Feed the Future Nigeria Agricultural Policy Activity

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Soil management, fertilizer types and associated practices for maize in Benue State

By

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ACRONYMS

AFRE	Agriculture, Food and Resource Economics
AMC	Available Moisture Content
BD	Bulk density
CEC	Cation Exchange Capacity
Coef. Var.	Coefficient of Variation
DAP	Di Ammonium Phosphate
Double- UP	Double-up technology where two legumes are intercropped
ECEC	Effective Cation Exchange capacity
EC	Electrical conductivity measured as dSm-1 or as us/cm
FSG	Food Security Group
GAPs	Good Agronomic Practices
GHGs	Green House Gases
IFPRI	International Food and Policy and Research Institute
LandPKS	Land Potential Knowledge System – A mobile application
LCC	Land Capability Classification
LGAs	Local Government Areas
Min	Minimum
Max	Maximum
MOP	Muriate of Potash
MSF	Medium Scale Farmer
NAPA	Nigeria Agricultural Policy Activity
NPK	Nitrogen Phosphorous Potassium
OC	Organic Carbon
OM	Organic Matter
PCA	Principal Component Analysis
PI	Productivity Index
SSF	Small Scale Farmer
SSP	Single Supper Phosphate
Std. Dev.	Standard Deviation

EXECUTIVE SUMMARY

Productive soils play a key role in agricultural production and crop yield. However declining soil fertility stemming largely from intense and mismanaged farming practices, limits smallholder farmer's productivity in Nigeria and many other parts of sub-Saharan Africa. Current fertilizer recommendations for maize farmers in Nigeria do not sufficiently take into account the diversity in soil types, the biophysical properties, rainfall intensities and farmer's resources and yield goals. When fertilizers are applied without a clear understanding of whether they are needed or not, this leads to nutrient imbalances. In addition, inappropriate fertilizer use typically leads to high production cost, yield loses and soil degradation causing loss of soil micronutrients and macro nutrients resulting in severe and most times invincible health problems for people and animals as well as contributing to greenhouse gases (GHGs) emissions.

In this light, a characterization of soil was carried out on small holder farmers' fields in Benue State Nigeria. Characterizing the soil nutrient status as well as the soil productivity index rating provides a foundation for understanding the current status and how to map out strategic site-specific recommendations tailored to the needs of the maize-based systems in Benue State. Benue State is one of the eight (8) Focal Feed the Future Nigerian Agricultural Policy Activity Focal States. Soil samples totaling 883 were geo-referenced and analyzed for pH, soil texture (sand, silt and clay), bulk density (BD), organic matter (OM), phosphorus, potassium, available moisture content (AMC) and nitrogen. Following **Pierce *et al.*** (1983) soil productivity index ratings, a digitalized map was created for Benue State. See link: https://bit.ly/3GfBN3P

This report presents findings of the soil tests and soil productivity index ratings from the geo referenced farmers' fields in Benue State. It builds on previous documents: Policy Research brief 69: Feed the Future Innovation Lab for Food Security Policy titled **Changing the fertilizer conversation in Nigeria: The Need for Site Specific Soil-Crop Fertilizer Use** (Policy_Brief_69 new.pdf (msu.edu)) and the Farmers manual created as an easy to use pamphlet titled **Guide on how to account for soil physical properties and fertilizer use in Maize based systems** see link: farmer_fertilizer_manual-finalized.pdf (msu.edu)**.** Farmers' perceptions on key issues are also documented.

The main objective of this report is to use the projects' generated soil maps, to characterize soil nutrient status and soil productivity for Benue State. We seek to proffer implementable solutions and policy recommendations for soil management, fertilizer types and associated practices in maize-based farming systems, geared towards sustainably increasing grain yield (through proper management) while reducing costs. We also provide baseline data for these soil properties open source for making informed decisions by diverse stakeholders including government, development practitioners and farmers.

Approach and Methodology

First, we purposively selected 10 small holder farmers and their fields in maize-based systems from three (3) council wards of 10 Local government areas (LGAs) in Benue State. These were areas that produced maize and prone to erosion. Soil samples were collected at three (3) depths and at three points within a farm field (except for instances where soils were shallow due to a hardpan). The Land*PKS* mobile application[1]was used to acquire geo-coordinates and to take soil

[1] Farmers capacity was built to use the *LandPKS* mobile application in keeping farm records, perform field observation for texture, land slope, read soil parameters following the pictorial prompts.

texture as field observations, land capability classification (LCC[2]) readings, soil management practices and farm history while building capacity of the farmers on how to use the application. In addition, some soil physical and chemical parameters were collected ***in situ*** with a sensor device while others were analyzed for, in the soil laboratory. Data for the perception survey was collected using structured interview questions. The questionnaire was physically administered to the target audience at their farms and sometimes at arranged meetings. Structured interview questions were used to gain insights into farmers' perception of soil fertility, inputs, soil management practices, yields, receipt of information from extension workers and on the use Land*PKS* mobile application as a soil health management tool. Geo referenced rainfall data, soil physical characteristics and farmer's field history was documented using the Land*PKS* mobile application.

Summary of Key Findings of the Benue State soil nutrient status and soil productivity study

- The physical soil characteristics (such as texture and bulk density contributed more variability to the overall soil fertility and invariably its productivity as compared to the chemical soil properties (such as nitrogen, phosphorus, cation exchange capacity (CEC) and pH).
- The Soil productivity index rating was generally low in small-holder farmer's field in Benue state. Soil productivity index values were below 0.5 on a 0 -1 scale. Generally, values were between 0.1 to 0.2 for the areas studied. In Michigan, soils(from the order alfisols like those of Benue) had PI values of 0.5 and above (or 10 on a scale of 1-19) see link: SSL20608 288..299 (usda.gov)
- There is a highly significant correlation between soil properties and the soil productivity index. Nitrogen, phosphorus, CEC and OM were all positively correlated with SPI indicating the need to increase and maintain these soil properties for healthier and more productive soils. The significant and negative correlation of BD and pH (acidity) to soil productivity implies the need for better soil management practices that will improve soil texture thus reducing compaction while increasing infiltration, aeration and better root development. It also shows the need for proper monitoring of the soil pH (acidity) so that nutrients can be released for plant uptake.
- There is a lot of variability in individual key soil physical, chemical and biological properties across the farms, wards and LGAs. This demonstrates the need to properly evaluate soil properties and move away from blanket rate fertilizer recommendations towards more site-specific nutrient management.
- Farmers' access to information on soil management practices from extension workers was low.
- The LandPKS mobile application can serve as a soil health information provision tool that informs land potential on the spot for farmers.
- LCC results showed that soils in Benue State were in the severe limitation class – Class III. Soils in this class, limit choices of plants, are low fertile soils, are subject to erosion and require conservation practices such as (cover cropping, mulching, minimal tillage, crop rotation) to be used for agricultural purposes.

Summary of Key Recommendations

In view of the many challenges identified, we propose the following six recommendations:

[2] LCC, is a report generated within the *LandPKS* application.

1. Rather than the current practice of purchasing inorganic fertilizers without ascertaining their quality through laboratory tests, we recommend that inorganic fertilizers be tested. This applies to all fertilizers whether compound NPK 15:15:15, 20:10:10; 27:13:13, di-ammonium phosphate (DAP) or straight fertilizers urea, muriate of potash (MOP) and single supper phosphate (SSP). These fertilizers should then be made available on time for farmers to aid production as farming activities such as fertilizer application, are time bound efficient use by the plants.
2. The timing of fertilizer application as split doses should be strictly adhered to.
3. When trying to satisfy a recommendation rate of say 120kgN/ha, $60P_20_5$/ha and 60 K_2O/ha for maize production in the area, the recommended dose to be followed is **8 bags** of NPK 15:15:15 and **2.5 bags** of urea.
4. The soil management practice, of ***mulching*** (the covering of the soil with polythene, dried animal waste or plant residues such as straw, husk, and twigs) improves soil health by preventing the loss of soil particles and nutrients through runoff given high intensity rains in the area. It is hereby recommended as it will support water retention, improve soil structure as compaction is reduced and will lower soil temperatures while suppressing weed infestation. The soil productivity of the fields of small holder farmers will be thus impacted.
5. Capacity building of extension workers and farmers should be improved in the following areas: timing of fertilizer application, determination of appropriate fertilizer types and recommendations for crops, types of organic amendments, crop rotation GAPs and the '**double-up** technology (double-up technology, is the inter-planting two grain legumes with different plant architecture e.g. soya-beans and groundnuts)in a bid to fix nitrogen from the atmosphere, build soil organic matter (OM) content with the residues improving water transmission characteristics and better root penetration/elongation.
6. In each community, a quarter of a hectare can be carved out as a demonstration farm with a lead farmer so as to learn and adopt new technologies and practices, preventing farmers from acting in isolation.
7. There is a need for a state-wide drive promoting the incorporation of residues from groundnut and soyabean or from animal wastes (such as poultry droppings, swine dung) to build soil organic matter.[3] Government should partner with private sector, research institutes, development practitioners and farmers to ensure that farmers are taught the benefits of slash and burn and the best way of doing it. The downed vegetation (slash) is burned in a controlled environment without air (pyrolysis) to produce *biochar* which is a stable form of carbon as against the current practice of slashing and burning with air which predisposes the soil to erosion.

