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# Soil Nutrient Status of Smallholder Farmers in Makurdi, Benue State, Nigeria


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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*


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## ABSTRACT


Soil nutrient depletion is a major threat to food security globally. The fertility status of soil forms the foundation of crop production in many small holder farm fields as nutrient element additions as inorganic, synthetic or organic fertilizers are low. Soils from small holder farmer fields were sampled individually with three (3) samples per the farmers field by three (3) depths of 0-30cm, 30-60 cm and 60-90cm with a population of thirty (30) farmers per council ward by three (3 )council wards only in ten (10) local government area (LGAs)) of Benue state. This paper reports for one (1) local government area - Makurdi, and one (1) depth, the topsoil (0-30cm). The study was to ascertain their nutrient status in three states in Nigeria with the creation of the first- ever digitalized and interactive nutrient elements and soil productivity index maps. We report findings for the soil



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nutrient status of the topsoils for Benue State as a digitalized map see link https://rb.gy/yfnz2m with focus on Makurdi local government area (LGA). The soil samples collected were geo-referenced and analyzed both *insitu* and in the laboratory following recommended standards for each nutrient element to define the soil nutrient status and critical limit for maize production. Generally, soils were sandy loam at the surface (0-30cm) while it was sandy clay loam at lower depths of 60cm and 90cm. The soils had moderate acidity with low to moderate levels of nutrients. The low nutrient status of the soil key nutrients of Nitrogen, phosphorus and potassium, underscores the need for improved soil management practices. These findings, supports a transition from current country wide fertilizer recommendation to site -specific nutrient management. New findings reported here are location specific and will aid in the curbing of greenhouse gases emissions for a healthier planet as well as increased productivity.

*Keywords: Soil nutrient status; first ever digitalized and interactive maps; food security; greenhouse gases; critical limit.*

## 1. INTRODUCTION

Cultivated soils on smallholder farms, are subjected to management practices that varies at a fine scale of ten to fifty meters [1]. Soil tillage, organic and inorganic nutrient amendments, diversity of plant species are grown, and these are expected to influence edaphic processes and thus spatial patterns of many soil characteristics within and across fields [2]. Also, farmer fields are general dispersed widely across a landscape with marked and varying management practices carried out. We do acknowledge climatic context too, as it affects agricultural performance being influenced by soil properties in dynamic interaction with precipitation patterns and temperature [1]. Soils in the tropics (including those in Sub Saharan Africa- SSA) are characterized by high spatial variability at both macro and or micro-scales due to the combined effects of inherent bio-physical and chemical processes and extrinsic factors such as crop management, fertilizer and tillage, among others. These factors are usually operating at different intensities and on different spatiotemporal scales[3-7]. These variability in soils and the corresponding variability of yield responses of various crops to nutrient application have already been reported across SSA [8-10]. Therefore, national uniform fertilizer recommendation and application might result in over application in certain farm-fields, or on soils with high nutrient status and under application in those with low nutrient status which needs more nutrients. Several literatures in SSA [11-14] have reported the need for nutrient management and fertilizer recommendation strategies to be tailored towards field-, site-, or soil-specific conditions to achieve balanced and effective fertilizer use and close nutrients related yield gaps. Matching the right fertilizer with the right recommendation/dose is therefore regarded as critical to optimize and sustain crop yields and preserve the environment [15-18].

Soil productivity in Africa is declining as a result of soil erosion, continuous cropping, nutrient and organic matter depletion [19]. In sub-Saharan Africa, soil fertility depletion is the fundamental cause for declining per capital food production as crop lands have a negative nutrient balance, with annual losses ranging from 1.5 - 7.1t $ha^{-1}$ of nitrogen (N), phosphorus (P) and potassium (K) mainly due to crop harvest, leaching and low inputs applied to the soil [20] and [21]. Research findings, have revealed that prolonged intensive cultivation and fertilization resulted in the depletion of plant nutrients. Deforestation and cultivation of virgin tropical soils often lead to depletion of N, P, sulfur (S) and other plant nutrients [22-24]. With all these losses SHFs in SSA while preparing for the next circle of production, rarely factor the need to test their soils. The high cost of soil testing services and awareness are some of the reasons given. 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 SHFs field[25-27]. Therefore, the objective of this study was to; i) characterize soil nutrient status and key soil physical properties in Makurdi. ii) Generate digital and interactive maps of the soil nutrient status and soil productivity index rating.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was carried out in Makurdi local government area of Benue State. It lies on

