# THE USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) TECHNOLOGY FOR SPATIAL ANALYSIS AND MANAGEMENT OF SOIL ORGANIC CARBON

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## ABSTRACT

*Precision agriculture that maximizes crop yields and reduces the cost of production can be achieved by spatial analysis of soil properties using Geographic Information System (GIS) technology. The spatial variability of soil organic carbon (SOC) in relation to topography and site-specific management of organic material to increase the SOC using GIS technology was carried out on a 51 ha arable farmland in Minna, Nigeria. The field was partitioned into 50 m x 50 m grid or subplots numbered 1 to 204. Out of these subplots, forty were selected using stratified random sampling technique, for soil sampling at 0-20 cm depth, and the sampling points were geo-referenced. Field data collected and laboratory analysis results were imputed into computer software, SURFER 11 for interpolation and digital mapping. The SOC ranged from 1.44 to 13.27 g kg$^{-1}$ and rated low to medium, with a low coefficient of variability (CV) of 6.35 %. Topography of the field ranged from 185 to 213 m above sea level (asl) with a medium CV of 16.23 %. There was no significant correlation between SOC and topography. Based on the SOC content of very low, < 5 g kg$^{-1}$ and low, > 5 g kg$^{-1}$, two relatively homogenous units designated MU1, covering 35.06 ha and MU2, covering 15.94 ha, were obtained. The site-specific application of organic materials to the two units reduced the quantity required by blanket application to the whole field by about 16 %.*

**Key words:** Soil organic matter management, topography, spatial variability.

## INTRODUCTION

Organic farming is a practice of the cultivation of crops and rearing of animals devoid of using any synthetic farm inputs such as fertilizer, pesticides and the likes. Indeed, the system emphasizes the use of organic amendments such as green manure, compost manure, crop rotation, and other cultural practices to improve the health of the soil (Olayide *et al*., 2011; Kutama *et al*., 2013; Mgbenka et al., 2015). Thus, the growing advocacy for organic farming is linked to its ability to conserve soil, produce quality food of natural origin on sustainable basis and reduced cost (Bello, 2008; Agunbiade, 2013; Mgbenka et al., 2015). Soil organic carbon (SOC) is the main constituent of soil organic matter (SOM)(Chan, 2008), and a key component of any integrative parameters relating to soil quality (Udom *et al*., 2015). The importance of SOM in agriculture cannot be overemphasized. However, as a basis of soil fertility, SOM plays the following vital roles. First, it promotes soil structure by holding the soil particles together as stable aggregates, thus improving soil physical properties such as water holding capacity, water infiltration, gaseous exchange, root growth and ease of cultivation. Secondly, it releases nitrogen, phosphorus and a range of other nutrients for plant growth through decomposition processes and lastly, it is a food source for soil fauna and flora, which perform important functions such as nutrient-cycling and availability, assisting root growth and plant nutrient uptake, creating burrows and even suppressing crop diseases (Chan, 2008).

Organic farming is being faced with some challenges, especially those associated with the management of organic materials to increase SOC due to the spatial variability of SOM. Soils have inherent differences in organic matter contents, depending on the vegetation history and mineral parent materials (Cooperband, 2002). Such spatial variability can be a threat to food security (Okeyo *et al*., 2006). The effects of spatial variability are not limited to differences within field crop growth alone, but also reduction in yields (Brouwer *et al.*, 1993; Udoh *et al.*, 2010). Hence, fields identified with a high degree of spatial variability of soil properties are better managed by delineating them into relatively homogenous units (Inman *et al.*, 2005).

Conventional methods of soil surveys are major sources of soil spatial information in most parts of the world (Zhu *et al.*, 2001), particularly in Nigeria (Nkwunonwo and Okeke, 2013). However, the advent of modern tools such as geographic information system (GIS) and remote sensing (RS) technologies now makes digital mapping of spatial variability of soil properties for any given site possible (Scull *et al.*, 2003). The GIS technology in particular has opened newer possibilities of improving soil statistic system as it offers accelerated, repetitive, spatial and temporal synoptic view. Furthermore, GIS can effectively be used to represent and illustrate the geo-referenced laboratory's analysis findings of soil properties as well as in the identification and mapping of areas suitable for cultivation of crops (Mohamed and Abdo, 2011).The use of GIS technology in mapping spatial variations of SOC for precision management of OM has not been reported anywhere in North-central Nigeria, particularly, Minna, Niger State. The fact was that the use of the technology for understanding and improving soil data in Nigeria remains speculative (Nkwunonwo and Okeke, 2013). Therefore, this study was designed to fill the location gap in knowledge concerning the application of GIS technology in the assessment and digital mapping of spatial variability of SOC in surface soils for OM management.