[1]Double-up technology involves intercropping two legumes with different plant architecture

[3] We focus on swine and poultry droppings because others such as goat droppings have lower nutrient content compared to poultry droppings and pig dung while cow dung brings weeds that are invasive species.

1.0 INTRODUCTION

1.1. Background

For sustainable farming, good soil management provides the bases for adequate supply of nutrients to meet crop needs. Building soil health requires a long-term management plan to improve soil organic matter that would feed beneficial soil microbes and ensure nutrient supply and timely release to plants. This approach is termed "**feed the soil to feed the plant".** (Morrone and Snapp, 2011). Knowing that small holder farmers don't test their soils due to lack of awareness and cost, the USAID Feed the Future Nigerian Agricultural Policy Project (2015-2020) sought to characterize soil nutrient status in Nigeria. The project went a step further to evaluate the productivity of the soil whilst building capacity of extension workers, students and faculty of research institutions.

Despite reported increase in inorganic fertilizer use, yields are still low in cereal-based systems (Liverpool-Tasie *et al.*2017). As the call for fertilizer use increase is made across the continent (often via expensive government and development programs), particular attention needs to be made to site specific management of input use along soil health management. This is necessary to ensure that such efforts translate to increase productivity and greater returns on investment as well as reduce nitrogen losses through volatilization, leaching and runoff ensuring a safer environment (Agada, 2018).

To date, most soil fertility studies are on research plots and findings are scaled up, this study however, sought to do differently in order to raise farmer's productivity at the level of their fields. Omotilewa et al. (2022), reports that any apparent relationship observed between farm size and productivity in small-scaled farmers (SSF) or even medium scale farmers (MSF) fields, was relatively small and that non-size related factors were much more important drivers of productivity. One of such nonfarm factors is the quality of the land resource available to the farmer. Characterizing the nutrient status and productivity potential of their field and outlining better management practices will increase productivity and invariably, their economic livelihood. It will also provide a foundation for how to strategically apply fertilizers and organic inputs (Snapp, 1998), provide information (data) as baselines for further monitoring and be a step towards revised soil management recommendations (Morrone and Snapp, 2011).

Table 1 presents a summary of the soil properties collected from maize farmers in Benue State in 2021. The following key points stand out. First, major limiting nutrients for maize production are nitrogen, phosphorus and potassium. Second, organic carbon was too low to support crop production and maintain soil structure. Third, the soil acidity varied widely across fields and this variation in acidity increased as soil depth increased.

Table 1. Descriptive Statistics for Soil characteristics and Soil Productivity from Smallholder Farmers' Fields in Benue

Soil properties/Measures	N (%)	Avail. P(mg/kg)	Potassium (mg/kg)	pH	Soil Moist. (%)	BD. (gcm3)	CEC (cmol(+)kg)	Org. Matter (%)	Sand (%)	Silt (%)	Clay (%)	PI
Min	0	0.0	0	3.67	4.92	0.90	1	0.06	26.30	3.10	4.12	0
Max	0.39	6.0	3	7.76	01.8	1.86	16.30	4.78	79.0	53.90	37	0.76
Range	0.39	6	3.0	4.09	64.08	0.16	15.3	4.72	52.70	50.80	32.88	0.76
Mean	0.12	0.64	0.15	5.94	23.55	1.38	9.36	1.58	54.19	27.29	18.32	0.13
Std. Dev.	0.07	1.18	0.43	0.51	10.89	0.10	1.84	1.18	0.27	6.36	4.16	0.13
Coef. Var.	0.61	1.84	2.86	0.09	0.46	0.07	0.2	0.75	0.15	0.23	0.23	0.99

Where critical soil test values used in this study are sand 60%; OM 1%; pH 5.2; nitrogen 0.15%; phosphorus 15 mg/kg; Potassium 0.2 cmol (+)/kg or 78 mg/kg; available moisture content (AWC) > 20%, PI =0 .5 and BD 1.1 < 1.5 gcm^{-3}.

Key: N=Nitrogen (%); Avail. P = Available Phosphorus (mg/kg); Potassium ((mg/kg); Soil Moist. = Soil Moisture Content (%): BD = Bulk density (gcm^{-3}); CEC = Cation Exchange Capacity (Cmol(+)/kg; Org. M= Organic matter (%); PI = Productivity index; Max= Maximum; Min = Minimum; Std. Dev. = Standard deviation; Coef. Var. = Coefficient of Variation.

1.2 Correlation Analysis

We conducted a correlation analysis to see the relationships between different soil chemical and physical properties as well as between soil chemical and physical properties and the soil productivity index. The opensource R programing language software (version 4.2) was used to carry out the correlation analysis. We find that a positive correlation exists between organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), CEC and clay. This reveals the importance of organic manure application in the study area (Figure 1). Since N and P are the major limiting nutrients in maize cultivation of the studied soils (Abbas *et al.* 2012), addition of OM will provide these key nutrient elements. There was significant and negative correlation between sand and clay, N and pH, AWC and pH, BD and CEC, BD and sand. This explains the low fertility status of the soils of this area as sand-dominated soils will drain easily and promote easy leaching of soil nutrients (Snapp, 1998). Thus, the addition of organic manure will help in improving the nutrient status as well as structure of these soils.

We also find significant positive relationships for soil pH with CEC, pH with silt, pH with clay (Appendix 1). Implication is that as pH increases cation exchange capacity will increase in silt and clay soils as opposed to sand soils. In contrast, we find a negative correlation ($R^2 = -0.1$) between N and soil pH. This suggests that the soil pH impacted on the concentration and availability of nitrogen. Furthermore, we find that CEC was significantly inversely related to Nitrogen ($R^2 = -0.13$), BD ($R^2 = -0.15$), and Sand ($R^2 = -0.08$). There is also significant positive correlation of the soil properties to the Soil Productivity Index ratings. Nitrogen phosphorus, CEC, OM and BD are all positively correlated indicating the need to increase and maintain these soil properties for healthier and more productive soils. The significant negative correlation of BD and pH to soil productivity explains the need for better soil management practices that will improve soil texture while monitoring the soil reaction.

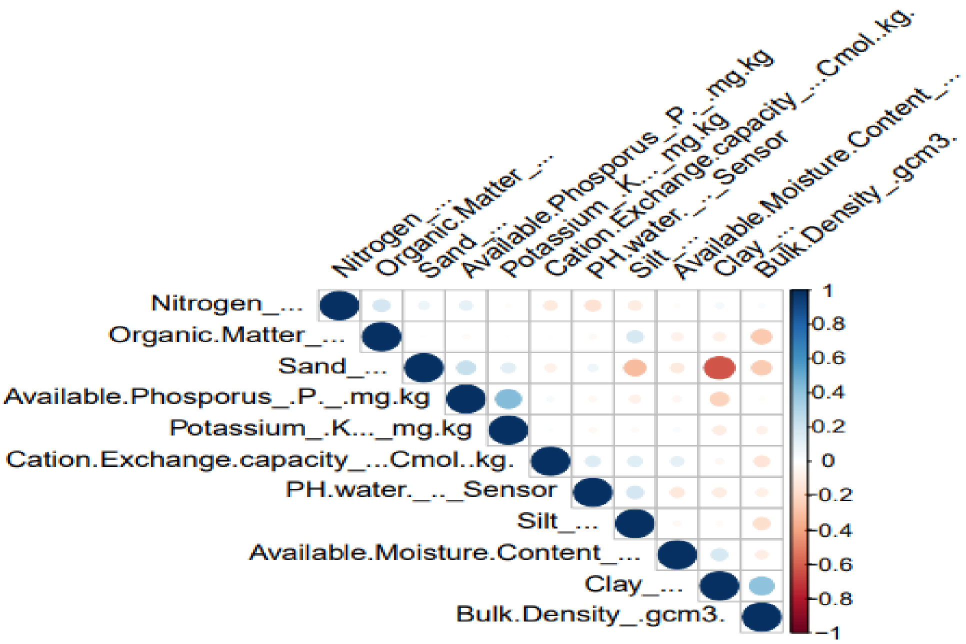


Figure 1. Pearson Correlation Matrix of Soil Properties tested.

2.0. SOIL CHARACTERISTICS AND NUTRIENT STATUS OF THE STUDY AREAS

Soil samples from farmers' fields were tested for chemical, biological and physical properties to ascertain the nutrient status as well as rate the productivity of their farmlands. The soils were largely sandy at the surface and deficient in nitrogen, phosphorus and potassium. BD was below critical limit although with the soils having low organic carbon, this low BD may lead to surface sealing and exacerbating runoff and loss of soil particles and nutrients. Drawing on Principal Component Analysis (PCA) conducted, the soil properties are discussed based on extracted factors and their contribution to variability. In both the first and second dimensions, the physical properties contributed more to the variability while dimension three and four housed chemical properties contributing to the variability. Descriptive statistics for soils' properties in the various locations in Benue State are presented in (Table 1). Results discussed on nutrient availability are for the surface (0-30cm depth). In evaluating the fertility status, the data were compared to critical soil nutrient levels established for maize production in the tropics (Landon 1991; FMANR, 1990). Critical soil test values used in this study are Sand 60%; OM 1%; pH 5.2; Nitrogen 0.15%; Phosphorus 15 mg/kg; potassium 0.2 cmol(+)/kg or 78 mg/kg; AWC >20%, PI =0 .5 and BD 1.1 < 1.5 gcm^{-3}.

The productivity ratings comprising physical, chemical and biological properties along the soil profile are discussed separately from the surface fertility.

