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ASSESSING THE INTER-RELATIONSHIPS OF SOIL TEXTURE AND CROP TYPES IN CENTRAL AND SOUTHERN ZONES OF PLATEAU STATE, NIGERIA USING GEOSPATIAL DATA AND TOOLS

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Abstract:

Soil texture extent determines soil structure, and influences soil properties like permeability, aeration, water-holding capacity, and nutrient availability. The texture of soil alone does not determine soil fertility but it plays a vital role in creating a suitable environment for promoting plant growth. In this study, we analyzed the relationship between soil texture and crop types in the central and southern zones of Plateau Stat using remote sensing and Geo-information data and tools. Furthermore, the study aimed to establish how and to what extent soil texture interrelates with crop types found in the study area. Primary data which included soil samples, GPS points and Land use cover were obtained from various sources. Soil samples were collected from randomly selected farm locations using soil sampling auger at depths of 0–30cm, altogether, a total of 738 soil samples were collected. The analysis involved sieving the soil samples through a 2mm-mesh after air drying the samples and gently crushing them before undergoing physio-chemical examiniation in the laboratory. The results revealed that the central and southern Plateau is dominated by sandy clay loam, sandy loam and sandy clay which accounts for the large production of maize, millet, sorghum and groundnut. Crop types such as rice and yam flourished with under clay and clay-loamy soils, which is favourable to the growth of rice particularly, while silty-clay and silty-clay-loamy were most suitable for the growth of irish potatoes. Generally, the assessment of crop types' spatial distribution unveiled distinct patterns in the cultivation of various crops across the study area. Yam and rice cultivation predominated in the southern zone, while the central zone was characterized by a dominance of irish potatoes and maize. On the other hand, millet, sorghum, and groundnut showed a spatial spread that overlapped both the central and southern zones. These findings provide valuable insights into the regional agricultural landscape, highlighting the preferences and choices of crops in different zones, which can be instrumental in developing targeted agricultural strategies and policies.

Keywords **—Remote Sensing, Soil Properties, Soil Structure, Geo-information, and Suitability**

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I. INTRODUCTION

Soil is an essential component of Earth's ecosystem. It is a complex substance composed of minerals, organic matter, air, and water. It provides the mechanical support and nutrient reservoir necessary for plant growth and is essential for plant life processes. Effective management of these resources for crop production requires the producer to understand the relationships between soil and crop [1]. Whereas, soil texture relates to the proportions of sand, silt, and clay in a soil sample. It is an essential property of soil that influences various factors, including soil fertility, water-holding capacity, and plant growth [2]. Understanding soil texture is a primary step to determine its potential for agricultural and horticultural purposes[3].Sand particles have a diameter ranging from 0.02 to 2mm, silt particles from 0.002 to 0.02mm, and clay particles have a diameter less than 0.002mm[4]. To identify soil texture, particles of soil are separated according to their size referred as soil separates[4]. These Soil separates are the individual size-group of mineral particles. There are a number of systems to classify and name of soil separates. There are United States Department of Agriculture (USDA), English System and International Society of Soil Science Society System. In USDA classification, soil separates are sand (2.0mm- 0.02mm diameter), silt (0.02- 0.002mm) and clay (less than 0.002 mm). Sand is again subdivided into five subgroup as very coarse (2.0-1.0 mm), coarse sand (1.0-0.5 mm), medium sand (0.5 -0.25 mm), fine sand (0.25 -0.1 mm) and very fine sand (0.1- 0.05 mm)[4, 5].

Soil texture determines soil structure, which further influences soil properties like permeability, aeration, water-holding capacity, and nutrient availability [6]. The texture of soil alone does not determine the fertility of the soil, but it plays a vital role in creating a suitable environment for promoting plant growth[7]. [8] provides general information on the physical characteristics of soil, soil and crop interactions, and how plants growth on soil, particularly as these topics relates soil and crop. Knowledge about available soil and soil texture can influence the decision-making process, such as determining what crops to plant and on which type soil will the crop be suitable for bomber harvest. In like manner, soil texture determines the relative amount of the diverse particle size fractions [9].

