1.40	3.80	0.32	0.24	5.76	98.29
Mean	6.0	0.07	4.70	8.10	3.38	1.37	0.17	1.87	2.73	0.21	0.15	4.95	96.77
Duwari													
A	6.1	0.06	5.50	9.48	2.10	2.80	0.10	2.00	3.40	0.20	0.04	5.64	98.26
B	5.7	0.04	1.60	2.76	2.80	0.40	0.10	1.40	4.00	0.19	0.04	5.63	98.25
C	5.8	0.06	3.50	6.03	1.05	1.10	0.10	2.40	1.00	0.22	0.06	3.68	97.35
Mean	5.9	0.05	3.53	6.09	1.98	1.43	0.10	1.93	2.80	0.20	0.05	5.65	97.95

Available Phosphorus

Available phosphorus values were low in all the samples ranging from 1.05 – 6.65 mg/kg. Esu (2005), stated that soils with available P values of <10, 10-20, and >20 were rated as low, medium and high respectively. Similar findings have been reported by Yakubu *et al.* (2008), Noma and Yakubu (2002). Phosphorus is a critical element in agriculture next to nitrogen. The problem of phosphorus in soil fertility is three-fold; the total phosphorus level of soil is low and are mostly unavailable for plants uptake because they are highly insoluble. When soluble forms are added to the soil, they are fixed and in time form unavailable forms, leaving about only 10-15% for plant utilization. Soil phosphorus is available in very low amounts to plants since most of the total soil phosphorus is tied up in insoluble compounds, and its availability depends on the soil pH. In any fertilizer recommendation, the phosphorus fixing capacity and the desirable soil pH between 6 and 7 should be considered. Proper liming programme can enhance the P availability to plants in acid soils.

Exchangeable bases, CEC and Base Saturation

According to Hazelton and Murphy, (2007) soil ratings; The content of exchangeable bases showed that Ca was rated low in all the locations (1.40 - 3.00 cmol/kg), Mg was low to high (0.80 – 4.00 cmol/kg) and K rated low to moderate (0.12 – 0.32 cmol/kg), and the least was exchangeable Na (0.04 - 0.24 cmol/kg) rated as very low to low. The cation exchange capacity (CEC) of the soils is rated very low to low with values ranging from 2.83 to 6.27 cmol (+) kg⁻¹. The CEC provides a buffering effect to changes in pH, available nutrients, calcium levels and soil structural changes. As such it is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and the soil's reaction to fertilizers and other ameliorants. A low CEC means the soil has a low resistance to changes in soil chemistry that are caused by land use. Base saturations were very high through the profile (97.57 and 98.97 %). Base saturation provides an indication of how closely nutrient status approaches potential fertility. This may be affected by variable charge of the clay minerals in the soil.

Fertility assessment of the soils of study area

The assessment of the soils revealed that, low CEC, Nitrogen content and inadequate organic matter content, pH, inadequate moisture storage has led to low nutrient availability in the soil. This is believed to be the main constraints to a sustained wheat and rice production in the study areas. Although, inadequate rainfall and variation in their distribution pattern due to climate change also has a masked effect on crop performance and yield, these can be ameliorated with supplementary irrigation. The ratings also suggest how severe a given limitation is and to what extent

it may restrict the use of the land and the need for adequate protective measures and what kind of land use may be safely selected and adhered to.

Land suitability Evaluation for Mashamari, Mandarari and Duwari

The factor ratings representing the land use criteria for wheat and rice (refer to Tables 3 and 4) were matched/compared with the characteristics of the studied soils (see Table 5). The final assessment of qualitative land suitability for wheat and rice land uses, conducted through simple limitation was presented in Tables 6 and 7 respectively.

3: Rating of land use requirements for Wheat.

Land quality	Diagnostic factor	Unit	Factor rating			
			S1	S2	S3	N
Soil workability	Texture	Class	SL, L	SCL	CL	C
Rooting condition	Depth	Cm	>90	90-50	50-20	<10
Nutrient availability	Base saturation	%	>80	80-50	50-35	<35
Nutrient availability	Soil reaction	pH	6.5-6.0	6.0-5.6	5.6-5.2	<5.2
Nutrient availability	Organic carbon	%	0.81-1.0	0.61-0.80	0.41-0.60	<0.40
Nutrient retention	CEC	Cmol (+)	>24	24-16	16-10	<10
Moisture availability	Annual rainfall	mm	>750	500-750	350-500	<350
Climate	Temperature	°C	30	25-30	20-25	<20

Source: (Sys et al. 1993)

Table 4: Rating of land use requirements for Rice.

