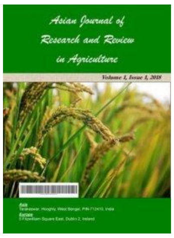

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Spatial Variability and Fertility Mapping for Site-Specific Management of a Smallholder Farm in Minna, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author BAL designed the study, managed the literature searches, transformed the digital data into maps and prepared the manuscript. Author MKAA helped in the design and editing of the manuscript. Author PAT performed the statistical analysis, while authors TM and AAP supervised field and laboratory exercises. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Farmers' practice of blanket application of fertilizers negates the inherent variation of nutrients in the soil. This work assessed and mapped the spatial variability of some soil properties in a smallholder maize farm in Minna, north-central Nigeria, for site-specific soil nutrients management. The study was conducted on a 1.13 ha farm. The farm was divided into 9 subplots of 35 m x 35 m dimension. In each subplot, geo-referenced soil sample was collected at 0-20 cm depth for purpose of interpolation and mapping. The samples were analysed in the laboratory for particle size distribution, soil reaction (pH), soil organic carbon (SOC), total nitrogen (N), available phosphorus (P) and potassium (K). Data from laboratory analysis was subjected to descriptive statistics to describe the spatial variability of the nutrients in the soil. Mapping of spatial distribution of the measured parameters was based on point krigging interpolation techniques using Surfer 11 GIS software. Texture of the soils varied from sandy loam to sandy clay loam. Soil reaction was slightly acid to neutral. Nitrogen was high in all the soil, while K ranged from high to low. Phosphorus was low in all the soils. Soil organic carbon (CV = 51.17%), N (CV = 36.11%) and K (CV = 47.62%) all had a high spatial variability, while silt (CV = 27.72%) and P (CV = 27.50%) had moderate spatial. Spatial variability was low in land configuration (CV = 9.37%), sand (CV = 5.18%), clay (CV = 13.66%) and pH (CV = 1.64%). Micro-relief had non-significant (P = .05) effect on distribution of soil separates. Mapping could be helpful in partitioning of the farm into relatively uniform units to allow site-specific management of SOC, N and K with high spatial variability.

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Keywords: Site-specific management; soil quality; spatial variability; GIS-based mapping; smallholder farm.

1. INTRODUCTION

Besides natural pedogenic processes, land use related activities such as tillage and other soil management practices such as fertilizer application and cropping systems contribute to spatial variability in soil properties [1]. Such variations have been a great concern to workers, especially as it relates to reduction in field crop growth and yields [2;3]. One major way to manage spatial variability in soil properties is to delineate (map) the farm into relatively uniform bits based on similarities of soil properties to serve as reference in taking rational farm management decisions. The absence of a good soil map is a clear manifestation of insufficient soil information, which leads to inaccurate recommendations for crops and soil management [4].

A survey carried out by Abdulrasak et al*.* [5;6] showed that most smallholder farmers in several agrarian communities of Niger State, north-central Nigeria lack or have little knowledge of spatial variability of soil properties. This category of farmers treats their soils as a homogenous entity in terms of soil fertility management. Such approach to farm management, as reported by Nadagouda [7], disposes some sections of the farmers' fields to differential response to applied inputs such as fertilizer. This could results in either over-application of fertilizer in some parts of the farm or under-application in others. The implication is not limited to differential crop yield, but it also affects the overall operational costs. In this regard, intimate knowledge on spatial distribution of soil properties across fields is essential to allow rational (proportionate) application of agricultural inputs (e.g. fertilizer) and optimizing crop yield [8].