## MATERIALS AND METHODS

### *Description of the Study Site*

The study site is the Commercial Farm of the Federal University of Technology, Minna, situated at Garatu, kilometer 20-23, along Minna-Bida Road. The site lies between latitudes 0927′ 5.167″ N and 0927′ 44.049″ N and longitudes 0624′ 24.714″ E and 0625′ 42.182″ E. The climate of Minna is sub-humid tropical with mean annual rainfall of about 1283 mm and relative humidity of 33-87 % (FDALR, 1985; Ojanuga, 2006). The mean daily temperature rarely falls below 22 C with peaks o 40 C and 36 C between February to March and November to December respectively (Adeboye *et al.*, 2011). The site is underlain by igneous and metamorphic rocks of the pre-Cambrian Basemen Complex with granites, gneisses, migmatites, quartzites and schists, while the dominant soils ar Ferric Luvisols, Ferric Acrisols and Ferric Cambisols (Ojanuga, 2006). Minna is located within th southern Guinea wooded savanna of Nigeria. Cereals (maize, sorghum and upland rice), legume (groundnut and soybean) and tubers (yam) are the major crops grown in the area.

### ***Soil sample collection and analysis***

Fifty-one hectares field was selected for the assessment, partitioned into 50 x 50 m grid (subplots and numbered 1 to 204. Forty subplots were randomly selected for sampling using a stratifie random sampling technique (Wilding and Drees, 1983). Soil samples were collected at 0-20 c depth for laboratory analysis. At each sampling point, geographic coordinates and elevations wer recorded using GARMIN eTrex-10 GPS device purposely for interpolation and production digital soil map for the study site.

The air-dried samples were gently crushed and sieved through a 2 mm mesh. The processed so samples were analysed according to standard laboratory procedures for particle size distributio using the Bouyocous hydrometer method (Gee and Or, 2002) and organic carbon using Walkle Black method of wet combustion involving oxidation of organic matter with potassium dichromat ($K_2Cr_2O_7$) and sulphuric acid ($H_2SO_4$) (Nelson and Sommers, 1996).

### ***Data Processing and Digital Mapping***

Data from field and laboratory were analyzed was carried out as outlined by Wilding and Drees (1983), in which 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 SOC and other soil properties measured. Geostatistical (point kriging) model was used for interpolation and digital mapping of SOC using computer software, SURFER 11 for Windows (Golden Software Inc., 2012). The geostatistical interpolation followed the equation: (1) where? is the value to be predicted at the location , is the known value at the sampling location , n is the number of locations within the search neighborhood used for the prediction, and is the kriging weight assigned to (Bhunia *et al.*, 2016).