On the basis of soil texture, nine textural classes have been classified and correlated with the suitable crops production. Considerably by the size of the soil particles, crops are recommended to be cultivated according to the size of soil textural groups[4]. Soil density, availability of water and retention of water by soil are depended on soil separates[10]. Therefore, crops are selected according to the given soil textural class. Soil texture promotes the ability of a soil to perform function that are essential to people and the environment. It provides the capacity of soil to perform specific function of interest to human. Similarly, soil texture connects with different crop types productivity[11]. Soil texture is also a critical factor in determining the management practices that can be implemented on the soils, including the type of crops that can be grown and the season suitable for cultivation. soil texture has significant effects on soil properties and ultimately impacts plant growth. These highlights the importance of soil texture to crop types distribution and food production. As such, an extensive understanding of soil texture is essential in determining its potential for agricultural and horticultural purposes, and it is vital for sustainable agriculture and efficient land use planning. It is against this background that this study seeks to examine and map the interrelationship between soil texture and crop types for sustainable agricultural practices in the Central and Southern regions of Plateau State, Nigeria which an important agricultural production area in Nigeria.

II. STUDY AREA

The central and southern zones of Plateau State are located between 8°21’50.885” N to 9°46’24.955” N and 8°38’23.358” E to 10°38’28.662” E. Both regions comprise of 11 Local Government Areas (LGAs), with a total land area of approximately (20,411 km^2). The central zone covers five LGAs namely; Bokkos, Mangu, Pankshin, Kanke and Kanam, whereas the Southern zones captures six LGAs and namely; Langtang North, Langtang South, Wase, Shendam, Mikang and Qua’an-pan (Figure 1). The central and southern zones of the state are located within the Koppen climatic classification which is characterized by dry and rainy seasons alternating together. Rainy season begins from April to October and dry season begins from November to February, with annual rainfall of about 1,500mm, also with average humidity of about 80 percent. The two zones have a temperature range between 17°C to 38°C. The Central and Southern regions of Plateau state Nigeria is one of the major food-producing regions in Nigeria. With crops like maize, potato, sorghum, rice, yam and so on produced in abundance. Rain fed cultivation is the dominant practice in the region and crop production is influenced by the onset of rain in the month of April. The major crops produced in the rainy season are maize, millet, sorghum, rice, groundnut and millet. Whereas crops like yam are produced at the end of the rainy season, also in substantial quantities.

The geology of area lies within the Pre-Cambrian Basement rocks, which comprises mostly the migmatite – gneiss complex believed to have been emplaced more than 600 million years ago. This complex has been in some places, intruded by Pre-Cambrian to Late Paleozoic Pan-Africa Granite (Older Granite) rocks, such as the biotite granites, Hornblende biotite granite, syenite, the medium and coarse-grained biotite granites. These older granites occur as inselbergs mostly in the central zone of the project area.

Consequently, the Jurassic younger granites and volcanic rocks such as the older basalts overlie or cross-cut these basement complex rocks. These volcanic rocks are believed to have been formed during the early Cenozoic (Tertiary), that is the ‘’Older Basalts’’. The southern parts of the study area are overlain by the Cretaceous and Tertiary to Recent sediments. The crystalline basement rocks (Granite gneiss) and the older granites occur as pockets of highland in the southern zone whereas the cretaceous sedimentary rocks occur in low-lying areas which dominated the southern zone. The rock forming minerals are quarts, feldspars, mica, biotite and hornblende. These rock units were subjected to different degree of weathering leading to the formation of soils with textural variation spatially distributed across the area.