Latitude 7.7322° N and Longitude 8.5391° E. Makurdi has two distinct seasons, namely wet season and dry season. The wet season starts in April and lasts till October; while the dry season starts in November and lasts till March. Rainfall ranges from 775mm to 1792mm, with a mean annual value of 1190mm. It is characterized by a mixture of tall grasses and trees of average height. Most of the trees are deciduous and shed their leaves during dry season. Dominant soil types in the area are Entisols, Inceptisols, Alfisols, Ultisols (Soil Explorer mobile app).

## 2.2 Soil Sampling

First, a purposeful selection of 10 small holder farmers and their fields in maize-based systems from three (3) council wards each in 10 Local government areas (LGAs) was carried out in Benue State. Soil samples were collected at three (3) depths of 0-30 cm, 30-60cm and 60-90cm at three points within a farm field (except for instances where soils were shallow due to a hardpan). The land Potential Knowledge system (Land*PKS)* mobile application was used to acquire geo-coordinates and to take field observations, soil management practices and farm history as well as precipitation data. Also, some soil parameters (Nitrogen, Phosphorus, Potassium and pH) were collected ***insitu*** with a sensor device while other parameters were analyzed for in the soil laboratory. These procedures have been documented extensively in a USAID working Research paper 7 (Unpublished). Reports here are for the topsoil of farmers' fields in three council wards of Agan; Baa and Fidi all in Makurdi LGA a leading producer of maize. The metadata and the site - specific soil nutrient characteristics can be downloaded with this link: https://rb.gy/yfnz2m

## 2.3 Laboratory Analysis

The methods described by [28]. were used to analyze each soil sample [22]. The particle-size analysis was performed using the bouyoucous hydrometer method described by Bouyoucous [29] and the texture was determined using the USDA textual triangle. The organic carbon was determined using the Walkely-Black wet-combustion method (CF 1.32), as described by [30]. The total nitrogen, available phosphorus, potassium and pH was read insitu with a sensor machine. Cation exchange capacity was determined by ammonium saturation method as described by [31].

## 2.4 Statistical Analysis

The data obtained was subjected to descriptive analysis (which include mean, median, standard deviation, minimum, maximum, and coefficient of variation (CV)). Principal component analysis was carried out so as to discard correlated or redundant variables. Given that each variable is standardized to obtain a variance of 1 in PCA, only PCs with eigenvalues ≥1 was selected, so that the variability explained by each selected PC is greater than that attributed to individual parameters. The dimension of the selected PCs was used to explain the variability of the extracted soil parameters. Correlation analysis was also performed to understand the relationships among these soil properties. [32] and [33] version 4.2 software was used for the analysis.

# 3. RESULTS AND DISCUSSION

## 3.1 Results

Table 1 presents a summary of the soil properties collected from maize farmers' fields in Benue State. Descriptive statistics for soils properties in the various locations are also presented in (Table 1). Results 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 [34-36]. Where **critical soil test** values used in this study are: Organic matter > 2%; pH > 5.5; Nitrogen > 0.15%; Phosphorus > 8 mg/kg; CEC > 10 cmol/kg; Potassium > 80 mg/kg; Available Moisture content (AMC) >20%: BD 1.4 gcm$^{-3}$; Sand > 65%; Silt >20%; Clay >35%; and Soil Productivity Index rating > 0 .5.