2.1 Soil physical properties

Texture

The high sand fraction (52%) observed from the particle size distribution compared to silt and clay fractions can be attributed to the parent materials. These soils were predominantly developed over deeply pre-Cambrian basement complex rocks such as granite (Voncir, 2008). The high sand content may also be linked to the sorting of materials by clay eluviation and surface erosion by water. The silt content ranged from 3.1% to 53.9%, with a mean value of 27.29% while clay content ranged from 4.12 % to 37.0% with a mean value of 18.32%. Soil texture is described on the basis of the percentages of sand, silt and clay. It greatly influences soil response to management. The PCA loadings in dimension 1 and 2, further highlight the physical properties' contribution to variability (see Appendix). The soil texture affects soils' ability to drain and to hold water during droughts, root development, susceptibility to form hardpans, erodibility, and ability to protect and build soil organic matter. With improved aggregation from manure additions, soils' bio-physical characteristics such as water infiltration and porosity are impacted positively (Snapp and Morrone, 2008). Building soil organic matter (SOM) is the primary means to improve soil physical texture and structure. Over 70% of the soils were sandy loam at the surface while it was sandy clay loam at the subsurface. Soils that are sandy tend to drain quickly, are low in organic carbon and low in nutrients (Landon 1991). The distribution of soil texture can be seen in (Figure 2) culled from the digitalized map web portal for Benue State. Soil texture cannot be changed by farm management, so it is important to consider the soil texture when selecting a field site for crop production.

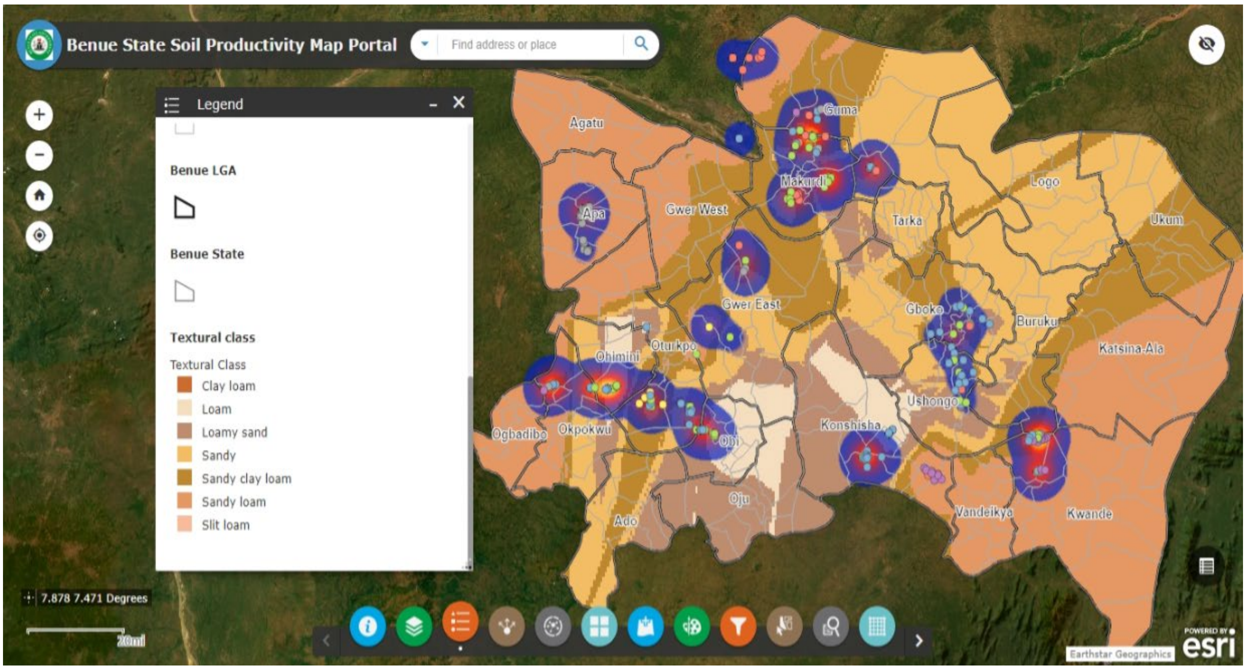


Figure 2. USDA Soil Texture classification for the soils of the study area.

Bulk Density (gcm-3)

BD ranged from 0.90(gcm^{-3}) to 1.86 (gcm^{-3}) with a mean value of 1.38 (gcm^{-3}). These values show that the soils are not compacted and would allow for root elongation and infiltration. Grossman and Berdanier (1982). Over 70 % of the soils were not compacted with values less than 1.4 (gcm^{-3}) (Figure 3). BD significantly negatively correlated with sand (R=-0.25, p=*0.01*).

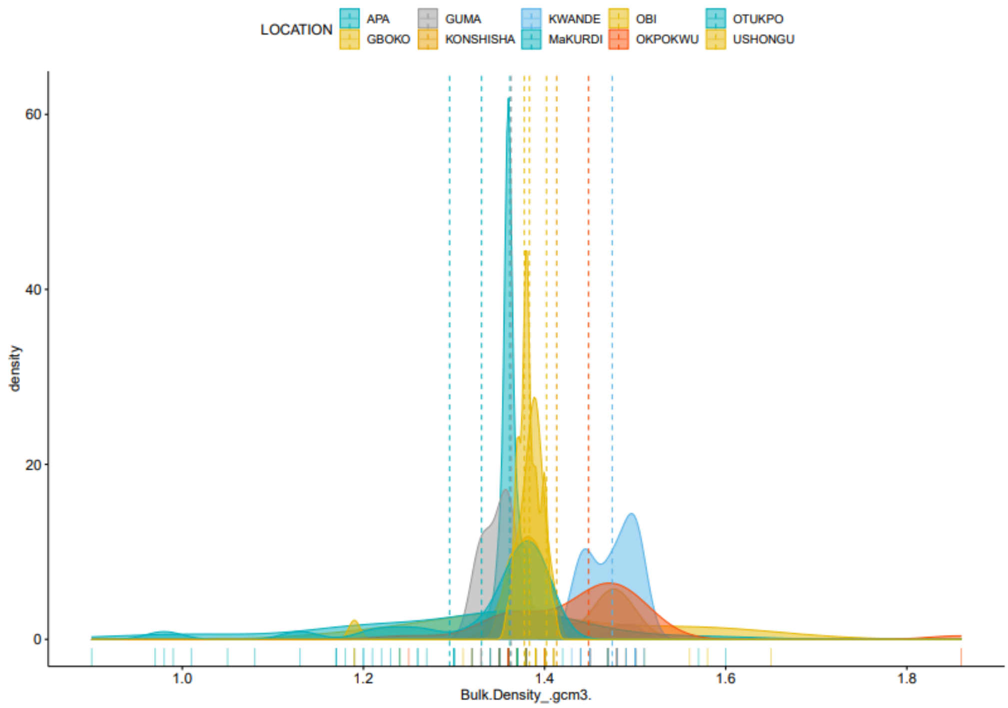


Figure 3. Soil BD distribution across the LGA under study.

Available Moisture Content (AMC)

AMC is critical to the growth of crops. Moisture ranged from 69.8% to 4.92% with a mean value of 23.55%. Over 50% of the soils of the area had sufficient moisture above the critical value of 20 percent (Figure 4). However, with the soils being sandy at the surface, and reported high rainfall intensities (Agada, *et al.* 2016) encouraging soil management practices that will enhance water transmission and storage is imperative. El-Nady (2015), reported maize yield decline when soil moisture content was reduced.