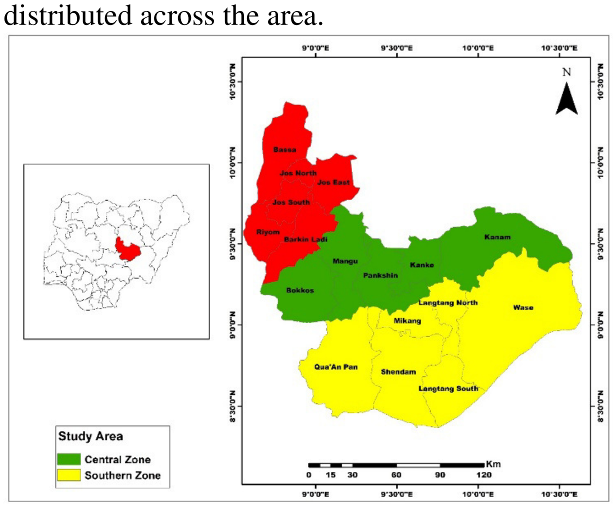

Fig 1. The study area

III. MATERIALS AND METHODS

The primary data used for this research included soil samples, Global Positioning System (GPS) fixes and Land use/ land cover. The field work was conducted for a period of 4 weeks which spanned from 3rdApril 2021 to 4th May, 2021; GPS points of the soil samples were obtained using a handheld GARMIN GPSMAP 78s receiver. Soil samples were collected from selected farm locations using soil sampling auger at depths of 0–30cm. The samples collected were mixed thoroughly inside a plastic rubber to have one soil composite. The stratified random sampling method was used for the soil sampling based on the variability of the soils in the study region. Alltogether, a total of 738 soil samples were obtained from different farmlands in 525 villages within eleven LGAs namely; Langtang North, Langtang South, Mikang, Qua'anpan, Shendam and Wase in the southern zone; Bokkos, Kanam Kanke, Mangu and Pankshin in the central zone.

The laboratory analysis of the soil samples was conducted at Centre for Dry Land Agriculture, Bayero University, Kano, Nigeria. Total soil organic carbon (total C) was measured using a modified Walkley & Black chromic acid wet chemical oxidation and spectrophotometric method[12]. Total nitrogen (total N) was determined using a micro-Kjeldahl digestion method[13]. Soil pH in water (S/W ratio of 1:1) was measured using a glass electrode pH meter and the particle size distribution following the hydrometer method[14]. Available phosphorus (avail. P), exchangeable cations (K, Ca, Mg and Na) and micronutrients (Zn, Fe, Cu, Mn, and B) were analyzed based on theMehlich-3 extraction procedure preceding inductively coupled plasma optical emission spectroscopy (MP-AES, 4200, Agilent Inc., Waltham, MA, USA). Exchangeable acidity (H + Al) was determined by extracting the soil with 1N KCl and titration of the supernatant with 0.5M NaOH[15]. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable cations (K, Ca, Mg and Na) and exchangeable acidity (H + Al).

The next phase of the study involved organizing and preparing the field data for spatial analysis. Initially, the collected field data's coordinates were carefully arranged within an excel worksheet and subsequently saved in the "CSV" format. To facilitate further spatial analysis, the data was imported into the ArcGIS 10.8 software for conversion into a shapefile format. This transformation allowed for more comprehensive and in-depth spatial analysis to be performed on the data.The main technique employed for spatial analysis was the Inverse Distance Weighted (IDW) interpolation extension in the Spatial Analyst tool of ArcGIS. This interpolation method is valuable for estimating values at unmeasured locations based on a set of known data points.

To build a relational database, the soil parameter values were imputed into the attribute table of the ArcGIS 10.8 software and linked accordingly. This database facilitated a comprehensive analysis of the spatial distribution of the physicochemical properties under investigation.The Inverse Distance Weighting interpolation method was particularly employed to delineate the spatial variation of the soil parameters across the study area. This approach allowed us to generate thematic maps representing the distribution of the chosen soil parameters.The point data obtained from the field were interpolated using the IDW technique.