### 3.1.1 Principal component analysis (PCA)

PCA was performed to summarize the variability in the data into principal components (PCs). The number of PCs produced is always equal to the number of variables involved in the analysis. 10 PCs were produced (Figure, 2), out of which the first five (5) that together explained 76.6% of the variation were retained for further analysis based on having an Eigen value ≥1 (Figure, 1). A PC with eigen value ≥1 explains more variance than an individual attribute. The contribution of the PCs is shown as (Figure 2). Principal component one (1) explained 29.7% of the total variance in the data (Figure 1), and is associated with texture and related soil parameters, such as available P, K, Organic matter, pH, CEC, Bulk density, and available moisture (Figure, 2). The additional 16.5% of the variance was explained by PC (2), which seems to be associated with pH and related parameters such as Nitrogen. PC (3) explained another additional 11.6% with cation exchange capacity (CEC) loaded in that dimension. Following the Principal Component Analysis, the soil properties are discussed based on extracted factors and their contributions to variability.

**Table 1. Descriptive statistics for soil characteristics and productivity ranking for 67 samples from small holder fields in Makurdi Benue State**

| Soil Properties | %> Critical Limit | Min | Max | Median | Mean | Std. Dev. | Coef. Var. |
|---|---|---|---|---|---|---|---|
| Nitrogen (%) | 41 | 0.01 | 0.30 | 0.14 | 0.14 | 0.07 | 0.49 |
| Available P. (mg/kg) | 0 | 0 | 4 | 0 | 0.4 | 0.89 | 0.47 |
| Potassium mg/kg) | 0 | 0 | 2 | 0 | 0.23 | 0.47 | 2.06 |
| pH | 93.7 | 3 | 7.05 | 5.9 | 5.98 | 0.68 | 0.11 |
| Soil Moisture (%) | 54 | 4.92 | 69 | 16 | 26.89 | 19.95 | 0.54 |
| BD ($gcm^{-3}$) | 8 | 0.9 | 1.60 | 1.34 | 1.29 | 0.15 | 0.11 |
| CEC (cmol/kg) | 52 | 3 | 16.3 | 10.9 | 10.34 | 2.77 | 0.27 |
| OM (%) | 98 | 1.92 | 4.07 | 3.26 | 3.11 | 0.45 | 0.14 |
| Sand (%) | 35 | 39.2 | 79.0 | 54.55 | 7.25 | 8.16 | 0.14 |
| Silt (%) | 79 | 3.1 | 34.40 | 28.3 | 26.45 | 6.39 | 0.24 |
| Clay (%) | 0 | 6 | 22.7 | 15.95 | 15.23 | 3.79 | 0.25 |
| PI | 0 | 0 | 0.46 | 0.16 | 0.17 | 0.13 | 0.76 |

*Key: Avail. P = available phosphorus (mg/kg); BD = bulk density ($gcm^{-3}$); CEC = Cation exchange capacity (Cmol (+)/kg; OM= organic matter (%); PI = productivity index; Max= maximum; Min = minimum; std. dev. = standard deviation; Coef. Var. = coefficient of variation*