Recent development in science particularly in Geographic Information System (GIS) technology makes mapping of spatial variability of soil properties not only possible, but faster and more accurate [9]. The GIS tools are now effectively used to graphically represent or illustrate the geo-spatial data of soil properties in areas of interest collected in the field or laboratory-generated for management of field crops [10]. In addition to GIS tool, both classical statistics and geostatistics methods have been found to be very useful tools in analysing spatial variability of soil properties across agricultural fields; and in taking rational decisions for efficient implementation of site-specific management systems [1]. Therefore, the objective of this study was to assess and map the spatial variability of some soil quality attributes for precision management of a smallholder farm in Minna, Nigeria.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was conducted on a smallholder farmer's field located at Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State of Nigeria. The site was located on latitude 9º 32' 14.356" N and longitude 6º 27' 53.418" E on elevation of 199-205 m above sea level. The geology of the site is undifferentiated basement complex rocks [11]. The vegetation is southern Guinea savanna zone of Nigeria, characterized with distinct wet and dry seasons. Mean annual rainfall for Minna is 1200 mm with 90 % of the rains usually falls between the months of June and August. Mean daily temperature rarely falls below 22 °C with peaks of 40 °C and 36 °C in months of February-March and November-December respectively [12]. Dominant soil type is Typic Plinthustalfs/Haplic Plinthosols [13]. Cultivation of rice, maize, cowpea and yam at subsistence level is a common practice in the community.

2.2 Geospatial Data Collection, Soil Sampling and Analysis

The farm selected for the study was 1.13 ha and was divided into 9 subplots of 35 m x 35 m dimensions. In each subplot, soil sample was collected from 0 – 20 cm depth using hand trowel. At each sampling point, geographic information data (latitudes, longitudes and elevation) were recorded using GARMIN eTrex-10 GPS device purposely for interpolation and production of digital map of some soil quality attributes for the farm. Geo-referenced soil samples were sent to the laboratory for analysis.

Soil samples were air-dried, gently crushed using ceramic pestle and mortar and passed through 2 mm sieve prior to analysis. The processed soil samples were analysed according to standard laboratory procedures as outlined in IITA [14] for particle size distribution, total nitrogen, available phosphorus and exchangeable potassium.

2.3 Data Processing and Mapping

Data from field and laboratory were analysed using SPSS version 20 [15] for the computation of means, range, standard deviation and coefficient of variation (CV). SURFER 11 for Windows [16] was used for interpolation and mapping of the geospatial data collected from the field and laboratory analysis. Spatial variability ranking was carried out as outlined by Wilding and Drees [17], in which CV values of 0-15, 16-35 and 36 % and above were classified as low, moderate and high variability, respectively. Correlation analysis was carried out to determine the relationship between micro-relief and some soil properties.

3. RESULTS AND DISCUSSION

3.1 Land Configuration and Spatial Distribution Soil Separates

Geo-spatial data on land configuration of the site and particle size distribution of the soils are presented in Table 1. The elevation of the farm ranged from 199 to 205 m with coefficient of variation (CV) of 9.37 %, implying low variation in the landscape. Management of this farm may not require partitioning it into smaller units for the purpose of land preparation/tillage practices.

Sand fraction was dominant in the soils, reflecting the nature of the parent materials which are rich in quartz minerals, from which the soils were derived [11; 13]. This confers on them sandy loam to sandy clay loam textures. Distribution of sand and clay fractions in the soils showed low spatial variability with CV of 5.8 and 13.66 % respectively, while silt was moderate with CV of 27.72 %. Further investigation revealed non-significant correlation between the micro-relief of the site and spatial distribution of sand (*r* = -.09), silt (*r* = .24), clay (*r* = .08). Hence, the near homogenization of the soil separates observed confirms the genetic history of the soils in one part, and seasonal cycles of tillage activities which churns soil separates. On this basis, partitioning of the farm into smaller units for tillage operations may also not be necessary.

3.2 Spatial Variability Mapping and Quality (Fertility) Attributes of the Soils

Results of spatial variability and quality/fertility attributes of the soils are shown in Table 2. Spatial distribution maps of some soil properties are graphically represented in Figures 1 to 4. Ratings of soil quality attributes followed the classifications of Esu [18] and Chude et al. [19]. Soil reaction (pH) was slightly acid to neutral. By implication, the pH of the soils fall within a favourable range of 5.5 to 7.0 which has been established as optimal for overall availability of plant nutrients in the soil [20]. Spatially, pH values ranged from 6.5 to 6.8 with CV of 1.64 % implying low spatial variability, probably due to similar parent material in which the soils were developed. Although pH shows significant correlation (*r* = .53) with micro-relief of the farm, its low spatial variability favours uniform management when the need arises.