IV. RESULTS AND DISCUSSION

The results revealed nine textural classes namely; sandy, sandy clay, sandy loam, sandy clay loam, clay, clay loam,loam,silty clay and silty clay loam. The spatial distribution of this soil texture is represented in figure 2.The map revealed that the dominant soil type in the north eastern parts of the region are sandy, sandy clay and sandy loan, whereas the western parts of the study region are dominated by silty clay loam, silty slay and loan.

Surprisingly, the southern and central parts of the study region is occupied by a mixture of all nine soil textural classes.

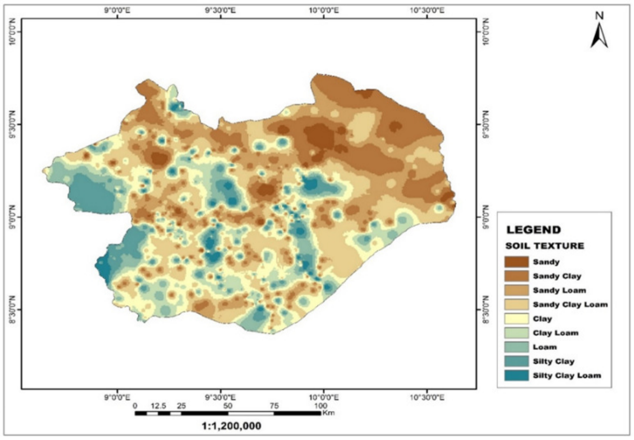

Fig. 2. Map of soil texture

Figure 2 showed a wide textural variation of the soil. The spatial distribution map (Fig 2.) indicates that sandy clay loam covered4681.8 km^2 (22.1%) of the total area mapped. On the other hand, silty clay loam covers the least area (317.1 km^2) which is less than 2% of the total area. The table 1 shows the percentage of all the soil texture classes in terms of area coverage, with Sandy Clay Loam appearing to be the most dominant soil type in the region, this is followed by Sandy Loam and then Sandy Clay.

TABLE 1: SOIL TEXTURE CLASS IN TERMS OF PERCENTAGE AND AREA OF COVERAGE
(SOURCE: AUTHOR GIS ANALYSIS, 2023).

S/N	Class Name	Percentage (%)	Area (km^2)
1	Sandy	2.7	571.5
2	Sandy Clay	15.6	3293.3
3	Sandy Loam	18.7	3961.3
4	Sandy Clay Loam	22.1	4681.8
5	Clay	13.6	2882.1
6	Clay Loam	11.2	2370.9
7	Loam	7.8	1661.6
8	Silty Clay	6.8	1431.3
9	Silty Clay Loam	1.5	317.1

V. SOIL TEXTURE AND CROP TYPES INTERRELATIONSHIPS

Figure 3 revealed that soil texture influences the distributions of crop types. for instance, Sandy soil is suitable for (groundnut, sorghum, irish potatoes) while sandy clay soil is good for (maize,millet,rice,groundnut).Sandy loam is favourable for (maize,sorghum,millet);sandy clay loamenables the cultivation of (sorghum,yam,millet);clay is appropriate for (irish potatoes, millet),clay loam enhances the production of (rice,sorghum),loam favours the cultivation of (rice, yam),silty clay is suitable for (maize,millet) and silty clay loam is appropriate for rice and sorghum production.