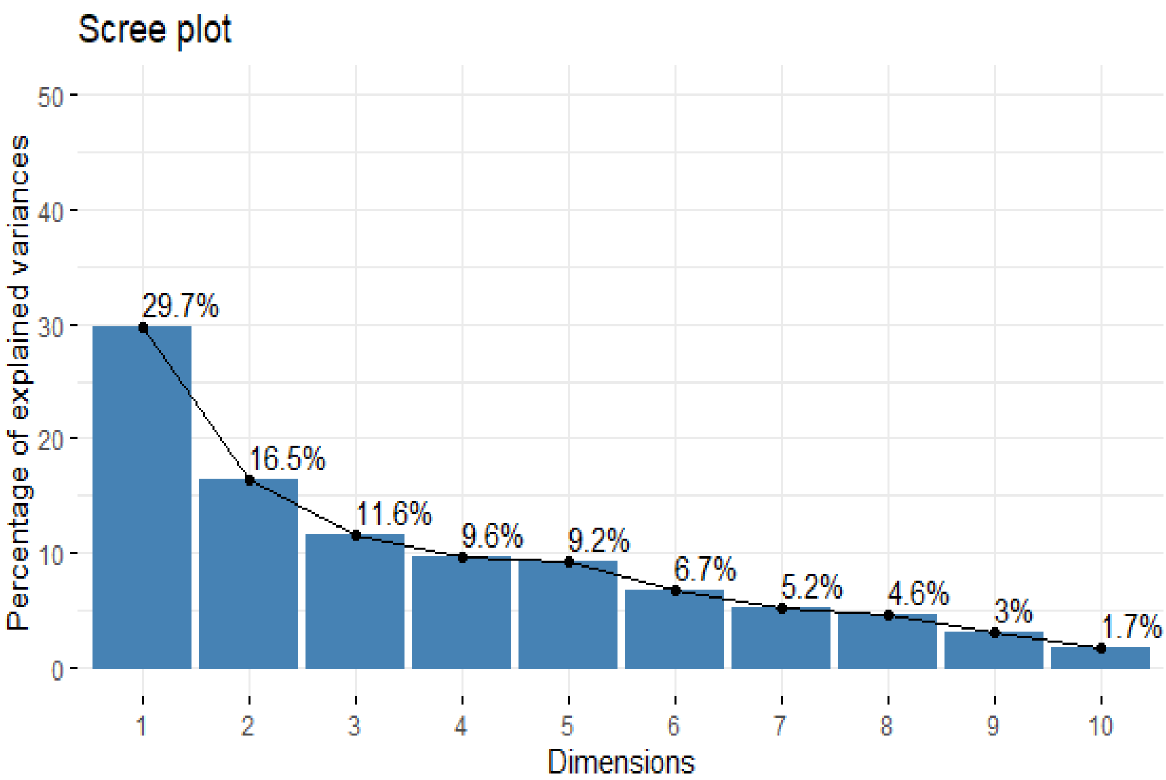


**Fig. 1. Scree plot of the principal components**

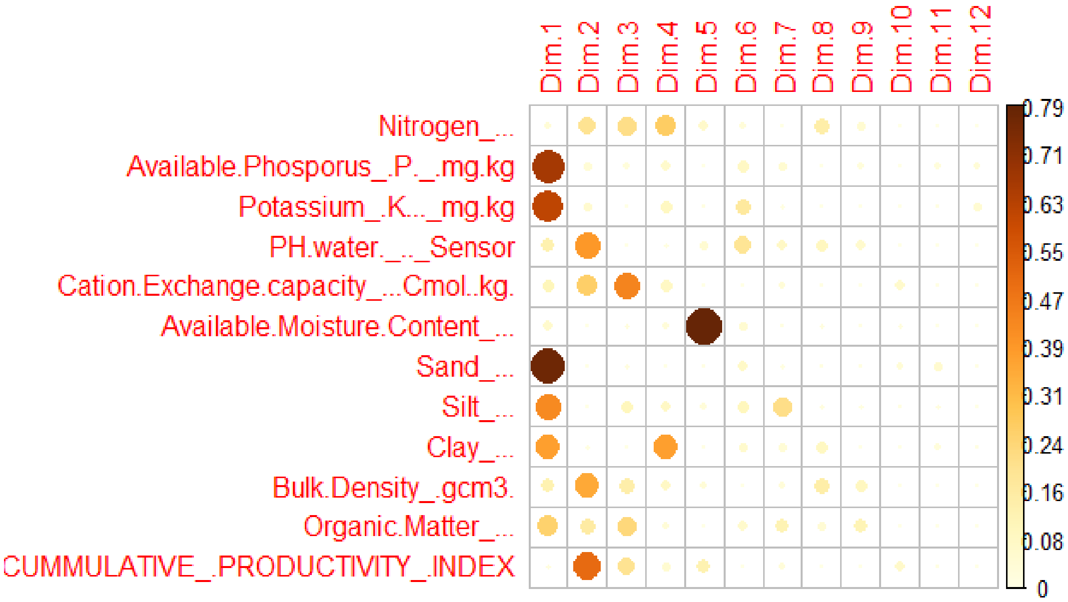


**Fig. 2. Dimensions to which soil properties contributes variability**

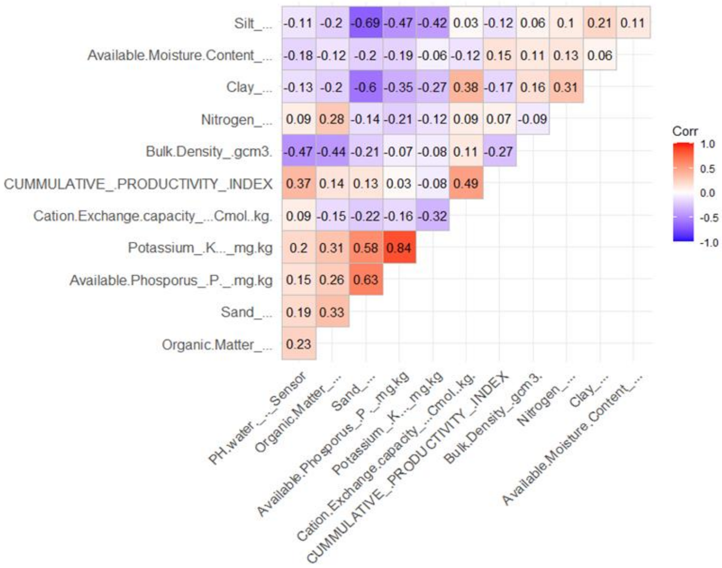


**Fig. 3. Correlation analysis of soil properties**

### 3.1.2 Correlation analysis

We conducted a correlation analysis to see the relationship between different soil chemical, biological and physical properties as well as their relationship to the soil productivity index. We find that a positive correlation exists among nitrogen (N) and potassium (K). There was also, a significant positive correlation between available phosphorus and potassium (P <.001) and between cation exchange capacity (CEC) and bulk density (BD). This reveals the importance of the soil being puddled (loosened) to reduce compaction for cation exchange between the soil particles and the root hairs of the plant as well as enable better flow of water and air (Fig. 3&4). The significant negative correlation between organic matter (OM) and potassium, phosphorus, pH and nitrogen explain the low fertility status of the soils of this area. This may be partly due to crop removal due to continuous cropping of these fields, leaching giving high rainfall amounts and intensity [37]. CEC was positively correlated with bulk density ($P < .001$) (r = .15) and pH (r =

.02). The soil pH in the present study also covaried with and influenced CEC, and available P. This is evidenced by the positive correlation between soil pH and available P (*r* = .15), K (*r* = .20), and CEC (*r* = .08). Similarly, [38] and [39], observed variation in the soil CEC along with soil pH.

### 3.2 Some Soil Physical Properties in Makurdi Local Government Area

The physical properties of soil and their critical values are presented in (Table 1). Textural class was principally sandy loam however, there were substantial variation within and between farms. Over 35% of farm fields had sand content greater than the critical limit. Minimum sand contents were 39.2%. The available water content values ranged from 4.92 – 69 % with a mean of 26.89 %. 54 % of the farmers' field tested had soil available moisture greater than the critical limit of 20%. The bulk density (BD) of the farms were ideal with 8% of soils greater than the critical limit of 1.4gcm$^{-3}$. The soils had minimum BD values of 0.9 gcm$^{3}$ with 1.6gcm$^{-3}$ as its maximum. The coefficient of variability was 0.11%. The BD values were not significantly different statistically (Fig 5) however, we observed from on the field assessment, marked variation across within field, across field and between council wards.

