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Soil Characteristics in Semi-Arid Climate: A Case Study of a Northeastern Nigerian Plain of Low Relief

Ayodele Owonubi

Department of Horticulture and Landscape Technology, Federal College of Forestry/Forestry Research Institute of Nigeria, Jos, Plateau State, Nigeria.
Email: ayowonubi@gmail.com; Phone Number: 08186714472,
ORCID ID: 0000-0001-60001-3952

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ABSTRACT

This study was embarked upon to evaluate soil resources on a plain of low relief in a semi-arid area of northeastern Nigeria. Field work was accomplished first by delineation of study area based on soil type and then obtaining soil samples by auger drillings to a depth of at least 90cm. Three major soil mapping units were identified: Aeolian, alluvial, and seasonal inundated areas. The area is characterized by low rainfall and humidity with a mean of 883mm and 56% respectively. Vegetation distribution is low especially in the dry season when 88% of the landscape is without vegetation. A major problem identified in the study area is the prevalent nature of soil infertility. This has to do especially with low cation exchange capacity (< 4cmol/kg), organic matter contents (< 1.4%) and macro nutrients. These soils showed low levels of organic matter (<2%) and medium base saturation (45–50%). Cation exchange processes were also extremely low, being less than 5 cmol/kg. Moreover, the amounts of available phosphorus and nitrogen were quite low. Coupled with these is the poorly aggregated nature of the soil. Soil and water conservation measures recommended include conservation tillage complemented with biochar application.

Keywords: *alluvium, aeolian, soil fertility, soil conservation.*

1.0 INTRODUCTION

The need for more information about the soil as a means for its sustainable use and proper conservation has continuously demanded soil characterization (Osujieke *et al.*, 2018). With yearly precipitation ranging from 250 to 500 mm, semiarid soils are found in places with a slightly less dry climate than arid ones (Monger *et al.*, 2005). If irrigated, semiarid soils, although transitional between arid and humid soils can be a significant source of food production both locally and globally. Soil management in semi-arid climates is crucial for sustaining agricultural productivity, ensuring water availability, and maintaining ecosystem health. Semi-arid regions, characterized by low and erratic rainfall, face unique challenges such as soil degradation, water scarcity, salinity and nutrient depletion (Gupta *et al.,* 2023). Effective management practices are essential to mitigate these issues and promote environmental sustainability. These regions experience prolonged dry seasons and occasional intense rainfall events, leading to challenges in water management and soil conservation. The high evaporation rates further exacerbate water scarcity, making efficient water use and soil conservation critical.

Effective soil management in this region involves integrated approaches to managing water resources and soil health across the area. Soil management in semi-arid climates requires a holistic approach that integrates water conservation, soil health, and sustainable agricultural practices (Weil and Brady, 2017). By adopting effective management strategies, it is possible to enhance agricultural productivity, ensure water availability, and promote environmental sustainability in these challenging environments. Continued research, community involvement, and policy support are essential to implement and sustain these practices for the long-term benefit of semi-arid regions. The objective of this study is to evaluate soil resources in a semi-arid region of northeastern Nigeria.

2.0 MATERIALS AND METHODS

2.1 Field Studies

The study area is located at the Upper Jamare area of Bauchi state, Nigeria; between latitudes 12° 9' 27.77" N and 12° 20' 22.94" N and longitudes 10° 8' 48.62" E and 10° 27' 5.07" E. The vegetation of the area is Sahel savanna. Farming of crops such as millet and guinea corn is the major socio-economic activity in the area. However, at the peak of the rainy season when some of the farmlands are inundated with water, some of the farmers take to fishing as a source of livelihood. The area was stratified based on soil type at a scale of 1: 250,000. Soil observation was made in selected areas by auger drilling to a depth of 90cm. Soil samples were collected at intervals of 15 to 30cm to a depth of 90cm. Sampling was carried out during the peak of the raining season and the friable consistency of the soils made it easily to drill to a depth of 90cm with ease. Furthermore, it was not possible to sample flooded areas during the period of study.

2.2 Laboratory Analysis

Laboratory analysis was carried out on soil samples after sieving with a 2mm mesh sieve. Particle size distribution was determined by the hydrometer method as described by Hossain, *et al.,* (2021). Soil consistency was described using the guideline for soil description (FAO, 2006). Soil pH was determined in 0.01M $CaCl_2$ solution at a 1:2.5 soil/solution ratio as described by Kissel and Sonon (2014). Ca, Mg, K and Na were determined using NH_4OAc saturation method whereas exchangeable acidity was determined from the extract by titration with standard NaOH solution. The effective cation exchange capacity (ECEC) was obtained by summation of the exchangeable bases and exchange acidity (Hendershot, *et al.,* 2008). Organic Carbon was determined by the Walkley-Black dichromate wet oxidation method (FAO, 2021a). Total nitrogen was determined using the Kjeldahl method (FAO, 2021b). Available phosphorus was determined following the Bray-1 extraction method FAO (2021c). The phosphorus in solution was determined colorimetrically by the modified single solution using ascorbic acid.