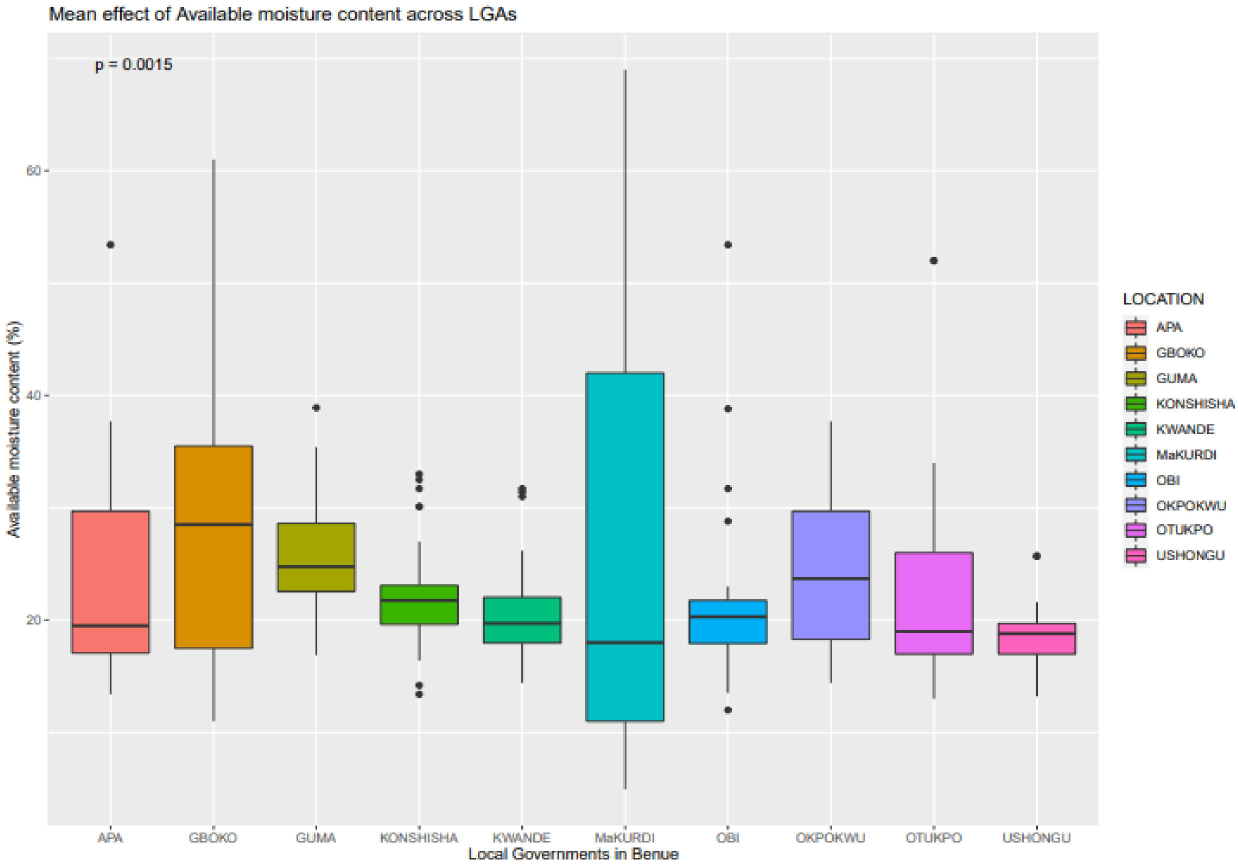


Figure 4. Distribution of Soil moisture in the various Local Governments Areas (LGAs)

2.2. Soil Chemical Properties

Acidity

Soil pH is an indicator of the soil's acidity which is a primary factor controlling nutrient availability, microbial processes, and plant growth. Cation and anion exchanges are directly impacted by pH. At the pH range of 6.5-8 most nutrients are readily available for uptake by plants. For the topsoil of the smallholder farmers in Benue State, severe soil acidity was not a major edaphic threat. Landon (1991) stated that critical values for acidity below which maize production is affected in the tropics was between 5.1 and 5.3. On this basis, 5.2 was chosen as the critical value to evaluate the pH (Snapp, 1998). The soil surface pH ranged from 3.67 to 7.76 with a mean value of 5.94 indicating medium acidic soils (Figure 7). Over 90% of the topsoil (0-30cm) had pH greater than the critical value of 5.2. Low acidity may constrain corn yields in a few areas as pH greatly influences nutrient availability, release and uptake by plants (Figure 5). The pH of the soils did not differ significantly statistically (*p=0.05*) across some wards in the study sites (Figure 6). However, site specific georeferenced sampling, showed marked differences within and between farmlands (Figure 7). It was further observed that the lowest pH value of 3.67 was at Agan ward in Makurdi local government area of the state.

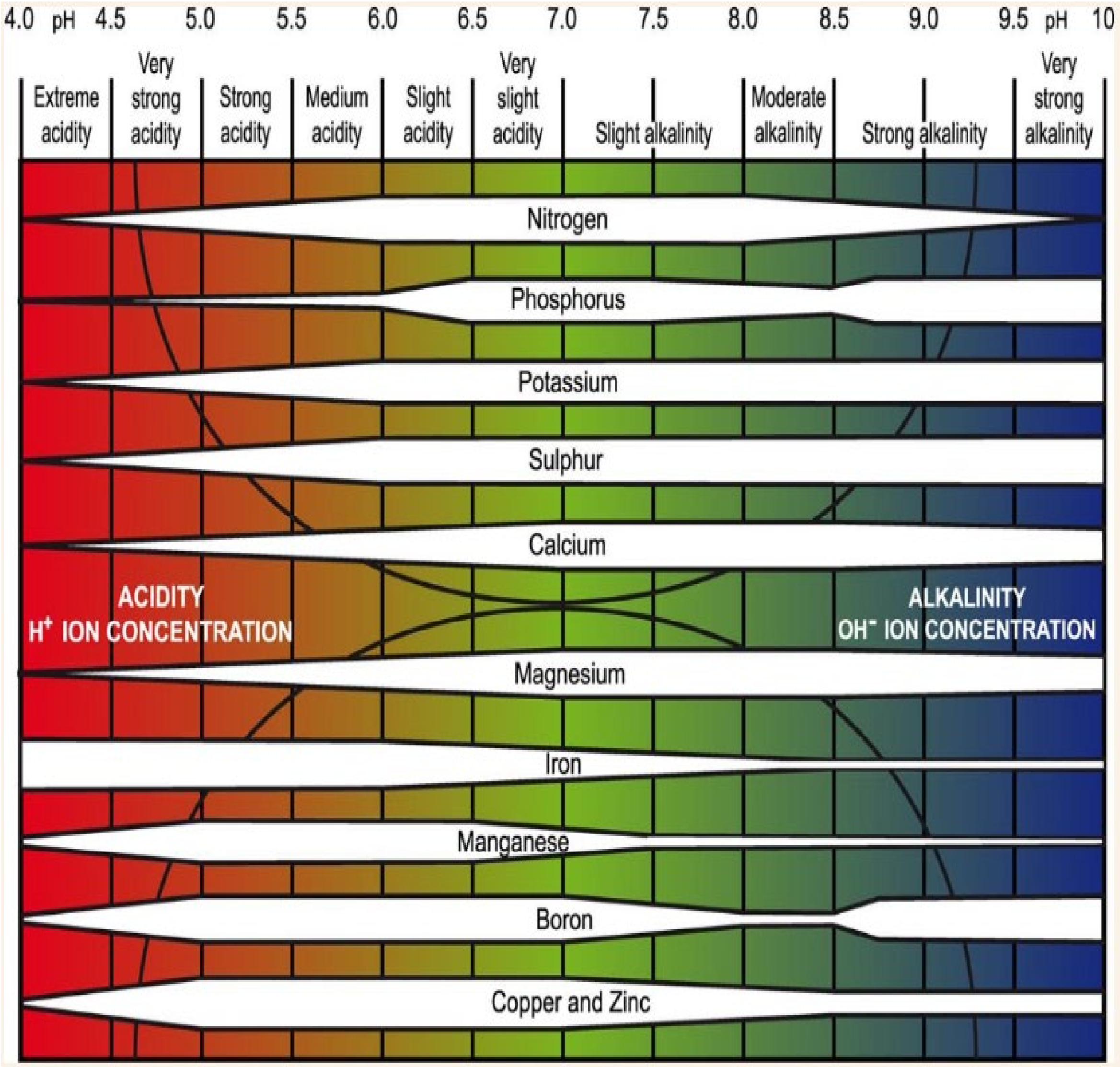


Figure 5. Detailed pH chart explaining nutrient availability for optimal plant growth

Source:(https://www.pda.org.uk/pda_leaflets/24-soil-analysis-key-to-nutrient-management-plan)

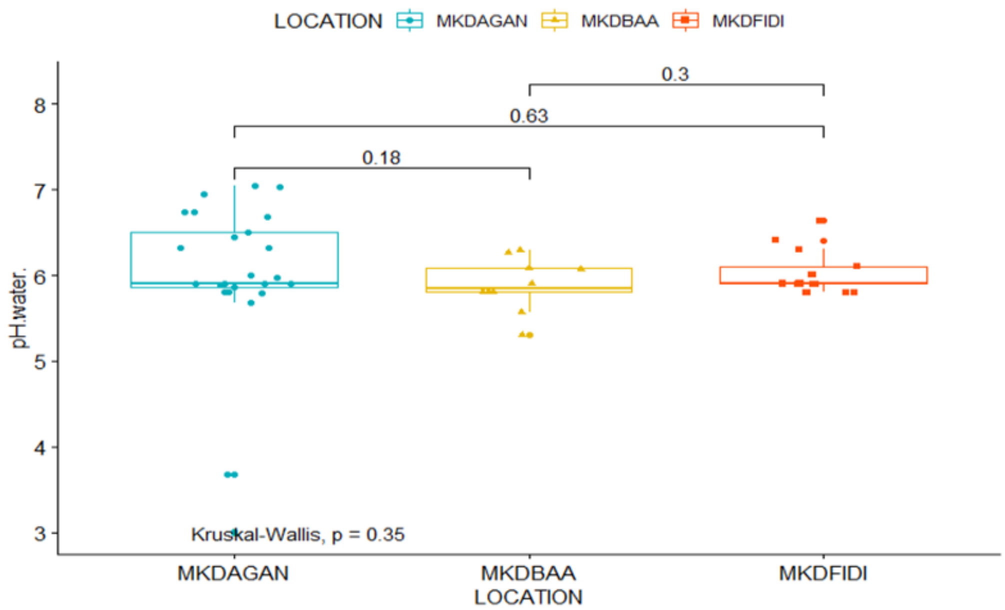


Figure 6. Comparison of Mean pH values across wards within an LGA.