### 3.3 Some Soil Chemical Properties in Makurdi Local Government Area

Soil reaction being a measure of the soil acidity and alkalinity had values ranging from 3 – 7.05 indicating strong acidity to neutral. Mean pH values was found to be 5.9 indicating moderate acidity across farm fields within Makurdi. The pH was not statistically significantly different ($p$ > 0.05) (). Over 93% soils had pH greater than the critical limit of 5.5.

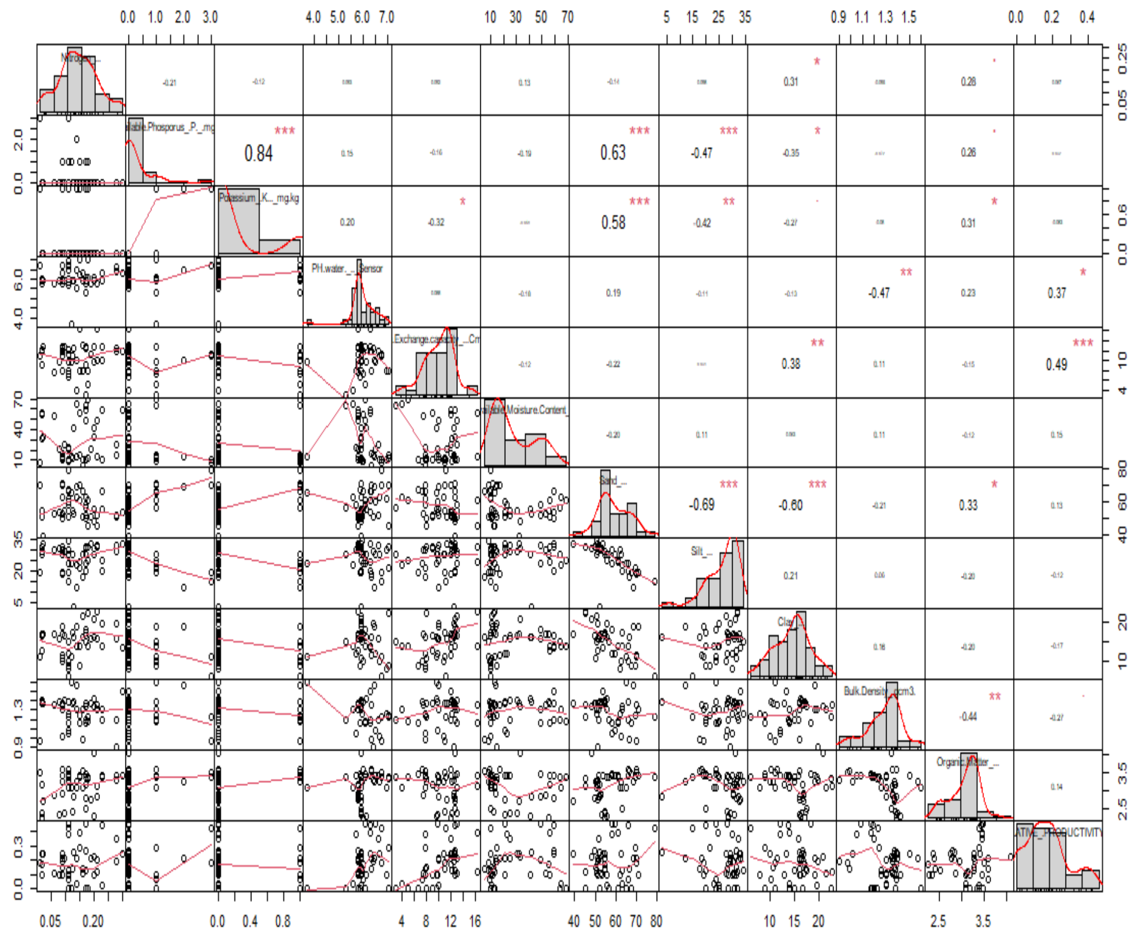


**Fig. 4. Correlation analysis and significant values of Soil properties**

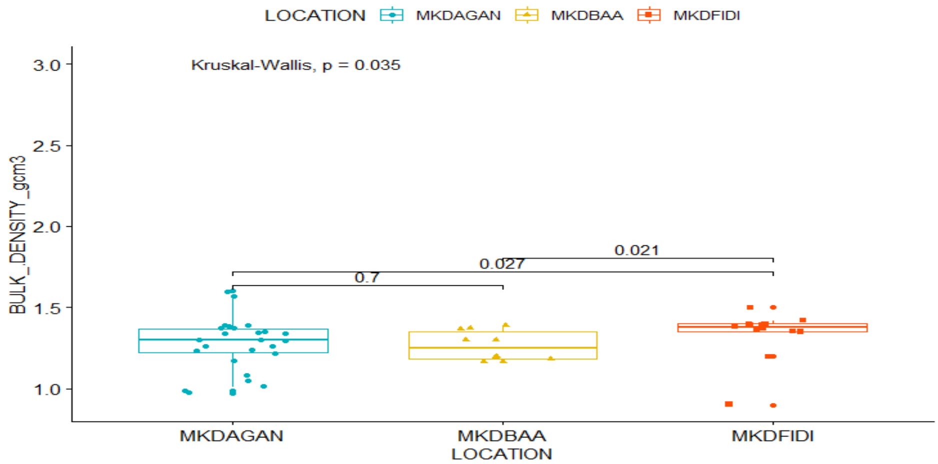


**Fig. 5. Bulk density (gcm³) with significance levels across the wards within Makurdi**

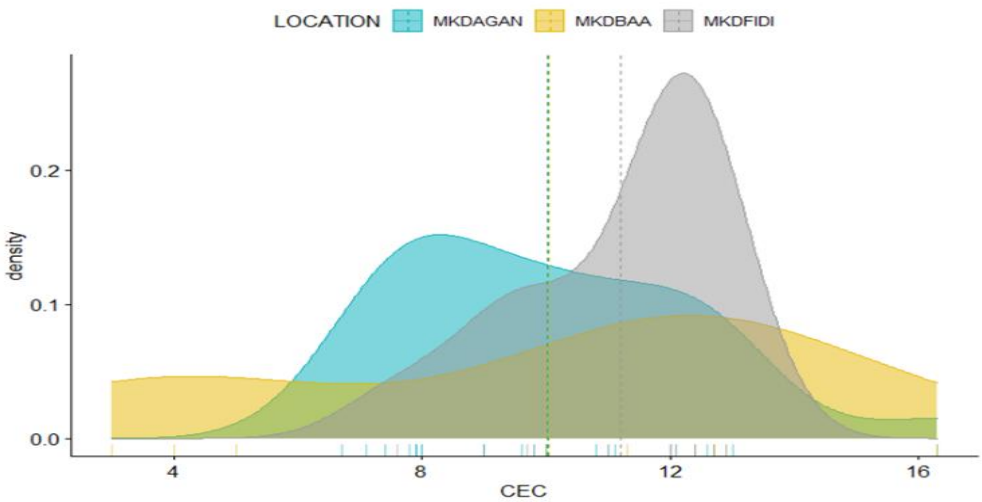


**Fig. 6. Distribution of CEC (cmol/kg) values across the locations in Makurdi LGA**

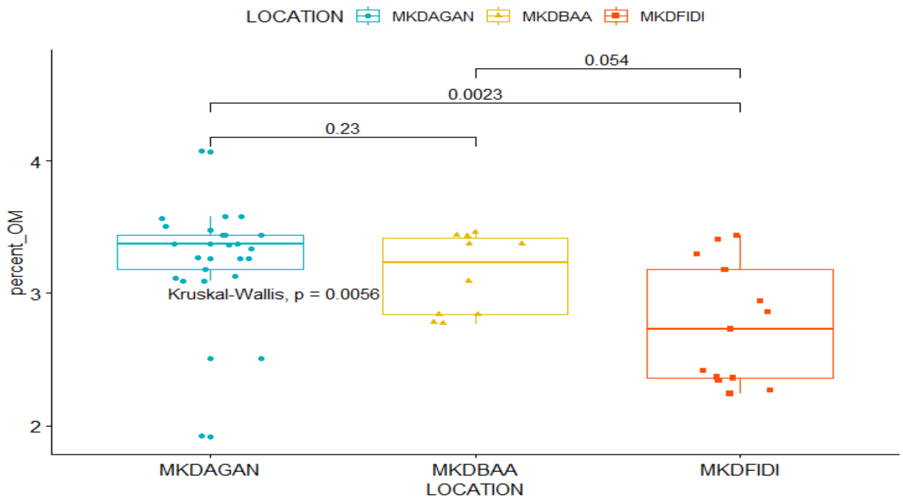


**Fig. 7. Organic matter (%) with significant levels of difference across the locations**

The Cation ion exchange capacity (CEC) for the soils under study ranged from 3 to 16.3 cmol/kg with a mean of 10.34 and a CV of 0.27%. Generally, the CEC varied widely across the field with 52% of the soils in farmers 0fields greater than the critical limit of 10 cmol/kg. The CEC was not statistically significant ($p$ > 0.05) (Fig 6) across the three wards within Makurdi LGA. Similar CEC content has been reported in most studies conducted in the area [12]. The obtained low CEC could be due to the predominance of sesquioxides and kaolinite clays [40], over 2:1 clay mineral in the soil.