2.3 Climate and Terrain Analysis

Climatic data was sourced from Climwat 2.0 software (Grieser, 2006) using meteorological data closest to the study area. Elevation data from the Shuttle Radar Topography Mission (SRTM) at 30-meter resolution was used to compute relative slope position. Normalized Difference Vegetation Index (NDVI) was computed using Sentinel 2 satellite imagery for March and September for the year 2020 with a cloud cover of less than 20 %. Using Sentinel 2 imagery for September, the Normalized Difference Water Index (NDWI) was used to identify seasonally flooded areas (McFeeters, 1996) or areas at risk of seasonal flooding using the equation below (a threshold of -0.3 was used):

$$NDWI = \left(\frac{Green - NIR}{Green + NIR}\right)$$

3.0 RESULTS AND DISCUSSION

Environmental characteristics of the study area

Climatic attributes of the area are presented in Figure 1. Mean annual rainfall and humidity are 883mm and 56% respectively. Onset of rains begins from the month of March and peaks in the month of August and ends with a sharp decline in the Month of October. Humidity is higher in the rainy season and follows the same trend with rainfall. Not much variation is observed in sunshine hours, solar radiation, atmospheric temperature and evapotranspiration across the months. Mean annual wind speed is 160 km/day with higher wind speeds recorded in the months of March and April. Relative slope characteristics of the study area are shown in Figure 2. Minimum and maximum elevation are 351 and 375m respectively with a range of 24m. Longitudinal rock ridges can be seen stretching across the landscape. Vegetation characteristics of the study area is presented in Figure 3. In the rainy season 85% of the terrain is covered with sparce vegetation while 1% consist of thick vegetation. In contrast, 88 and 12% consist of bare land and sparce vegetation in the dry season. These vegetation characteristics have been noted to be typical of semi-arid areas (Ibrahim *et al.,* 2019) The low mean annual rainfall undoubtedly is responsible for the low vegetation characteristics, and consequently significant aeolian activity in the area.

3.1 Soil Physical Characteristics

Soil physical and chemical characteristics of the study area are presented in Table 1. Soils of the area are dominated by sandy loam textures. This is due to low clay and high sand contents in the soils. Gupta *et al.* (2023) had remarked that semi-arid soil exhibits a wide range of soil types depending on the parent material from which the soil was derived. Sandy loam, which is the dominant texture in the study area has relatively low water holding capacity of about 1.25 to 1.40 inches/foot as reported by (Peterson, 2024). Soil texture influences soil moisture characteristics which are a critical factor in semi-arid ecosystems, affecting evapotranspiration, photosynthesis, and overall water dynamics (Weil and Brady, 2017). These soils are also poorly aggregated due to very high dispersion ratios. Clay dispersion ratios though low are insignificant due to very low clay content observed in the soils. Surface soil consistencies range from soft to hard, very friable to friable, non-sticky and non-plastic surface soils, subsurface soil range from non-sticky to slightly sticky and non-plastic to slightly plastic. Similar soil consistencies have been observed by Nabinejad and Schüttrumpf (2023) for semi-arid areas. The friable consistencies of these soils would most likely make it less a challenge to cultivate theses soil for dry season irrigation farming. Furthermore, the low content of clay in these soils could be responsible for the non-sticky and non-plastic consistencies observed