Table 1. Geo-spatial data on land configuration and particle size distribution of the study site

Sampling points		**Elevation (m)**	**Particle size distribution (g kg^{-1})**			**Textural class**
Easting	Northing		Sand	Silt	Clay	
6.46483	9.53732	200	714	80	206	Sandy clay loam
6.46532	9.53924	199	744	80	176	Sandy loam
6.46515	9.53727	199	724	90	186	Sandy loam
6.46514	9.53791	199	684	90	226	Sandy clay loam
6.46524	9.53773	201	744	50	206	Sandy clay loam
6.46583	9.53784	205	714	109	177	Sandy loam
6.46503	9.53872	201	714	50	236	Sandy clay loam
6.46534	9.53860	200	724	90	186	Sandy loam
6.46601	9.53842	201	624	120	256	Sandy clay loam
Mean:		200.56	709.56	84.33	206.11	
Standard deviation:		1.88	36.78	23.38	28.15	
Coefficient of variation (%):		9.37	5.18	27.72	13.66	
Spatial variability ranking:		Low	Low	Moderate	Low	

Table 2. Spatial variability and quality/fertility attributes of the soils

Sampling points		**pH**	**SOC**	**Nitrogen**	**Phosphorus**	**Potassium**
Easting	Northing		(g kg^{-1})	(g kg^{-1})	(mg kg^{-1})	(cmol kg^{-1})
6.46483	9.53732	6.7	6.60	0.98	4	0.12
6.46532	9.53924	6.8	5.60	0.56	6	0.27
6.46515	9.53727	6.5	5.00	0.53	5	0.23
6.46514	9.53791	6.6	8.10	0.70	4	0.21
6.46524	9.53773	6.7	12.70	1.54	5	0.42
6.46583	9.53784	6.8	8.80	1.30	6	0.20
6.46503	9.53872	6.8	3.30	1.40	7	0.09
6.46534	9.53860	6.7	6.43	1.37	7	0.12
6.46601	9.53842	6.8	1.30	1.34	9	0.19
Mean		6.7	6.43	1.08	5.89	0.21
Standard deviation		0.11	3.29	0.39	1.62	0.10
Coefficient of variation (%)		1.64	51.17	36.11	27.50	47.62
Spatial variability ranking		Low	High	High	Moderate	High