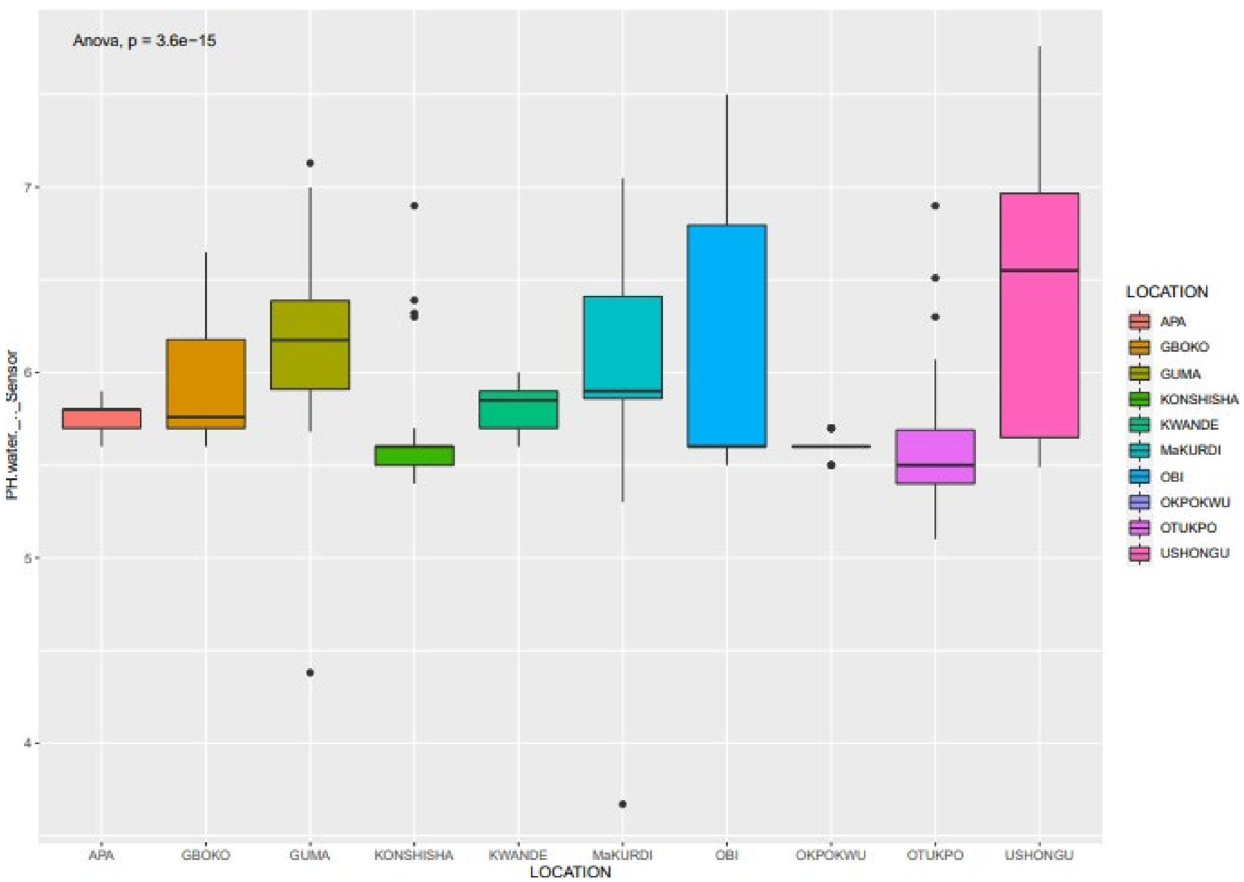


Figure 7. Distribution of PH across the various LGA studied in Benue State.

Cation Exchange Capacity (CEC)

The CEC indicates the ability of the soil to hold onto as well as exchange cations such as Ca2+. Mg2+, K+ Na+, Al3+ and other micronutrients. For this study, mean CEC values differed significantly (p>.005). Generally, the CEC in the small holder farmers' fields were very low to high. A CEC value above 10 cmol (+) kg-1 is preferred for plant growth (Shehu et al. 2016). The values obtained from the fields ranged between 1 cmol (+) kg-1 and 16.3 cmol (+) kg-1 with a mean of 9.36 cmol (+) kg-1. 76.9% of the farms had CEC lower than the preferred value of 10 cmol (+) kg-1, while 23% of farms are rated as having high CEC values. Similar ECEC content has been reported in most studies conducted in the area (Austin, 2007). The obtained low ECEC could be due to the predominance of sesquioxides and kaolinite clays (Najera *et al.* 2015), over 2:1 clay mineral in the soil.

Organic Carbon

Soil organic matter (SOM) primarily consists of organic carbon, which is commonly used to assess soil fertility. Our study revealed that the SOM content among the sampled smallholder farmers' fields in Benue State is lower than the critical value of 2–5% required level for healthy functioning of soil (Figure 8). Minimum and maximum values across the farms ranged from 0.26 to 2.96%, with a mean of 1.13%. Over 44% of the study sites had soil organic matter content lower than the mean value. 33.8 % had a SOM content greater than 2% with a larger area (66%) having SOM content less than the critical value, suggesting that land management factors may be responsible for the SOM content on the farms. SOM is an essential component of soil, contributing to soil biological, chemical, and physical properties. SOM exists in three pools in the soil, with each pool affecting the amount and rate of SOM decomposition and nutrient mineralization (Figure 9). In addition to nutrient storage, SOM aids nutrient availability by the increasing the soils' CEC, providing chelates, and increasing the solubility of certain nutrients in the soil.(FAO Soils Bulletin, 2005).

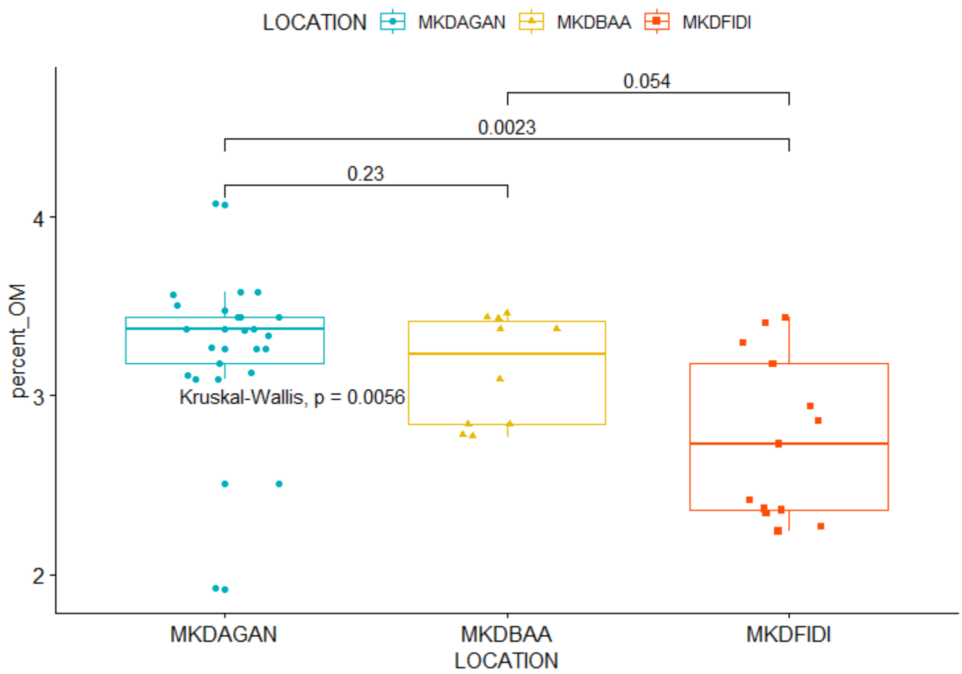
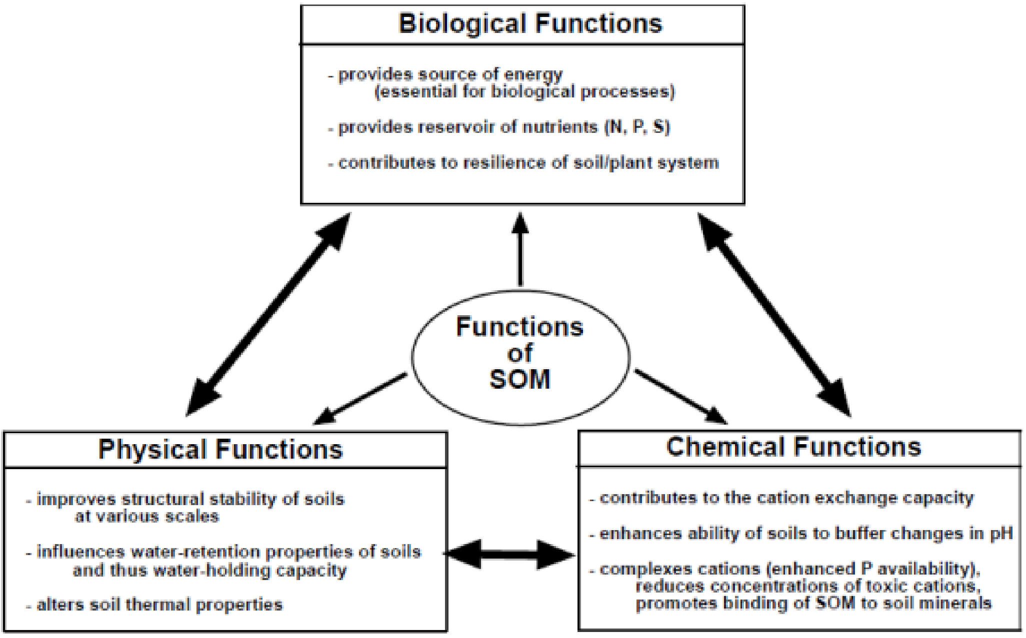


Figure 8. Distribution of Soil Organic Matter (SOM) across three wards in Makurdi LGA.