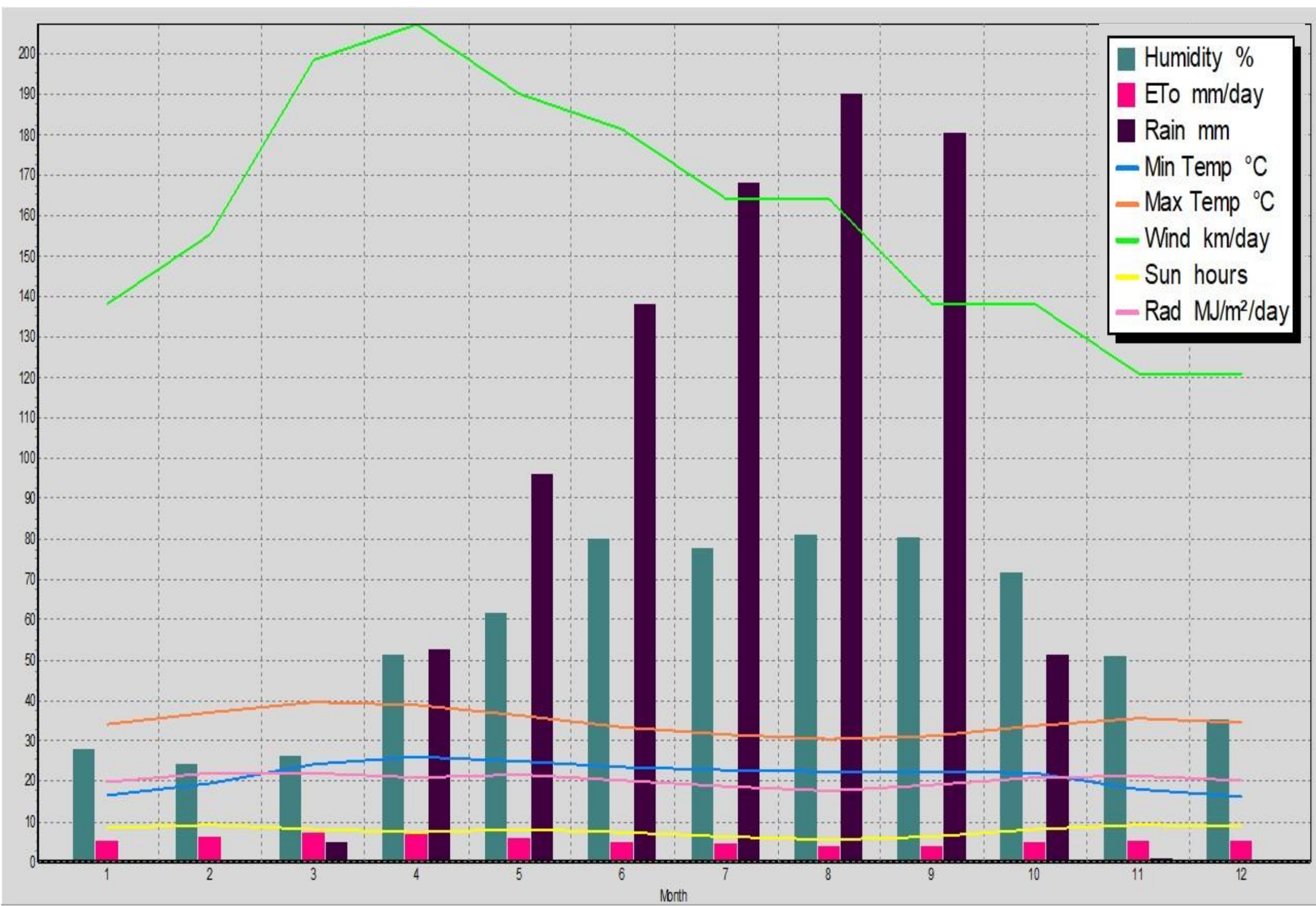

Figure 1: Climatic characteristics of the study area

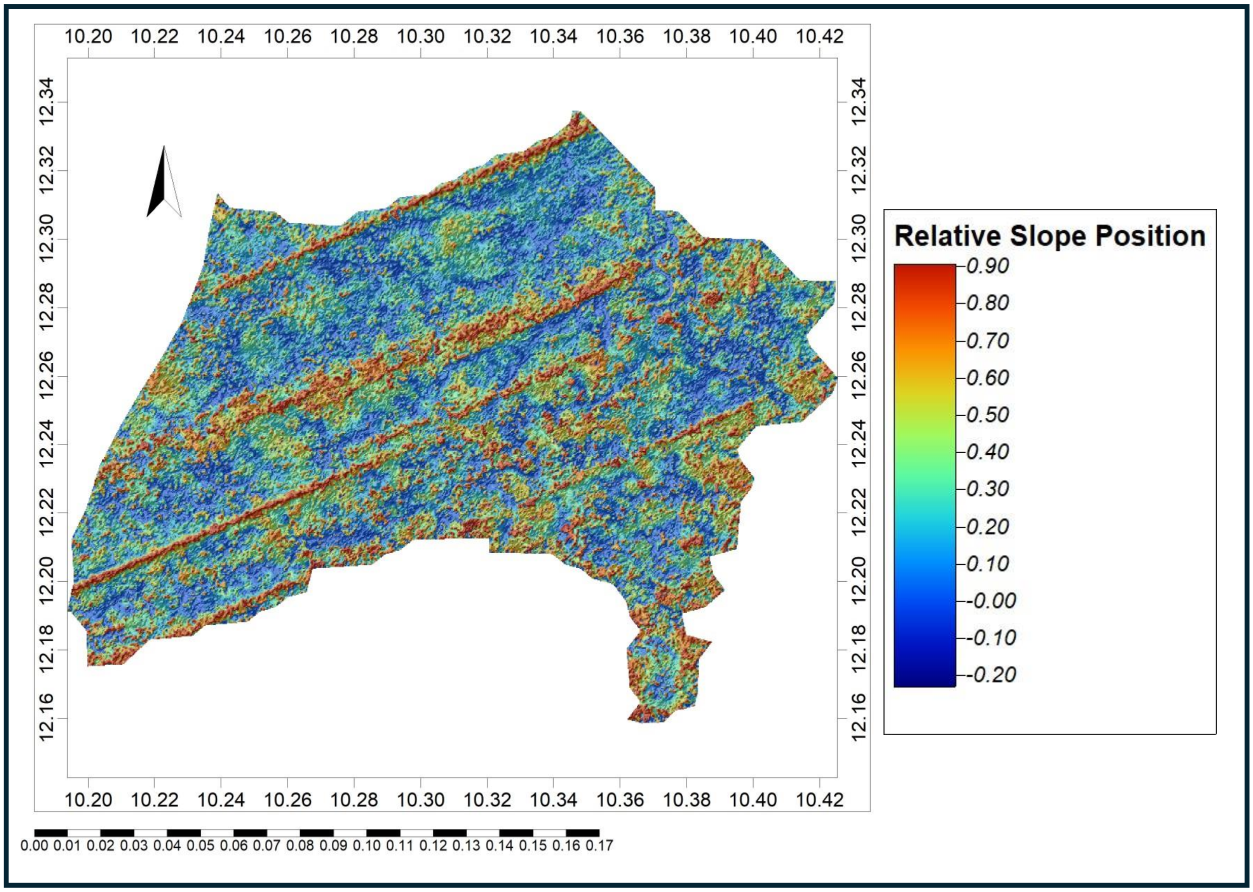

Figure 2: Relative slope position over the study area

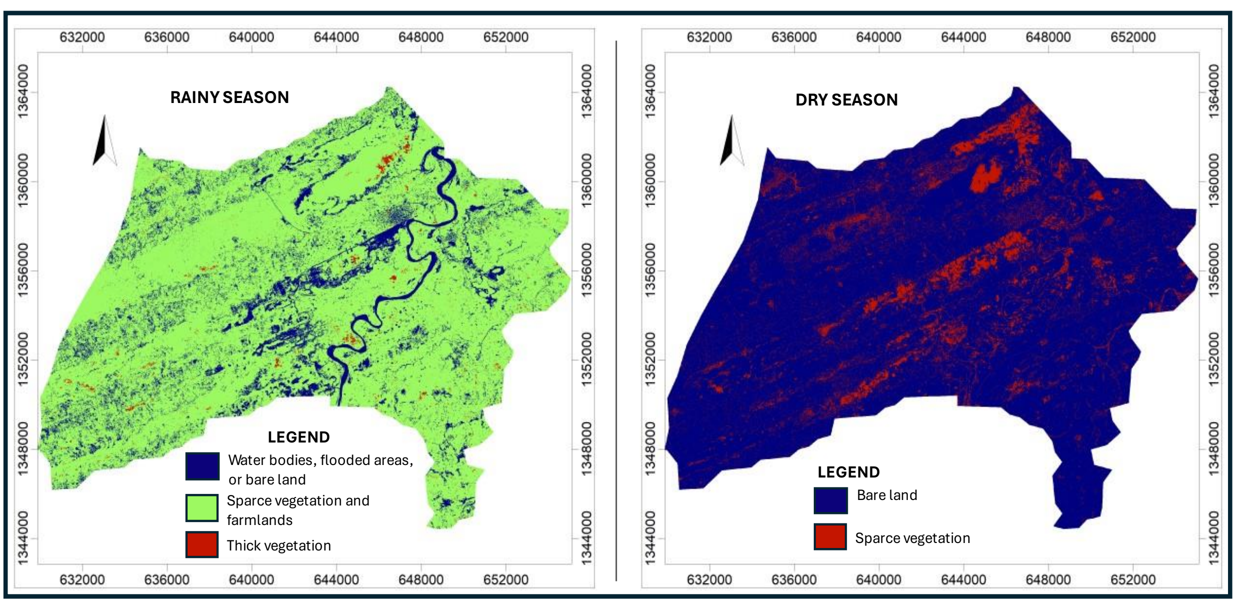

Figure 3: Vegetation distribution over the study area

Table 1: Soil physical properties

soil units	Location		Depth	Clay	Silt	Sand	Textural class	DR	CR
	N	E	(cm)		(%)				
L1	12.22317	10.33213	0-15	10	12	78	Sandy Loam	0.82	0.23
			30-60	10	12	78	Sandy Loam	0.82	0.23
			60-90	10	16	74	Sandy Loam	0.85	0.23
	12.2223	10.33684	0-30	12	16	72	Sandy Loam	0.82	0.20
			30-60	14	18	68	Sandy Loam	0.85	0.31
			60-90	14	16	70	Sandy Loam	0.67	0.31
	12.2131	10.3302	0-30	12	16	72	Sandy Loam	0.82	0.20
			30-60	12	18	70	Sandy Loam	0.74	0.20
			60-90	10	12	78	Sandy Loam	1.00	0.23
	12.26714	10.37227	0-30	10	16	74	Sandy Loam	0.70	0.23
			30-60	10	16	74	Sandy Loam	0.85	0.23
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.25507	10.39721	0-15	10	12	78	Sandy Loam	0.82	0.23
			30-60	12	10	78	Sandy Loam	0.78	0.20
L2	12.27668	10.36817	0-30	10	14	76	Sandy Loam	0.84	0.23
			30-60	10	12	78	Sandy Loam	0.82	0.23
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.28224	10.33626	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	10	12	78	Sandy Loam	0.82	0.23
			60-90	12	16	72	Sandy Loam	0.82	0.20
	12.27952	10.31938	0-30	12	18	70	Sandy Loam	0.84	0.20
			30-60	10	12	78	Sandy Loam	0.82	0.23
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.29598	10.29403	0-30	14	18	68	Sandy Loam	0.57	0.17
			30-60	12	14	74	Sandy Loam	0.70	0.20
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.30281	10.28391	0-30	10	12	78	Sandy Loam	0.82	0.23
			45-90	14	18	68	Sandy Loam	0.57	0.17
	12.30212	10.28417	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	12	16	72	Sandy Loam	0.86	0.36
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.30361	10.28516	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	14	18	66	Sandy Loam	0.85	0.31