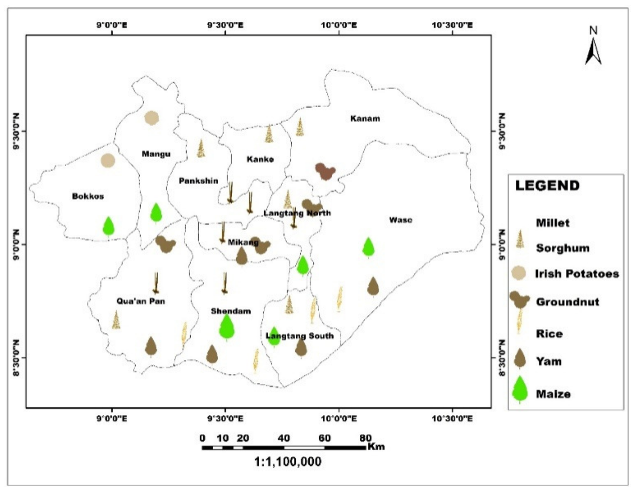

Fig. 3. Map of predominant crop types

Plateau state is famous for its sustainability in maize and irish potato cultivation, our field data and results revealed that these are largely located in Mangu and Bokkos LGA. The spatial distribution of the soil texture classes and the crop types found in the area showed that sandy clay loam, silty clay, silty clay loam and loam supports the growth of irishpotatoe and maize, which are the predominant crops found in Mangu and Bokkos LGAs (Figure 4). While millet, sorghum and groundnut appeared to flourished on sandy, sandy clay, sandy loam and sandy clay loam soils, as can be seen in Pankshin, Kanke and Kanam LGAs in the central zone of the state and Langtang North and Wase LGAs in the southern zone of the state. While clay and clay loam seem to supportthe growth of rice and yam crop types which are predominantly grown in Shendam, Qua'an Pan, and Langtang South LGAs in the southernzone. Finally, maize was seen to be cultivated all-round the LGAs in southernzone and in some local government in centralzone namely Mangu and Bokkos. Certain crop types such as Rice and Yam flourished with particular soil texture (clay and clay loam favoured the growth of rice) while (silty clay and silty clay loam favoured the growth of irish potatoes). Crops such as maize, sorghum, millet and groundnut flourished on all soil texture classes apart from clay and partly clay loam.

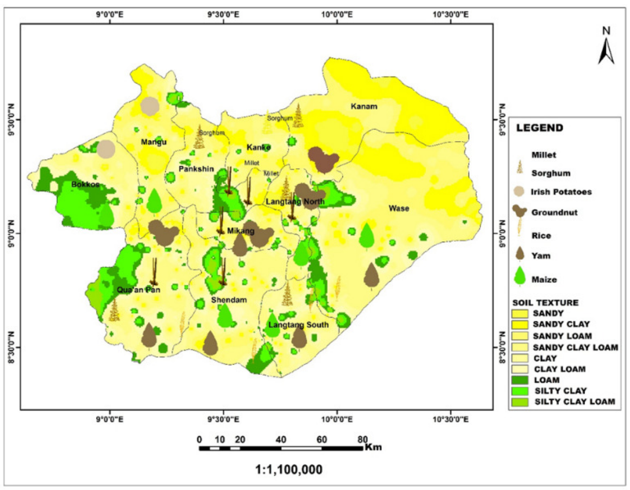

Fig. 4. Map of Soil texture and crop types(Source: Author GIS Analysis, 2023)

Our study findings unequivocally indicate that soil texture significantly impacts the distribution of diverse crop types in Plateau state. Each soil texture presents distinct levels of suitability for particular crops, and comprehending these associations holds paramount importance for promoting sustainable agriculture and maximizing crop yield.

Sandy soil, characterized by its coarse texture and low water-holding capacity, is found to be well-suited for the cultivation of groundnut, sorghum, and Irish potatoes. These crops thrive in well-draining soils that prevent waterlogging and allow for healthy root development. On the other hand, sandy clay soil, which contains a higher proportion of fine particles, is better suited for maize, millet, rice, and groundnut. The higher clay content in sandy clay soils enables better water retention, making it more suitable for crops that require a consistent moisture supply.

Sandy loam, a soil texture with a balanced mixture of sand, silt, and clay, is found to be favourable for the cultivation of maize, sorghum, and millet. The intermediate water-holding capacity and good drainage characteristics of sandy loam contribute to the successful growth of these crops.Sandy clay loam, which contains a higher proportion of clay than sandy loam, provides a suitable environment for crops like sorghum, yam, and millet. The increased clay content enhances water retention and nutrient availability, supporting the healthy development of these crops.