(Source: Google-SU LMS)

Figure 9. Interconnect of Soil Organic Matter to Key Physical, Chemical and Biological Functions in soil.

Nitrogen (N) Phosphorus (P) and Potassium (K)

Total percent Nitrogen (N) content of the soils at the surface for all the locations ranged from 0.0% to 0.39% with a mean of 0.12% (Table 1). The nitrogen content varied as can be seen with the CV of 0.61 which is higher than the mean value of 0.12. Using a critical level of 0.15% (Chester and Cory, 1964), over 70% of the soils had low nitrogen content with 30% above the critical value needed for optimal growth of maize. The N content level across the local government areas in the state can be seen in the map below (Figure 10) and varied significantly ($p < 0.05$) within farm fields, across depth in the profile and within/ across wards and LGAs.

Available phosphorus for all the locations ranged from 0 mg/ kg to 6.mg/kg (Table 1). Thus, indicating low content of phosphorus when compared to established critical value of 15 mg/kg (Snapp, 1998). All the soils were low in Available P indicating generally deficiency. The highest P content of 6 mg/kg and 4mg/kg was recorded at Okpokwu and Apa LGA respectively. Variability of extractable P has been reported supporting efforts to evaluate blanket fertilizer recommendations.

Exchangeable Potassium (K) for all the locations ranged from 0 mg/kg to 3.0 mg/kg. The exchangeable K content of the area was low. Over 80% of the soils had K content less than the critical value of 0.2 cmol/kg or 78 mg/kg (Snapp, 1998). Only 12.5% of the soils were sufficient in K content. Potassium rivals Nitrogen as the nutrient absorbed in greatest amounts by plants. Like nitrogen, crops take up a relatively large proportion of plant-available potassium each growing season. Plants deficient in potassium are unable to utilize Nitrogen and water efficiently. The observed low nutrient contents suggest that major interventions and agronomic recommendations should focus on optimizing the availability of major nutrients, with careful focus on maintaining pH balance.

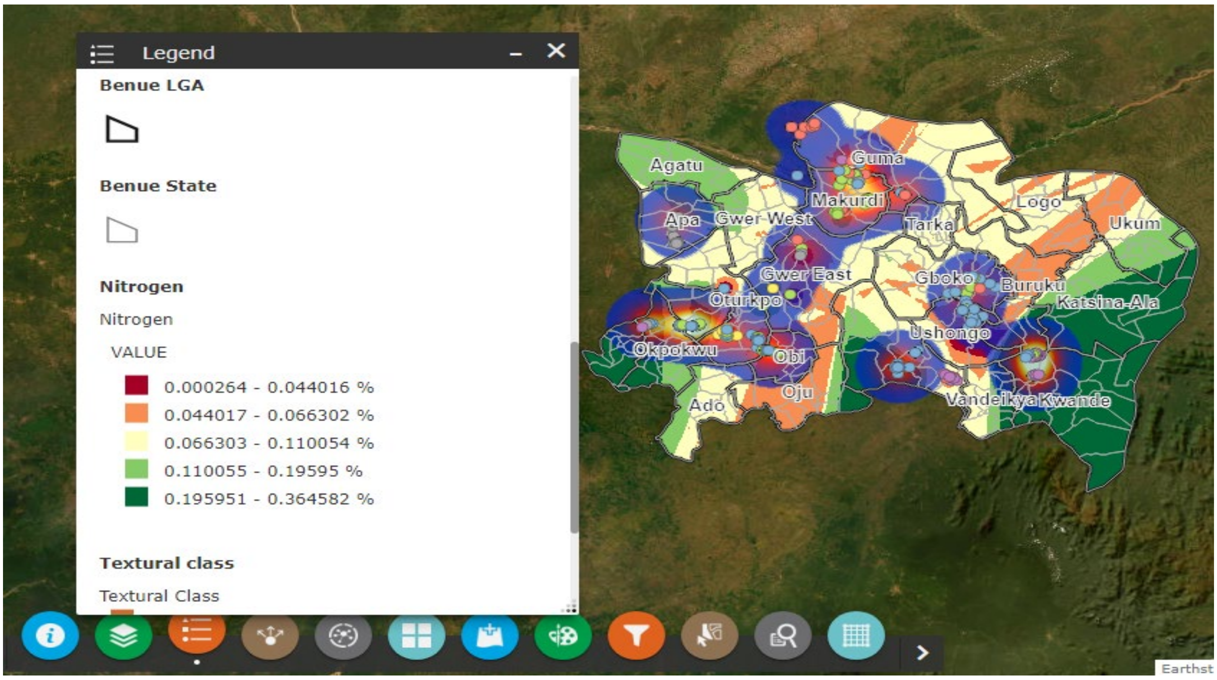


Figure 10. Map showing distribution of Nitrogen (%) in Benue State with points where soils were sampled.

3.0 PRODUCTIVITY OF SOILS

Generally, the overall productivity of the soils on a scale of 1-10 is low. Over 90% of the soils from the farmers' fields had PI values less than 0.5 while only one (1%) had values greater than the mid-scale value of 0.5. The productivity index takes into account biophysical properties as well as chemical fertility. It provides a road map for soil management. The variation in values were significant across the locations (Figure 11). Although still very low, the following LGAs Apa, Guma, Kwande, Makurdi, Obi Okpokwu and Oturpko had their productivity values greater than the mean of value 0.13 while Gboko and Ushongu LGA had PI values less than the mean. Large variability was also observed across and within wards in the various LGAs. The productivity index rating is an algorithm based on the assumption that crop yield is a function of root growth which is controlled by the soil environment including rooting depth. Thus, soil suitability for plant growth was a sum of the characteristics of each layer (Gantzer and McCarty, 1987). Soil Productivity index ratings are on a scale of 0 -1 with one being productive soils.

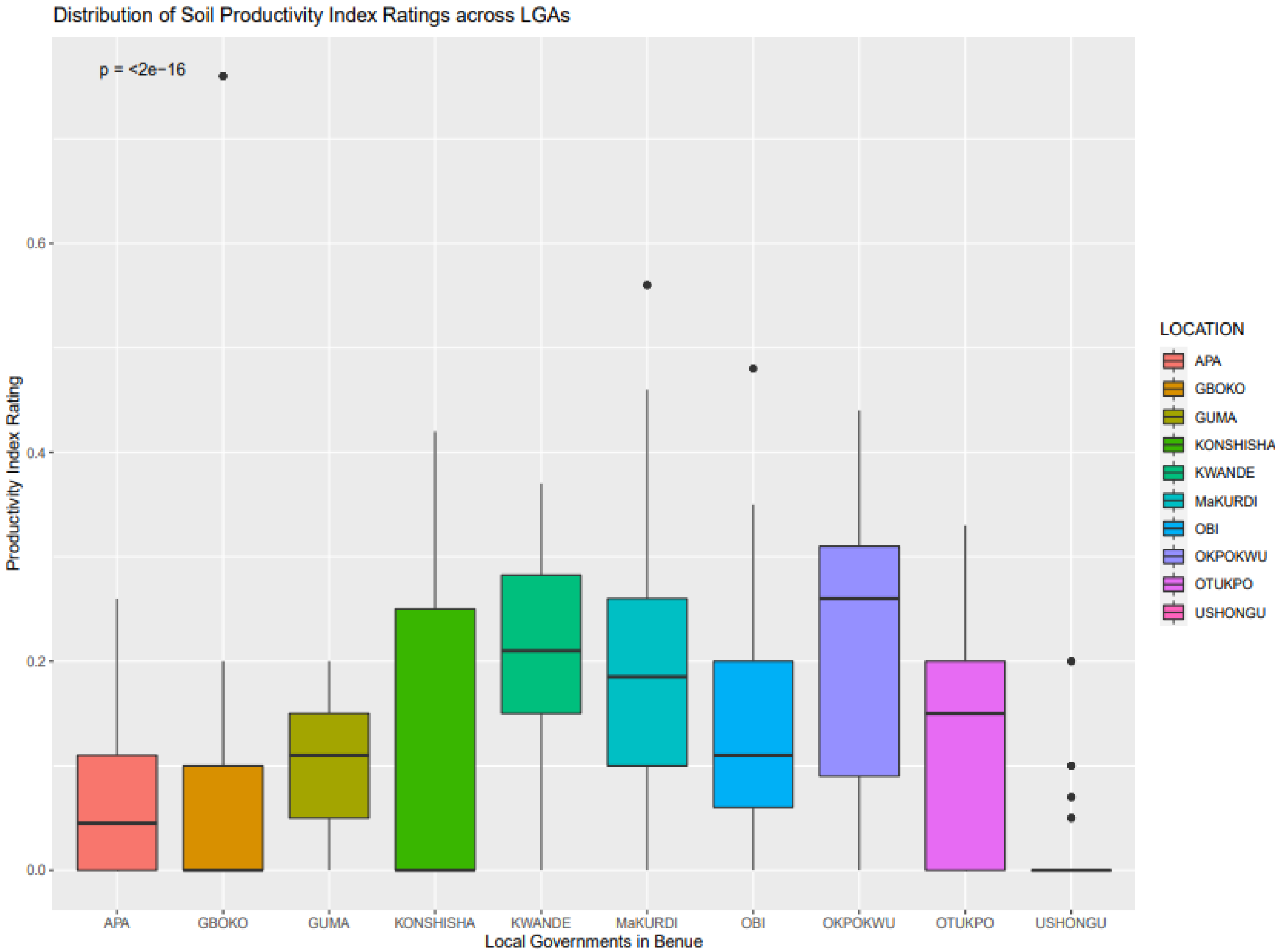


Figure 11. Distribution of Soil Productivity of the study areas

4.0. REPORTS FROM THE STRUCTURED SURVEY

4.1. Farmers' perceptions from structure survey tool and on the LandPKS mobile application

They farmers were asked how easy they found the use of the LandPKS application. 80 percent of the farmers confirmed that LandPKS mobile application was easy to use, given the pictorial prompts and detailed guiding documentation in simple language (Figure 12). They were also asked if they had received prior advice on how to manage their soil to which a great majority replied in the negative (Figure 13). This has implications on how well farmers were informed by government extension workers about soil management practices for improved production sustainably and in mitigating climate change issues. As a follow up question, the farmers were asked the distance of their homestead from an advisory services station of a government extension worker and (Figure 14) depicts responses obtained. The LandPKS mobile application would bridge this gap as information on climate, soil texture, color, topography, AWC and OM, can be accessed with the click of a button and records kept for each farmer to inform better management decisions.