L1 = Soil derived from aeolian sands, L2 = Soil derived from aeolian sands over alluvium, DR = Dispersion ratio, CR = clay dispersion ratio.

Table 1 (continued): Soil physical properties

soil units	Location		Depth	Clay	Silt	Sand	Textural class	DR	CR
	N	E			(%)				
L2	12.28164	10.30299	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	14	18	66	Sandy Loam	0.85	0.31
	12.28091	10.30159	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	10	14	76	Sandy Loam	0.84	0.23
			60-90	10	12	78	Sandy Loam	0.82	0.23
	12.28755	10.36343	0-30	10	12	78	Sandy Loam	0.82	0.23
			30-60	12	14	74	Sandy Loam	0.85	0.36
			60-90	12	18	70	Sandy Loam	0.84	0.20

L1 = Soil derived from aeolian sands, L2 = Soil derived from aeolian sands over alluvium, DR = Dispersion ratio, CR = clay dispersion ratio.

3.2 Soil Chemical Characteristics

Table 2 shows the data pertaining to the chemical characteristics of the soils. Remarkably, soil pH in both surface and subsurface soils range from slightly to moderately acidic. This is not unrelated to medium base saturation (45-50%) and low organic matter (<2%) observed in these soils. Also, cation exchange reactions are very low, being less than 5 cmol/kg. Furthermore, nitrogen and phosphorus contents were at very low levels. Soils of arid and semi-arid areas has been shown to have low levels of organic matter (Ibrahim *et al.,* 2019). Organic matter levels have been noted to significantly influence nitrogen and available phosphorus in soils (Weil and Brady, 2017). The soil moisture challenge is further exacerbated by low organic matter levels, further resulting in low soil fertility. Consequently, appropriate soil water conservation measures are needed for improved crop production. Taking into consideration the friable consistencies of these soils, conservation tillage such as zero and minimum tillage would help to ameliorate soil water challenges by improving soil structure and organic matter levels. Colunga *et al.* (2025) reported that conservation tillage increased soil organic carbon in sandy semi-arid soils, with an estimated 12.74 ± 1.46 % increase. Minimum tillage, mulch tillage, and zero tillage were observed to exhibit the highest increases of soil organic carbon by 18.94 ± 2.48 %, 11.45 ± 2.46 %, and 10.06 ± 2.46 %, respectively, compared to conventional tillage.

On the other hand, the use of biochar as a soil amendment could be complimentary to other conservation measures in these low fertility semi-arid soils. For instance, Blanco-Canqui *et al.* (2024) reported positive impact of biochar on soil fertility especially in the first year in a semi-arid environment. Similarly, Cen *et al.* (2021) noted that biochar increased organic matter content by 2.15 to 5.88 g/kg and water stable aggregates by 8.3 to 35.0% under semi-arid conditions.

3.3 Soil Map Units

Aeolian sands (L1):

The soil of this unit is developed from aeolian sands. The topography is nearly level to gently undulating plains. Soil is deep to very deep, well. Drainage conditions range from well to imperfectly drained.

Aeolian sands over alluvium (L2):

Soils of this unit are developed from aeolian sands and recent alluvium. The topography is nearly level to gently undulating plains. The soil is deep. Drainage conditions range from well to poorly drained soil.

Seasonal inundation (L3):

Soils of this unit are developed from either aeolian sands, or aeolian sands over alluvium. They occupy the lower slope positions. They are either at risk or are characterized by inundation during the rainy season.