The total nitrogen content of the topsoil in the various location ranged from 0.01- 0.30% with a mean of 0.14% and CV of 0.49%. The nitrogen content of these soils was moderately high with 52% greater than the critical limit of 0.15% [21].

The available phosphorus for the various farm fields under study had values in the range of 0 - 4 mg/kg with a mean of 0.4 mg/kg and a CV of 0.47%. The phosphorus content in these savannah soils were low when compared with the critical limit of 17mg/kg for cereal crops. All the soils tested were below the critical limit to support plant growth and development (Table 1).

For the exchangeable potassium, all the soils had values below the critical limit of 80 mg/kg. The potassium content across the locations ranged from 0 – 2 mg/kg with a mean value of 0.23 mg/kg and CV of 2.06 %. This showed that the soils were deficient in potassium.

The percentage organic matter values as presented in table 1 showed that the soils in the location under study had values ranging from 1.92 to 4.07 % with mean of 3.11 which was greater than the critical limit of 2%. The soil organic matter varied significantly ($p$ = 0.023) across Agan and Fidi council wards but not between Baa and Agan and between Baa and Fidi wards respectively. However, we observed marked variation between and within farm fields (Fig 7). Soil organic matter (SOM) primarily consists of organic carbon, which is commonly used to assess soil fertility. In addition to nutrient storage, SOM aids nutrient availability by the increasing the soil's CEC, providing chelates, and increasing the solubility of certain nutrients in the soil.

## 4. DISCUSSION

This study reveals that majority of the topsoil of small holder farm fields in Makurdi were sandy loam and was moderately acidic which is suitable for maize production. The slightly acidic soils of are associated with the inefficient and continuous use of nitrogenous fertilizers in the area [41]. However, caution should be taken in areas of Agan council ward that had low pH, it may require liming before fertilizer application. The soils had nitrogen, CEC and organic matter well above critical limits of these soil properties. Widely deficient phosphorus and potassium across the farms of these smallholder farmers in contrast to nitrogen availability. This indicates P and K deficient soils. Soil moisture was adequate in over 50% of the farm fields. This has implication on water retention, infiltration and run-off.

## 5. CONCLUSION

Site-specific nutrient management needs to be encouraged as blanket fertilizer recommendations are not improving efficient nutrient management and increasing yields for this smallholder farming system. Consequently, fertilizer recommendations cannot be generalized to the study area. Inorganic fertilizers high in phosphorus and potassium is needed to supplement organic amendments.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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