Land quality	Diagnostic factor	Unit	Factor rating			
			S1	S2	S3	N
Soil workability	Texture	Class	C	SC, SCL,	L	SL
Rooting condition	Depth	Cm	>60	40-60	20-40	<20
Nutrient availability	Base saturation	%	>70	50-70	40-50	<40
Nutrient availability	Soil reaction	pH	6.1-6.5	6.6-7.2	7.3-7.8	>7.8
Nutrient availability	Organic carbon	%	0.81-1.0	0.61-0.80	0.41-0.60	<0.40
Nutrient retention	CEC	Cmol (+)	>45	25-45	10-25	<10
Moisture availability	Annual rainfall	mm	>750	500-750	350-500	<350
Climate	Temperature	°C	20-25	25-30	30-35	>35

Source: (Sys et al., 1993)

Land Suitability Evaluation for Wheat and Rice Production Sys et al. (1991, 1993)

Following the FAO framework on Land evaluation for wheat and rice (1983) further modification were made to the land quality requirement of wheat and rice by Sys et al. (1991, 1993) and Udoh et al. (2011). Thus, the evaluation is done using the non-parametric methods otherwise known as Simple limitation method. The methods were in two phases: the actual and potential suitability. Actual suitability implies the suitability of the soil for the crops (wheat and rice) production in its present condition when correctable limitations were not corrected that is, Nutrient Availability (pH, EC, Base Saturation, Organic matter, CEC) and Moisture availability (rainfall). On the other hand, potential suitability is the assessment made on the basis that limitations were corrected (Faturoti et al., 2015).

The result of site characteristics of the study area is presented in Table 5. It is classified into five factors (land quality) Soil workability. Rooting condition, Nutrient availability, Moisture availability and Climate. Each of the factor has its characteristics (variables). The Climatic factor was represented as (c) has temperature as its variable. The Soil workability represented by (k) has texture as its characteristics. Rooting condition represented by (r) has soil depth as its characteristics. The Moisture availability factor represented by (m) has rainfall as its characteristics, while Nutrient availability factor represented with a symbol (n) had Base saturation, Soil reaction, Organic carbon and CEC as its variables. Each of these factors mentioned above are necessary for sustainable irrigated wheat and rice production (Naidu et al., 2006).

Table 5: Land unit (site) characteristics and qualities for soil suitability classification

Land quality	Diagnostic factor	Unit	Mashamari	Mandarari	Duwari
Soil workability	Texture	Class	L	L	SCL
Rooting condition	Depth	Cm	>100	>100	>100
Nutrient availability	Base saturation	%	96.4	95.4	98.3
Nutrient availability	Soil reaction	pH	7.5	5.9	6.1
Nutrient availability	Organic carbon	%	0.39	0.53	0.55
Nutrient retention	CEC	Cmol (+)	5.36	6.27	5.64
Moisture availability	Annual rainfall	Mm	456	456	456
Climate	Temperature	°C	28.1	28.1	28.1

(Landon, 1991).

Code for textural class: L= Loam; SCL= Sandy clay loam.

The matching results of wheat and rice were presented on Table 6 and 7 respectively. According to the matching, results showed that there was no limitation in soil workability (texture) for wheat production which classified the soils as highly suitable (S1) for having loam and sandy clay soils. For rice cultivation the soils were evaluated to be Marginally Suitable (S3) in Mashamari and Mandarari and moderately suitable (S2) in Duwari study area for having loam and sandy clay soils. Rooting condition (soil depth) shows that all the soils of the studied area were highly suitable (S1) due to the depth of the soil were greater than 100cm. The fertility status of the study area represented as nutrient availability (n) shows that base saturation results of the studied area were highly suitable (S1) for both crops, in terms of soil reaction (pH) results showed that Mandarari and Duwari studied area were highly suitable (S1) for both wheat and rice production while Mashamari studied area was marginally suitable (S3) for both wheat and rice production.