Table 2: Soil chemical properties

soil units	Location N	Location E	Soil Depth (cm)	pH	pHBC	Soil Reaction	OM (%)	N	P	Ca (cmol/kg)	Mg	K	Na	EA	CEC	ECEC	BS (%)
L1	12.22317	10.33213	0-15	5.9	233	Moderately acid	1.21	0.04	6	1.23	0.39	0.13	0.01	1.55	3.81	3.31	46
			30-60	6.1	249	Slightly acid	1.28	0.04	7	1.24	0.40	0.13	0.01	1.55	3.83	3.33	46
			60-90	6.1	288	Slightly acid	1.24	0.04	6	1.23	0.39	0.13	0.01	1.55	3.81	3.31	46
	12.2223	10.33684	0-30	6.1	253	Slightly acid	0.62	0.03	4	1.30	0.49	0.13	0.01	1.56	3.97	3.49	49
			30-60	5.1	168	Strongly acid	1.07	0.02	6	1.33	0.50	0.14	0.01	1.57	4.05	3.55	49
			60-90	6.4	353	Slightly acid	0.59	0.03	4	1.33	0.49	0.14	0.01	1.57	4.04	3.54	49
	12.2131	10.3302	0-30	6.1	253	Slightly acid	0.62	0.03	4	1.30	0.49	0.13	0.01	1.56	3.97	3.49	49
			30-60	5.9	337	Moderately acid	0.83	0.03	5	1.31	0.48	0.13	0.01	1.56	3.98	3.49	48
			60-90	5.7	288	Moderately acid	0.86	0.03	6	1.23	0.39	0.13	0.01	1.55	3.80	3.31	46
	12.26714	10.37227	0-30	5.7	216	Moderately acid	0.79	0.03	6	1.24	0.40	0.13	0.01	1.55	3.82	3.33	47
			30-60	5.9	265	Moderately acid	0.85	0.03	5	1.24	0.40	0.13	0.01	1.55	3.83	3.33	46
			60-90	5.9	268	Moderately acid	0.82	0.03	5	1.21	0.38	0.12	0.01	1.55	3.76	3.27	46
	12.25507	10.39721	0-15	5.9	345	Moderately acid	0.79	0.03	6	1.23	0.39	0.12	0.01	1.55	3.86	3.30	45
			30-60	6.0	261	Moderately acid	0.82	0.03	6	1.35	0.51	0.14	0.01	1.57	4.06	3.58	50
L2	12.27668	10.36817	0-30	5.9	243	Moderately acid	0.80	0.03	2	1.22	0.38	0.12	0.01	1.55	3.78	3.28	46
			30-60	5.6	240	Moderately acid	0.38	0.01	2	1.24	0.38	0.13	0.01	1.55	3.80	3.31	46
			60-90	6.0	244	Moderately acid	0.34	0.01	2	1.25	0.40	0.13	0.01	1.55	3.84	3.34	47
	12.28224	10.33626	0-30	5.7	222	Moderately acid	0.34	0.01	3	1.25	0.40	0.12	0.01	1.55	3.81	3.33	47
			30-60	5.7	221	Moderately acid	0.55	0.02	3	1.23	0.39	0.12	0.01	1.55	3.79	3.30	46
			60-90	5.7	216	Moderately acid	0.56	0.02	4	1.33	0.50	0.14	0.01	1.56	4.04	3.54	49
	12.27952	10.31938	0-30	5.7	309	Moderately acid	0.63	0.02	4	1.34	0.50	0.13	0.10	1.56	4.01	3.63	52
			30-60	5.7	246	Moderately acid	0.66	0.02	4	1.23	0.38	0.12	0.01	1.55	3.79	3.29	46
			60-90	5.8	250	Moderately acid	0.62	0.02	12	1.24	0.40	0.13	0.01	1.55	3.83	3.33	46

L1 = Soil derived from aeolian sands, L2 = Soil derived from aeolian sands over alluvium, DR = Dispersion ratio, CR = clay dispersion ratio.

Table 2 (continued): Soil chemical properties

soil units	Locations		Depth	pH	pHBC	Soil Reaction	OM	N	P	Ca	Mg	K	Na	EA	CEC	ECEC	BS
	N	E	(cm)				(%)			(cmol/kg							(%)
	12.29598	10.29403	0-30	6.1	387	Slightly acid	3.07	0.09	5	1.35	0.50	0.14	0.01	1.57	4.07	3.57	49
			30-60	6.7	357	Neutral	0.67	0.02	5	1.34	0.46	0.13	0.01	1.56	3.98	3.50	49
			60-90	7.0	377	Neutral	0.66	0.02	4	1.24	0.40	0.13	0.01	1.55	3.82	3.33	47
	12.30281	10.28391	0-30	5.9	245	Moderately acid	0.76	0.03	5	1.24	0.40	0.13	0.01	1.55	3.83	3.33	46
			45-90	5.7	351	Moderately acid	0.60	0.02	4	1.36	0.50	0.14	0.01	1.57	4.08	3.58	49
	12.30212	10.28417	0-30	5.6	215	Moderately acid	0.62	0.01	5	1.25	0.40	0.13	0.01	1.55	3.84	3.34	47
			30-60	5.6	309	Moderately acid	0.59	0.02	4	1.33	0.49	0.13	0.00	1.56	3.94	3.51	50
			60-90	5.5	221	Strongly acid	0.55	0.02	4	1.23	0.39	0.13	0.01	1.55	3.81	3.31	46
L2	12.30361	10.28516	0-30	5.6	215	Moderately acid	0.62	0.01	5	1.25	0.40	0.13	0.01	1.55	3.84	3.34	47
			30-60	5.4	270	Strongly acid	0.60	0.02	4	1.37	0.50	0.13	0.01	1.57	4.97	3.58	40
	12.28164	10.30299	0-30	5.6	215	Moderately acid	0.62	0.01	5	1.25	0.40	0.13	0.01	1.55	3.84	3.34	47
			30-60	5.4	270	Strongly acid	0.60	0.02	4	1.37	0.50	0.13	0.01	1.57	4.97	3.58	40
	12.28091	10.30159	0-30	5.6	214	Moderately acid	1.24	0.04	7	1.24	0.40	0.12	0.01	1.55	3.82	3.32	46
			30-60	5.4	217	Strongly acid	1.22	0.04	7	1.24	0.40	0.13	0.01	1.55	3.82	3.33	47
			60-90	5.3	204	Strongly acid	0.67	0.02	6	1.23	0.39	0.13	0.01	1.55	3.81	3.31	46
	12.28755	10.36343	0-30	5.8	250	Moderately acid	0.61	0.02	5	1.24	0.40	0.13	0.01	1.55	3.83	3.33	46
			30-60	5.8	333	Moderately acid	0.86	0.03	6	1.32	0.49	0.13	0.01	1.56	3.90	3.51	50
			60-90	5.6	271	Moderately acid	0.75	0.03	6	1.34	0.50	0.14	0.01	1.56	4.03	3.55	49