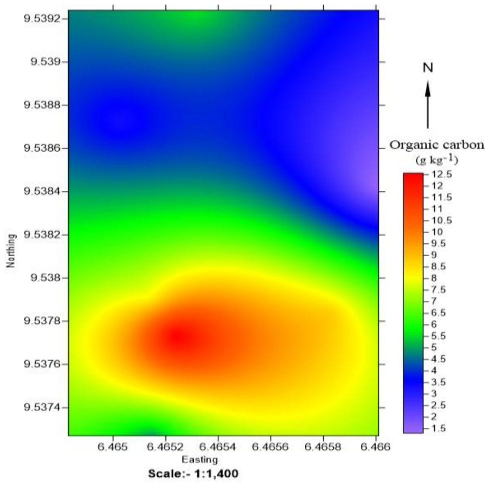

Fig. 1. Spatial distribution of soil organic carbon in the study site

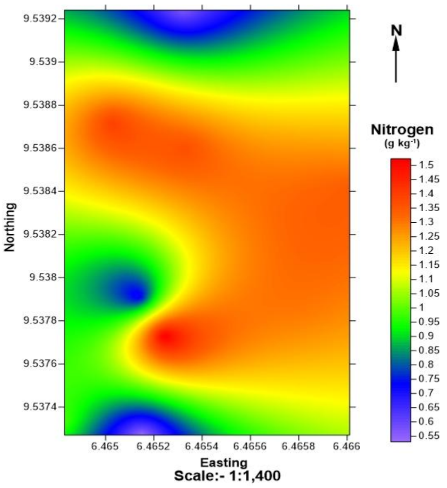

Fig. 2. Spatial distribution of nitrogen in soils of the study site

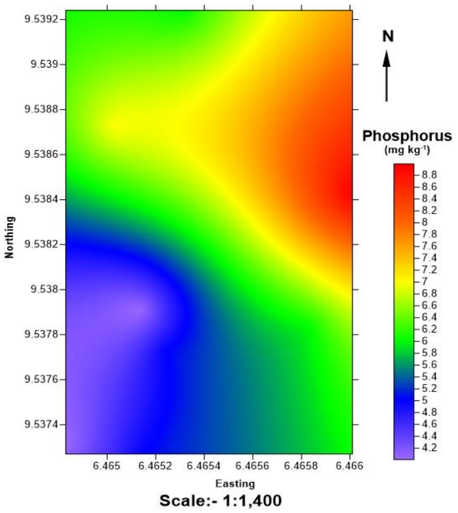

Fig. 3. Spatial distribution of phosphorus in soils of the study site

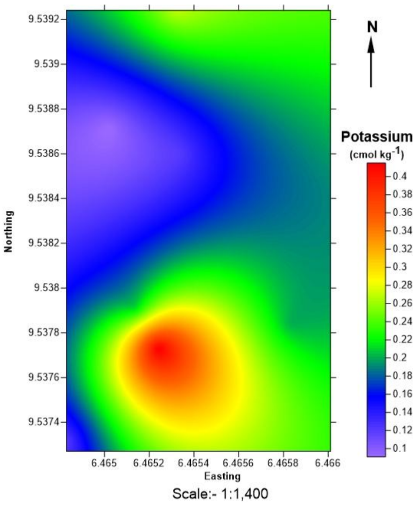

Fig. 4. Spatial distribution of potassium in soils of the study site

Soil organic carbon (SOC) ranged from 1.30 to 12.70 g kg^{-1} which was low to medium. This implies that the land had been under intensive cultivation over a long period of time. According to Greenland et al. [21], high intensity agricultural activities deplete soil organic matter (SOM) content. Management of this farm may require measures that will ensure recycling of crop residues or other forms of soil organic matter amendments. In terms of distribution, SOC had a CV of 51.17 %, signifying high spatial variability. The high variation observed may likely be associated with the management practices of the farmer as micro-relief showed non-significant (r = .21) correlation with SOC. It is therefore appropriate to partition the farm into relatively small homogeneous unit for precision management of SOC.

Nitrogen (N) content in the soils was high. This results was at variance with low N contents in similar soils as reported by Lawal et al. [22] and Adeboye et al. [23] despite the low to medium SOC content which has been reported to be a major contributor of N in the soil in different tropical agroecosystems [24; 25]. Therefore, high N content observed in all sections of the farm could be as a result of application of N-rich fertilizers, such as urea, in managing the fertility of the soils by the farmer. This was a departure from findings of Martey et al. [26] which indicated that improper fertilizer rates application by farmers contribute to the low contents of nutrients in soil. In terms of spatial distribution, N values in the soil ranged from 0.53 to 1.54 g kg^{-1} with CV of 36.11 % indicating high spatial variability. The farm may respond to further application of N fertilizer. The high spatial variability of N will require partitioning of the farm into small uniform units for effective nutrient management.

Phosphorus (P) concentration in the soil was low, and below the critical limit of 10 mg kg^{-1} recommended for most soils of Nigeria [18]. Previous studies [13;27;22;23] have reported low status of P in soils within the same agro-ecological zone which they opined could be due to their parent materials low in P-bearing minerals as well as the very low organic matter content in the soils. Thus, the soils under investigation will respond well to application of fertilizers rich in P. In terms of distribution, P values in the soil ranged from 4 to 9 mg kg^{-1} with CV of 27.50 % implying moderate spatial variability.

Potassium (K) concentration in the soil varied from 0.09 to 0.42 cmol kg^{-1}, which was low to high. Critical limits for rating K concentration in the soil was 0.15 cmol kg^{-1} for low and 0.30 cmol kg^{-1} for high fertility [18;19]. In terms of distribution, K had CV of 47.62 % implying high spatial variability in the soil.

4. CONCLUSION

Knowledge of distribution of soil properties is important in mapping for precision management even at the level of smallholder farm. This study observed low to moderate spatial variability in sand, silt, clay, soil pH and P and high spatial variability in SOC, N and K. Production of soil maps for site-specific management in respect of particle size distribution may not be necessary for tillage related activities and soil acidity management on the farms. Mapping is necessary in managing the distribution of SOC, N and K with high spatial variability to help in management of the amount of soil amendments, both organic and inorganic fertilizers that have to be applied to different partitioned units and reduce variation in crop yields within the farm.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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