Clay, with its fine texture and high water-holding capacity, proves to be appropriate for the cultivation of Irish potatoes and millet. These crops benefit from the higher water retention capacity of clay soils, ensuring sufficient moisture availability throughout their growth stages.Clay loam, another soil texture with a balanced mixture of clay and loam, promotes the production of rice and sorghum. These crops, particularly rice, require abundant water throughout their growth cycle, and the clay loam's water-holding capacity helps meet this demand.

Loam, a well-balanced soil texture with equal proportions of sand, silt, and clay, is found to favour the cultivation of rice and yam. The balanced composition of loam allows for good drainage, preventing waterlogging, while also retaining enough moisture to support rice and yam growth.

Silty clay, characterized by a higher percentage of fine particles, provides a suitable environment for the cultivation of maize and millet. These crops benefit from the increased water retention and nutrient availability offered by silty clay soils.

Silty clay loam, with a balanced mixture of silty clay and loam, appears to be particularly appropriate for rice and sorghum production. The combined advantages of good drainage and water retention make this soil texture conducive to the growth of these crops.

The spatial distribution of soil texture classes and crop types across Plateau state revealed some interesting patterns. The LGAs of Mangu and Bokkos stood out as centers for sustainable maize and Irish potato cultivation. Our field data indicated that these LGAs predominantly featured sandy clay loam, silty clay, silty clay loam, and loam soils, which were well-suited for the growth of maize and Irish potatoes.

In contrast, the central zone of the state, comprising LGAs like Pankshin, Kanke, and Kanam, along with the southern zone including Langtang North and Wase LGAs, appeared to be favourable for the cultivation of millet, sorghum, and groundnut. These areas mainly featured sandy, sandy clay, sandy loam, and sandy clay loam soils, which supported the growth of these crops.

Furthermore, the LGAs of Shendam, Qua'an Pan, and Langtang South in the southern zone were found to be conducive for the cultivation of rice and yam. The clay and clay loam soils prevalent in these areas offered the necessary water retention and nutrient availability required for these crops to thrive.

An interesting observation was the versatility of maize cultivation, observed across various LGAs in the southern zone and some central zone LGAs, such as Mangu and Bokkos. This adaptability suggests that maize is less dependent on specific soil textures and can grow in a broader range of soil conditions.

However, it must be noted that some soil texture types found in the central zone (e.g silty clay and silty clay loam) that support some crop types (e.girish potatoes and maize) are equally found in the southern zone, but those crops do not thrive in the southern part of Plateau state due to temperature. This is attributed to the conducive temperature compulsorily required for the cultivation of potato. The suitable temperature mandatory for the production of potato in the tropical region is below 21^0 [7, 16-19]. This is far exceeded in the southern parts of Plateau State and explains why potato are mainly cultivated on the Jos Plateau region as reported by [7], where a near temperate climate exists and it is attributed to the elevation of the Plateau rock formation. [7] mapped and reported the distributions of rain-fed potato in 2019 on the Jos Plateau using Sentinel 2A/B satellite imagery, their results also revealed that Bokkos and Mangu LGAs in our study region are major potato production areas. In general, their results estimated the potato production area to be 580 km², with maize intercropping as the dominant practice, accounting for upto 98% of the potato production area [7].Equally, some soil texture types found in the southern zone (sandy clay, sandy clay loam and clay) that support some crop types (e.g yam and rice) are equally found in the central zone, but those crops do not thrive in the central zone. This is due to day and night temperatures.

VI. CONCLUSION

The study clearly established the interrelationship of soil texture and crop types which shows a discernable pattern across the state. In General, the spatial distribution of crop types showed that yam and rice are predominantly cultivated in the southern zone while irish potatoes and maizeas the dominant crop types. Millet, sorghum, groundnut has spatial spread overlapping both the central and southern zone of the state in their production.

Although farmers possess important experience and knowledge regarding land mangement, and the right crops to produce in their local regions, the government should take the lead in working with agricultural institutes to regularly test soil in order to scientifically educate the farmers on the right crops to produce in order to maximize land potentials.

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