L1 = Soil derived from aeolian sands, L2 = Soil derived from aeolian sands over alluvium, DR = Dispersion ratio, CR = clay dispersion ratio.

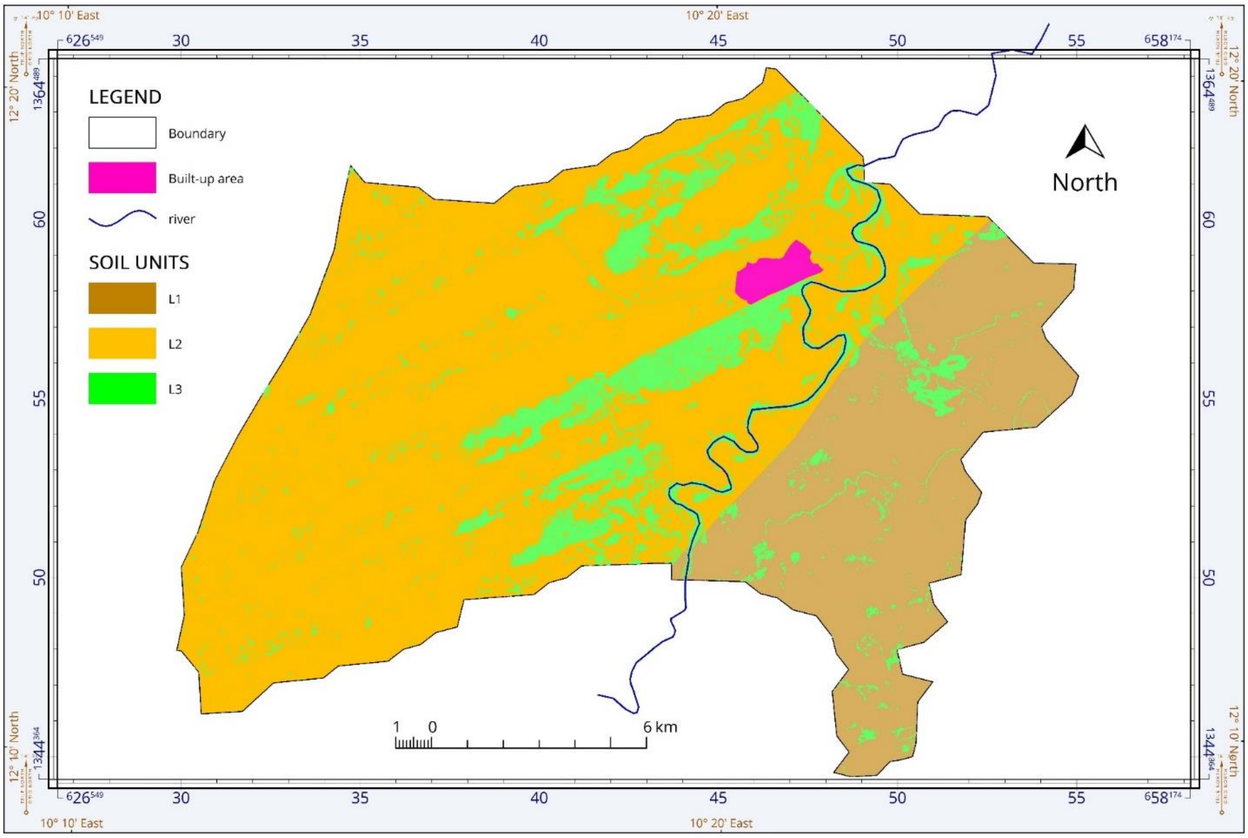

Figure 4: Soil map of study area

4.0 CONCLUSION

Major soil attributes affecting crop production in this semi-arid climate is the occurrence of low soil organic matter content and low activity clay content resulting in very low soil nutrient levels. Some areas of the study area are at risk of seasonal inundation. The following practices will help to improve soil fertility in the study area: conservation tillage such no-till, minimum, mulch till; the use of enriched biochar to boost soil fertility and productivity, crop rotation and or mixed cropping involving legumes; agroforestry involving leguminous shrubs and trees in the long term. Seasonally flooded areas could be used for paddy rice production in the rainy season, or irrigated farming after the rainy season.