Table 6: Matching land use requirements with land qualities for Wheat

Land use requirements/land quality	Symbol	Suitability ratings of land units		
		Mashamari	Mandarari	Duwari
Soil workability	(k)	S1	S1	S2
Rooting condition	(r)	S1	S1	S1
Nutrient availability	(n)			
Nutrient availability (base saturation)	(n1)	S1	S1	S1
Nutrient availability (soil reaction pH)	(n2)	S3	S1	S2
Nutrient availability (organic matter)	(n3)	S3	S3	S3
Nutrient retention (CEC)	(n4)	S3	S3	S3
Moisture availability (rainfall)	(m)	S3	S3	S3
Climate (temperature)	(c)	S2	S2	S2
Aggregate suitability: Current		S3n	S3nm	S3nm
Potential		S2c	S2c	S2c

The soil pH of Mashamari can be amended by the application of lime materials to neutralize the acidic nature of the soils to make it highly suitable (S1) for cultivation of both wheat and rice production. Results of organic matter, cation exchange capacity (CEC) and moisture availability (rainfall) of the studied area were evaluated to be marginally suitable (S3). Both organic matter and CEC can be corrected by the application of organic matter and inorganic fertilizer to the soil. Rainfall data evaluated was assessed to be marginally suitable (S3), can be corrected to (S1) with the use of supplementary irrigation for the production of irrigated wheat and rice cultivation. Climatic condition represented by temperature shows that the mean annual temperature for all the studied soil in the area were moderately suitable (S2) for production of both wheat and rice. Temperature it's a variable that can't be easily corrected in the studied area for both crops (wheat and rice), and its evaluated moderately suitable (S2) for both current and potential assessment. Therefore, the current aggregate suitability classification for the studied area was marginally suitable (S3nm) with limitation of nutrient availability and moisture condition (Table 8). After amendment were made, the soils of the study area were enhanced to moderately suitable (S2c) with only temperature as limitation. Hence, current suitability of the soils was marginally suitable (S3nm) while potential suitability was moderately suitable (S2c) for wheat and rice production respectively.

Table 7: Matching land use requirements with land qualities for Rice

Land use requirements/land quality	Symbol	Suitability ratings of land units		
		Mashamari	Mandarari	Duwari
Soil workability	(k)	S3	S3	S2
Rooting condition	(r)	S1	S1	S1
Nutrient availability	(n)			
Nutrient availability (base saturation)	(n1)	S1	S1	S1
Nutrient availability (soil reaction)	(n2)	S3	S1	S1
Nutrient availability (organic matter)	(n3)	S3	S3	S3
Nutrient retention (CEC)	(n4)	S3	S3	S3
Moisture availability (rainfall)	(m)	S3	S3	S3
Climate (temperature)	(c)	S2	S2	S2
Aggregate suitability: Current		S3nm	S3nm	S3nm
Potential		S2c	S2c	S2c

Table 8: Land suitability classification per land unit for Rice and Wheat performance

Land Unit	Suitability Class	Suitability Orders of Crops	
		Rice	Wheat
Mashamari	Current	S3n	S3nm
	Potential	S2c	S2c
Mandarari	Current	S3nm	S3nm
	Potential	S2c	S2c
Duwari	Current	S3nm	S3nm
	Potential	S2c	S2c

Key: n= Nutrient Availability (Fertility class), m = Moisture Availability (Rainfall) and c = Climate (temperature)

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

The fertility assessment of the three sites surveyed (Mashamari, Mandarari and Duwari) soils revealed, low nitrogen and inadequate organic matter content and pH, which led to inadequate moisture storage and low nutrient availability in the soil. According to the result obtained for Land Suitability Evaluation, the soils are considered to be moderately suitable (S3) for the cultivation of rice and wheat, due to low level of nutrient, organic matter content and cation exchange capacity in the soils. However, after amendment were done (potentially) to the fertility factors, the soil units were improved to moderately suitable (S3) with climate (temperature) as a limitation, which implies that with further corrections to the climatic constraints of (S2) in a controlled environment (glass/screen house) it might be improved to highly suitable (S1) for the cultivation and production of wheat and rice production.