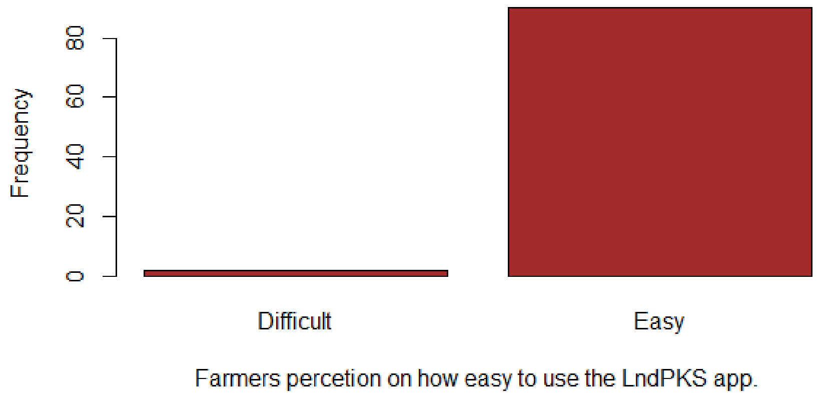


Figure 12. Farmers' perception on using the LandPKS mobile application

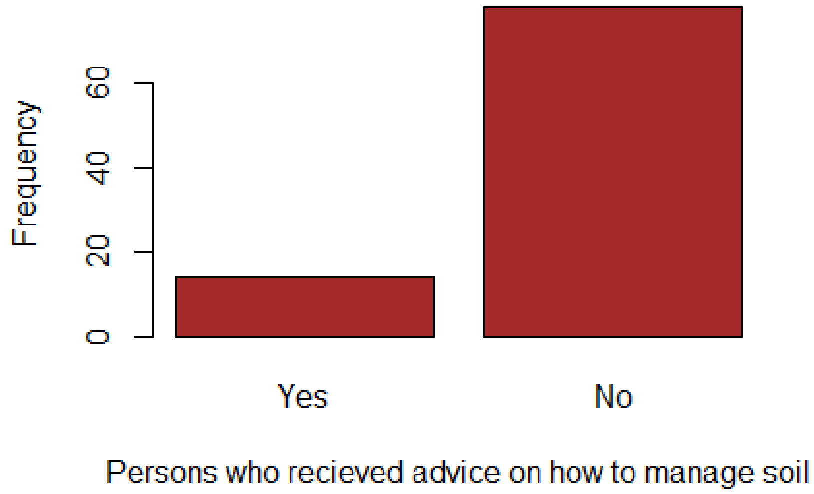


Figure 13. Number of farmers who received any advice on how best to manage their soils

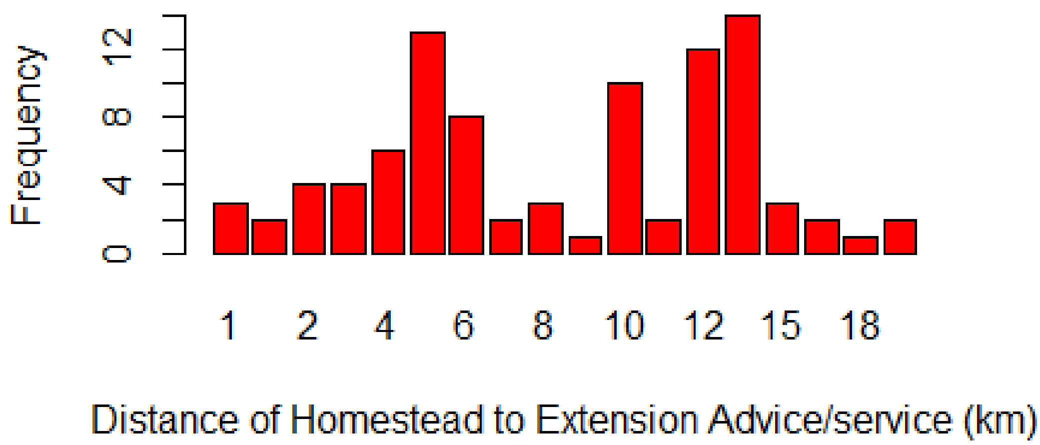


Figure 14. Distribution of Farmers' Access to Information from Extension Workers

4.2. Soil conservation Practices and Indigenous Knowledge.

A majority of the farmers indulged in one form of conservation practice at their level of understanding (Figure 15). It was in the order slash and burn agriculture>crop residue incorporation in soil> crop rotation> mulching>animal waste. Slash and burn can be beneficial if practiced correctly as nutrients can be supplied. These practices were in conjunction with inorganic fertilizer use (Kleinman *et al.*, 1995). Farmers expressed concerns about transportation of inorganic fertilizer and organic animal waste to their farms as the cost of their transportation to the farmlands, by motorbikes was high.

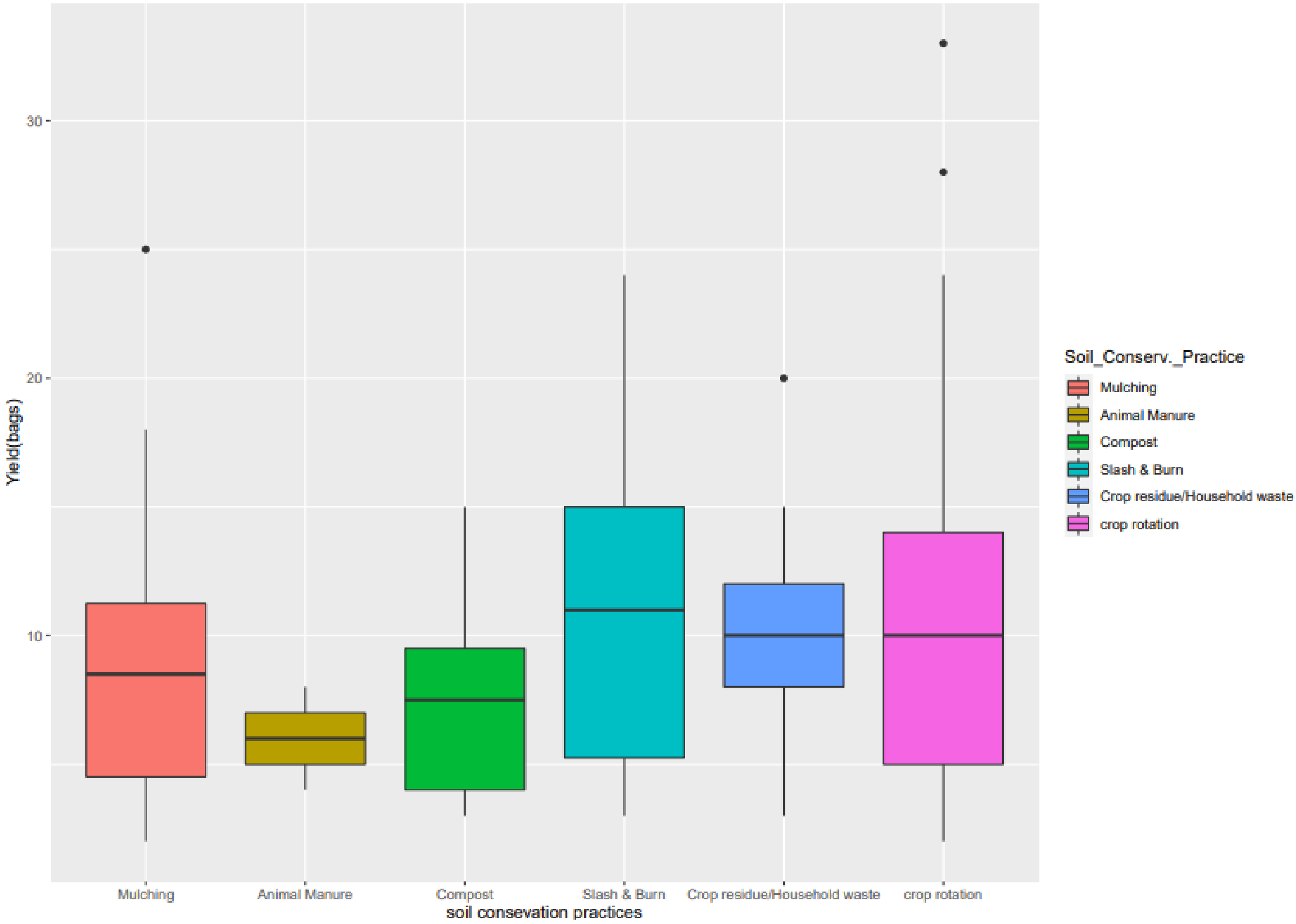


Figure 15. Comparing Some Conservation Practices to Yield (Bags)