5.0 REFERENCES

Blanco-Canqui, H., Creech, C. F., and Easterly, A. C. (2024). How does biochar impact soils and crops in a semi-arid environment? A 5-yr assessment. Field crops Research, 310: 109340. https://doi.org/10.1016/j.fcr.2024.109340.

Cen, R., Feng, W., Yang, F., Wu, W., Liao, H., and Qu, Z. (2021). Effect mechanism of biochar application on soil structure and organic matter in semi-arid areas. Journal of Environmental Management, 286: 112198. https://doi.org/10.1016/j.jenvman.2021.112198.

Colunga, S. L., Wahab, L., Cabo, A. F., and Pereira, E. (2025). Carbon sequestration through conservation tillage in sandy soils of semi-arid climates: A meta-analysis. Soil and Tillage Research, 245: 106310. https://doi.org/10.1016/j.still.2024.106310.

FAO. (2006). Guidelines for soil description. FAO (Food and Agriculture Organization), Rome.

FAO. (2021a). Standard operating procedure for soil organic carbon Walkley-Black method Titration and colorimetric method. Standard operating procedure for soil organic carbon Walkley-Black method Titration and colorimetric method. Rome.

FAO. (2021b). Standard operating procedure for soil nitrogen - Kjeldahl method. Rome.

FAO. (2021c). Standard operating procedure for soil available phosphorus, Bray I and Bray II method. Rome.

FAWB (2009). Adoption Guidelines for Stormwater Biofiltration Systems, Facility for Advancing Water Biofiltration (FAWB), Monash University, June 2009.

Grieser, J. (2006). Climwat 2.0. Water resources, Development and Management Service (AGLW) and Environmental and Natural Resources Service (SDRN) of FAO.

Gupta, H., Pancholi, R., Rawat, P., Thapliyal, S. and Raj, S. (2023). Fundamentals of soil science. Goldean Leaf Publishers, India.

Hendershot, W.H., Lalande, H., and Duquette, M. (2008). Ion exchange and exchangeable cations. In Carter, M.R., and E.G. Gregorich (eds). Soil Sampling and Methods of Analysis. 2nd ed. Canadian Society of Soil Science, CRC Press and Taylor & Francis Group. Oxford, UK

Hossain, S. Islam, A., Badhon, F. F., and Imtiaz, T. (2021). Hydrometer analysis. In: Properties and Behavior of Soil - Online Lab Manual. https://uta.pressbooks.pub.

Ibrahim, M., Ghanem, F., Al-Salameen, A. and Al-Fawwaz, A. (2019) The Estimation of Soil Organic Matter Variation in Arid and Semi-Arid Lands Using Remote Sensing Data. International Journal of Geosciences, 10, 576-588.

Kissel, D. E. and Sonon, L. (2014). Single addition of Ca (OH)2 for lime requirement. In: F. J. Sikora (Editor). Soil test methods from the southeastern United States. Southern Cooperative Series Bulletin No. 419, Southern Extension and research Activity Information Exchange Group-6; pages 54 - 58.

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7), 1425–1432. https://doi.org/10.1080/01431169608948714

Monger, H. C., Martinez-Rios, J. J., and Kresat, S. A. (2005). Tropical soils: Arid and semiarid. In: D. Hillel (ed.) Encyclopedia of soils in the environment. Pages 182-187, Elsevier, USA.

Nabinejad, S., and Schüttrumpf, H. (2023) Flood Risk Management in Arid and Semi-Arid Areas: A Comprehensive Review of Challenges, Needs, and Opportunities. Water, 15, 3113. https://doi.org/10.3390/w15173113

Osujieke D. N., S.N. Obasi, P. E. Imadojemu, M. Ekawa, M. D. Angyu (2018) Characterization and classification of soils of Jalingo metropolis, North-East, Nigeria. NJSS Vol. 28, 72-80 https://doi.org/10.5555/20193252102

Peterson, J. M. (2024). Soils - Part 2: Physical Properties of Soil and Soil Water. Plant and Soil Sciences eLibrary, Soils Home Study Course, University of Nebraska Cooperative extension, Institute of Agriculture and Natural Resources. https://passel2.unl.edu/view/lesson/0cff7943f577

Weil, R.R., and Brady, N.C. 2017. The Nature and Properties of Soils. 15th edition, Pearson Education, Incorporation. ISBN 9780133254488