Conclusion and Recommendations

The main constraints for a sustained wheat and rice crop production in the three (3) proposed farm sampled for fertility assessment and suitability evaluation were; low level of nitrogen and soil organic matter, inadequate moisture availability during dry season and moderately to slightly acidic (pH 5.7-6.3) nature of the soil, which has led to low nutrient availability in the soils of Mandarari and Duwari. Unless improved management practices are adopted, these hazards may lead to poor yields as well as severe degradation of the land resources. Based on outcome of the simple limitation methods of evaluation, these sites are classified as marginally suitable (S3) for both wheat and rice production with limitation of nutrient availability (CEC / organic carbon) and climate (temperature) but after managerial corrections were made to fertility class, the soils were potentially evaluated to moderately suitable (S2) with temperature as limiting factor.

In this context the following recommendations are suggested;

- Adequate supply and application of organic material
It is advisable that organic source of fertilizer be supplies in the required amount and adequate quantity as may be required by each crop; this will in part increase the activities of microbes and also improve the level of nitrogen, soil organic matter and CEC of the soils.
- Crop rotations

Crop rotations having a short period of cultivation is recommended for all the sites. Owing to the nature of natural vegetation and competition with livestock, it might be necessary to shorten the fallow period. It is suggested that cover crops like cucumber be introduced in the rotations, especially when fallow periods are kept short. Continuous cropping can also be practiced in all three (3) sites, provided water is made available, but this would certainly require improved management practices such as, adequate application of fertilizer and manure.

c. Precautionary fertilizer application and use

The limitation of soil fertility as a result of low level of-nitrogen and organic matter content in all the three sites is of great concern, this implies that chemical fertilizers and manures are required to obtain good crop yields. Soils of Duwari is expected to respond exceptionally well. It is therefore suggested that preference be given to 'natural' methods of restoring soil fertility, such as crop rotations with a shortened fallow period, cultivation of cover crops, application of crop residues and farm yard manures where possible.

REFERENCES

- Agbenin, J. O. (1995) *Laboratory Manual for Soil and Plant Analysis*. Department of Soil Science, Ahmadu Bello University Zaria, Kaduna State 140pp
- Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Hand book of methods*. Publication of CABI, Wallingford, U.K., 2, 68-70
- Arshad, M.A., Lowery, B. and Grossman, B. (1996). Physical tests for monitoring soil quality. In: J.W. Doran and A.J. Jones (eds.) *Methods for assessing soil quality. Soil Science Society of America Special Publication 49*. SSSA, Madison, WI. pp.123-142
- Black, C. A. (1965). *Methods of soil analysis*. Part I. American Society of Agronomy, Madison, Wisconsin, USA.
- BOLSA ANALYTICAL (2008). *Guidelines for Interpretation of Soil Analysis*. 2337 technology Pkwy., Suite K, Hollister, C.A.
- Brady, N.C. and Weil, R.R., (2008). *The Nature and Properties of Soils*, 14th ed. Prentice Hall, Upper Saddle River, NJ (975 pp.).
- Brady, N. C. and Weil, R. C. (2012). *The nature and properties of soils*. 14th ed. Dorling Kindersley India Pvt. Limited, 369 – 398
- Bremner, J.M. (1965). Total N in: Black, C.A. (ed). *Methods of soil analysis*. Part 2. Chemical and microbiological properties. Agronomy monograph 9, American Society of Agronomy, Inc. Madison, Wisconsin, USA. 1238-1255.
- Dent, D. and Young, A. (1981), *Soil Survey and Land Evaluation*. George Allen and Unwin, London 278p
- Ekwoanya, M.A. and Ojanuga, A.G., (2002) Productivity of Upland and Floodplain Soils at Makurdi, Nigeria. *Geoderma*. 108: 19 - 29.
- Esu I. E. (2005). Characterization, classification and management problems of the major soil orders in Nigeria. 26th Inaugural Lecture of the University of Calabar. pp65
- FAO (1983). *Guidelines: land evaluation for rainfed agriculture*. Food and Agriculture Organization of the United Nations, Soils Bulletin 52. Rome, Italy.
- FAO (2006). *Guidelines for Soil Description*. 4th edition. Food and Agriculture Organization of the United Nations, Rome, Italy. 97pp.
- FAO (2007). *Land Evaluation Towards a Revised Framework*. Food and Agriculture Organization of the United Nations, Land and Water Discussion Paper-6; FAO, Rome, Italy. 107pp.
- Farley, K.A., Kelly, E.F. and Hofstede, R.G.M. (2004). Soil organic carbon and water retention following conversion of grassland to pine plantations, in the Ecuadorian Andes. *Ecosystems*, 7, 729-739
- Faturoti, O. M., Ande, O. T., Amusan, A. A., Ojetade, J. O., Omodele, T. and Tobore, A. O. (2015). Suitability assessment of soils of Okemesi association for maize and cassava production using parametric and GIS based methods. *Nigerian Journal of Soil Science*, Special edition, 25:110-126
- Grema and Hess, 1994
- Hazelton, P. and Murphy, B. (2007). *Interpreting soil tests results: what do all the numbers mean?* [2nd ed.]. CSIRO Publishing, Collingwood, Australia. Pp. 59 – 91
- Jaiswal, P.C. (2004). *Soil, plant and water analysis*. John Wiley and Sons. New York.
- NIMET, (2021). *Nigerian Meteorological Agency; Climate Review Bulletin and outlook for November, Volume 2*.
- Noma, S.S. and M. Yakubu (2002). Properties and classification of soils of the Usmanu Dan Fodiyo University, permanent site. *Journal of Agric Environment*, 3 (1): 155-166.
- Noma, S. S., Tanko, I. I., Yakubu, M., Dikko, A.U., Abdullahi A. A. and Audu, M. (2011). Variability in the physico-chemical properties of the soils of Dundaye District, Sokoto State, Nigeria in M.K.A. Adebayo, A. J. Odofin,