5.0. FERTILIZER APPLICATION

The findings of improper use of fertilizers, low use of soil management practices and soil nutrients values being lower than the critical value for maize production explain the low yields recorded by farmers in these areas. With the use of hybrid maize varieties which are heavily nutrient dependent proper fertility regime is key. The fertilizer recommendations for the area's ecology- Southern Guinea Savannah Agro- climatic zone for maize cultivation (Chude *et al.*, 2012), is:

120kg/ha, 60kg/ha of P_2O_5 and 60kg/ha K_2O

Therefore, if we are using compound fertilizer e.g., NPK 15:15:15 packaged usually in a 50kg bag, the nutrient/ha will be:

5.1 Formula

$$\text{Amount of fertilizer per/ha} = \frac{\text{Recommended grade of nutrient}}{\text{Percentage of Nutrient}}$$

N = 50kg x 0.15 =7.5 kg/ha

P_2O_5 =50kg x 0.15=7.5 kg/ha

K_2O = 50kg x 0.15 = 7.5 kg/ha

Thus, to satisfy the nutrient need based on soil test and recommendations:

From a complete fertilizer (N: 15: 15: 15) and a straight fertilizer (urea)

$$\frac{60kg/ha}{0.15} = 400kg/ha$$ or **8bags**

i.e.

0.15x 400=60kg/N

0.15x 400=60kg/p

0.15x 400=60kg/K

Deducting these from the recommendation below:

120kg/ha,	60kg/ha of P_2O_5 and	60kg/ha K_2O
Minus 60	**60kg/ha**	**60**
60	**0**	**0**

Both phosphorus and Potassium needs are satisfied. To satisfy for Nitrogen, we use urea.

For Urea (46%N) to argument the Nitrogen still deficient at 60Nkg/ha

$$\frac{60}{0.46} = 130.4kg/ha$$ **or** 2.5 bags

5.1. Plant Population, Timing and Spacing

Timing is a key component of the 4R Nutrient regime as well as the rate to apply per stand. Thus, with a seed rate of 25kg/ha and a spacing of 75 cm x 25 cm we obtain a plant population of about 55,000 plants stand / ha. Application is best in split doses. 100 kg/ha of the 200 kg/ha of NPK 15:15:15 to be applied as basal treatment (1st dose 3WAP) While **7.2g** of the 100kg/ha NPK 15:15:15 be applied per /plant as top dressing mixed with the urea (2nd dose 6WAP). For urea, 2.4g of the 130kg/ha will be applied per/ plant stand.

5.2. Understanding and Addition of Organic Amendments as Associated Practices

Soil nutrient supply is determined by soil texture, soil organic matter and management practices. As mentioned earlier, soil texture cannot be changed, but implementing good management practices can increase soil organic matter (Monroe and Snapp, 2011). The nutrient supply from organic amendments is primarily provided by one component of SOM, the **active organic matter pool.** The drive for healthy soils is a push for one health (Figure16) (FAO Global Soil Partnership). Table 2 highlights some amendments that can be used to improve soil organic matter content as well as supply other nutrients rapidly or long term. Understanding these dynamics is important while combining SOM with inorganic fertilizers and knowing which kind of organic amendment to use for what.

Source: FAO Global Soil Partnership (fao.org)

Figure 16. Soil Health as a Precursor of One Health

Table 2. Organic Amendments that are Slow to Release Nutrients but are Effective at Building SOM.

Source	Management System Used	Carbon/ Nitrogen Content
Cattle Manure	Forage fed/ bedding	High carbon; builds SOM
Cattle and Swine	Grain fed	Low carbon; supplies nutrients. Could burn young seedlings.
Poultry manure	Bedding material (sawdust)	Medium to high carbon; builds active SOM and supplies nutrients
Compost	Straw/leaf	Stable; Medium to high carbon; builds active and stable SOM.
Cereal cover crops (Mature)	Stalk	Medium carbon; 1 – 2% Nitrogen; builds active and stable SOM; ties up nutrients for long periods.
Legumes cover crop	Straw	Medium carbon; Nitrogen 2.5 -4.5%; Builds SOM; rapidly release nutrients and supports microbial growth.

Source: Morrone and Snapp, 2011.

5.3 Recommendations

1. Proven and already tested compound NPK 15:15:15, 20:10:10; 27:13:13, di-ammonium phosphate (DAP) and straight fertilizers urea, MOP, be regulated, purchased and made available on time for farmers to aid production.
2. Only the recommended dose: 8 bags of compound fertilizer (NPK 15:15:15) and 2.5 bags of urea should be followed.
3. Mulching and use of organic amendments in conjunction with inorganic fertilizers is needed for crop growth and to improve soil properties given high intensity rains.
4. Capacity building of extension workers and farmers in the following areas: timing of fertilizer application, types of fertilizer best suitable for crops, GAPs and the '**double - up** technology to build soil organic matter content to help improve water infiltration and root penetration.
5. A quarter of a hectare can be carved out as a demonstration plot with lead farmers so as to learn and adopt these new technologies. It would also prevent farmers from acting in isolation.
6. Drive for incorporation of residue to build soil organic matter. Residues from groundnut and soya-bean would build soil health as well as supply nutrients.
7. Building capacity of extension workers and farmers to know the size of their farmlands so that accurate rates of recommendations for inputs (seeds, fertilizers, herbicides) are met and followed as all calibrations are based on mass/area. This also aids accurate documentation of output.

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APPENDIX

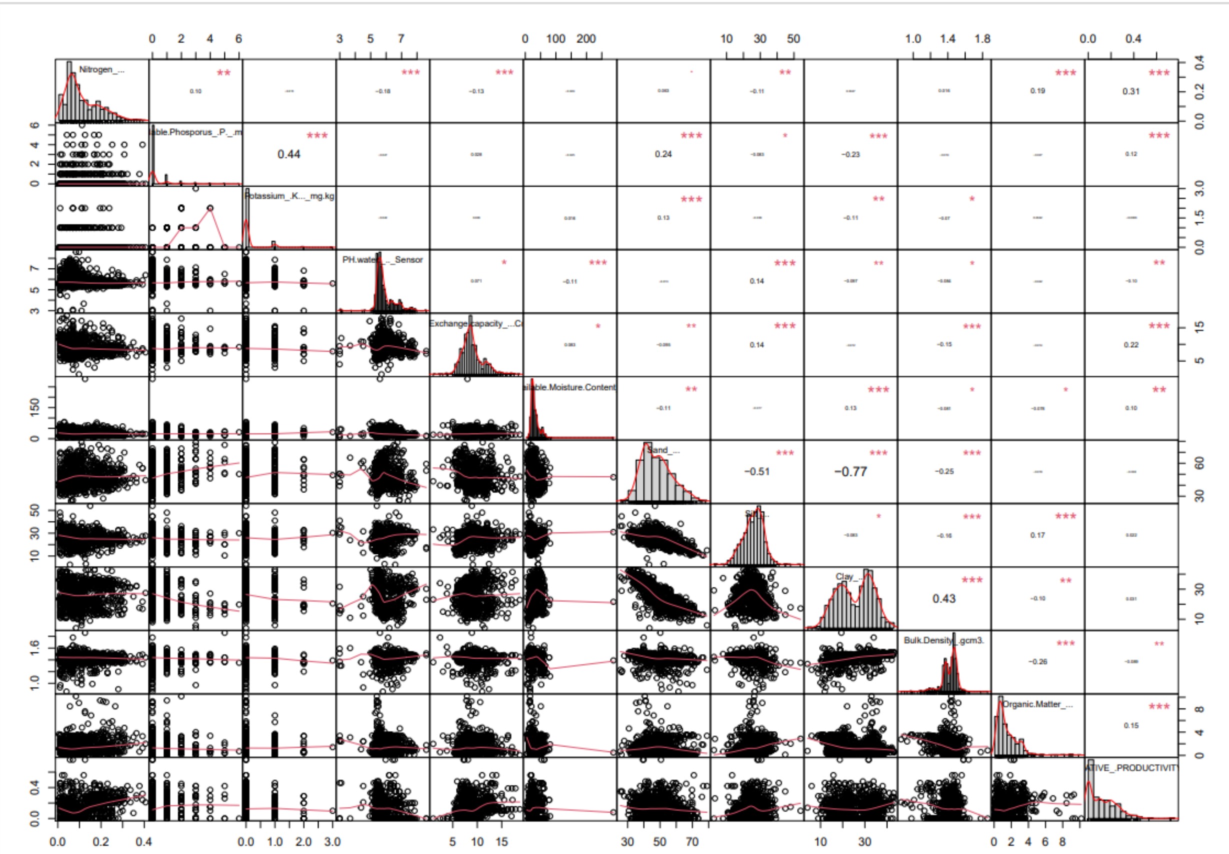

Figure 17. Person correlation among variables with significance differences

Figure 18. Contribution to variability by Soil Properties as Extracted Factors using Principal Component Analysis Matrix