- A.O Osunde, A. Bala and S.O. Ojeniyi (Eds). *Soil Resources Management, Global Climate Change and Food Security*. Proceeding of the 35th annual conf. of SSSN/Minna Niger State March 7th to 11th.
- Oguntoyinbo, J.S. (1982). Climate 3. Precipitation and radiation. In: Brabourne, K.M., Oguntoyinbo, J.S., Onyemelukwe, J.O.C. and Nwafor, J.C. (Eds.). *Nigeria in maps*. Holder and Stroughton, London, pp 18-19.
- Rhodes, J.D. (1982). Cation Exchange Capacity. In: Page A.L., R.H. Miller and D.R. Keeney, (Eds.), *Methods of soil Analysis part 2*. Chemical and microbiological properties. Agron. No 9, pp: 149-157.
- Sys C, Van Ranst E, Debaveye J, Beernaert F (1993). Land evaluation, Part III: Crop requirements. Agricultural Publications General Administration for Development Cooperation, Belgium. P. 7.
- Sys, C., Van Ranst, E., and Debaveye, J. (1991). "Land Evaluation, Part I: Principles in Land Evaluation and Crop Production Calculations." Agricultural Publications, Ghent, Belgium.
- Taylor, G. and Eggleton, R. A (2001) "Regolith Geology and Geomorphology" Wiley and sons Ltd. Chichester, New York.
- Udoh, B.T., Henry, H.B. and Akpan U.S. (2011). Suitability evaluation of alluvial soils for rice (*Oryza sativa*) and cocoa (*Theobroma cacao*) cultivation in acid sands area of south eastern Nigeria. *Journal of Innovative Research in Engineering and Science* 2(3): 148-161
- Walkley, A. and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromatic acid titration method. *Soil Sci.* **37**:29-
- Wilding, L.P., Bouma, J., and Vreeken-Buijs, M.J. (1995). "Land Quality Indicators: Research Plan." *Soil Science Society of America Journal*, 59(3), 856-860.
- Yakubu, M., Abdullahi I., Ibrahim B. and Noma S.S. (2008). Characterization of Upland and Floodplain Soils for Management Implications in Dundaye District, Sokoto, In: L. Singh, B.H. Usman, A. M. Sadiq, H. Musa and S.O. Ojeniyi (Eds). *Soil and Water Resources Management for sustainable Environment and Economic Empowerment*. Proceedings of the 32nd Annual Conference of the Soil Science Society of Nigeria, March 10 – 14th 2008, FUT Yola, Nigeria. pp 44-55.