## RESULTS AND DISCUSSION

### Land configuration and texture of the surface soils

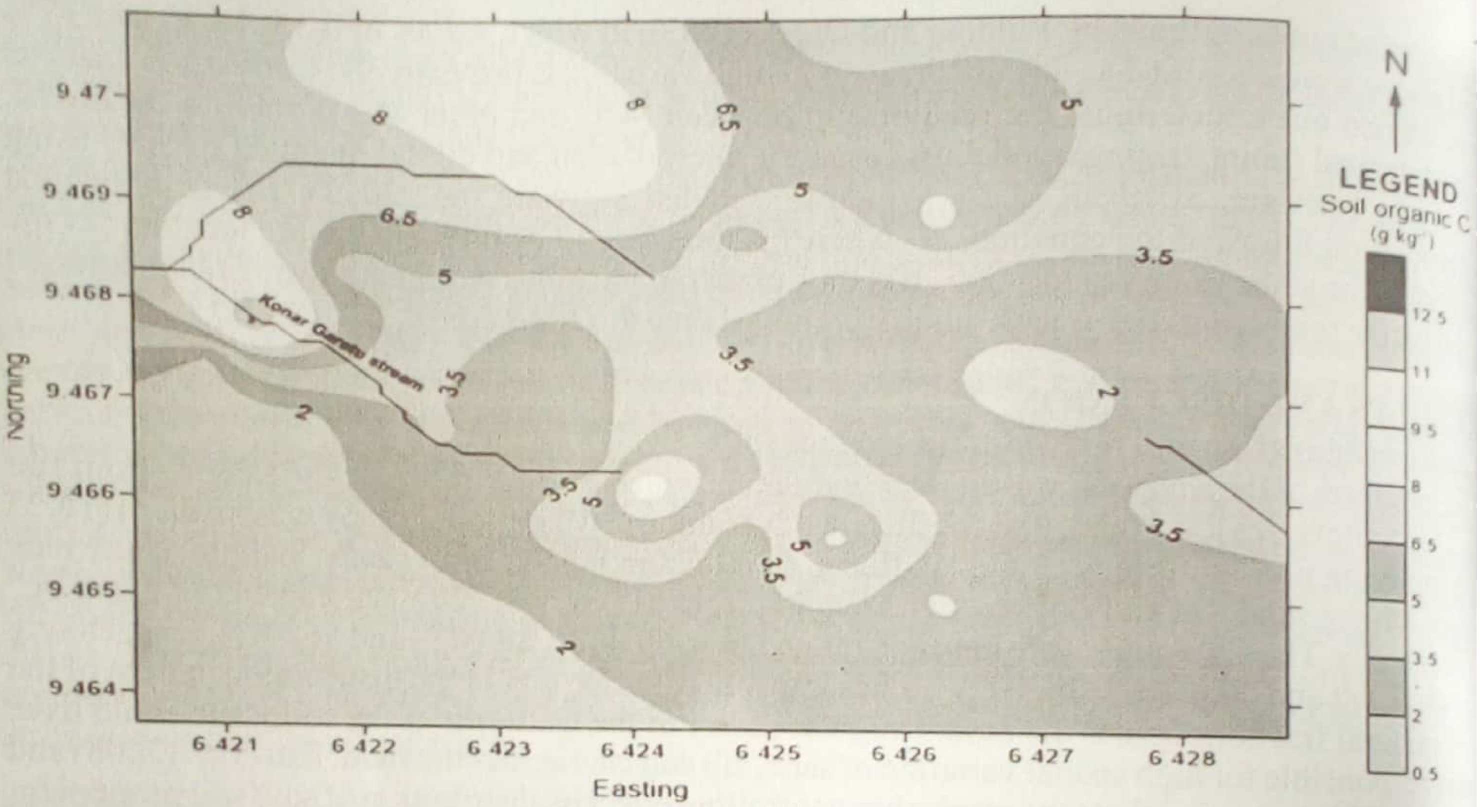
The landform of the study site was slightly undulating with elevation (topography) ranging from 168 to 213 m above sea level (asl). The coefficient of variation (CV) for topography was medium (16.23 %) implying non-uniformity of the landform. Soil texture ranged from sandy loam to sandy clay loam, having sand, silt and clay fractions ranging from 618 to 748, 72 to 162 and 142 to 236 g kg$^{-1}$ respectively. The CV values were high and ranged from 69.48 %, 38.60 % and 56.45 %, respectively for sand, silt and clay. These high CV values imply non-uniformity in the distribution pattern of the soil mineral fractions across the field. Irregular nature of the landform of the study site could have been responsible for high spatial variation of sand, silt and clay across the field. Esu *et al.* (2008) and Beyene (2011) reported that topography has controlling effect on distribution of soil/ soil properties.

### Spatial distribution of organic carbon in relation to the topography of the study site.

The soil organic carbon (SOC) distribution pattern of the soils is shown in Table 1 and the digital soil map showing distribution pattern of SOC is presented in Fig. 1. The SOC ranged from 1.44 to 13.27 g kg$^{-1}$ (mean, 4.13 g kg$^{-1}$) and was low to medium, with only a negligible portion (0.39 ha or 0.75 %) of the field having medium, while the rest had low SOC status (Esu, 1991). The CV of 6.35 % for SOC also was low, implying that its spatial variability across the field was low. However, low SOC content recorded in almost all portions of the field might be attributed partly to continuous cultivation and frequent burning of farm residues which tend to destroy much of the organic materials that could have been recycled back into the soil. Other possible causes of low SOC might be due to the effect of high temperature and relative humidity which favor rapid mineralization of organic matter (Fasina *et al.*, 2006). By implication, low status of SOC in the soil covering almost the entire field cannot sustain crop production program and therefore, it has to be substantially increased through application of organic materials.

**Table 1: Soil Organic carbon distribution of study site**

| Statistical measurement | Soil organic carbon |
|---|---|
| Range | 1.44-13.27 (g kg$^{-1}$) |
| Mean | 4.13 (g kg$^{-1}$) |
| Standard deviation (SD) | 2.54 |
| Coefficient of variation (CV) | 6.35 (%) |



**Scale:- 1:4,265**

**Figure 1: Digital map of the study site showing spatial distribution of organic carbon of surface soils**

The spatial distribution of SOC in the surface soils was not significantly correlated (r = -0.25 P>0.05) with the topography of the study site (Table 1). These results differed from the reports o Kalivas *et al.* (2002) and Esu *et al.* (2008), that topography has influence on soil physical an chemical properties as well as on pattern of soil distribution over landscape. Thus, the non significant correlation in this case may imply that other factors, such as field cultural practice including regular tillage operations could have contributed to reduction in spatial variability of SO thereby suppressing the effect of topography on SOC. According to Ozgoz (2009), tillage practice generally, have considerable effects on reducing spatial structure and spatial variability of so properties. The relationships between SOC and sand, silt and clay were also not significant (P>0.0 probably due to low status of SOC in the study soils.

**Table 2: Correlation matrix of SOC and other parameters measured**

| Land /soil attributes | Soil organic carbon |
|---|---|
| Elevation | 0.254 NS |
| Sand | 0.297 NS |
| Silt | 0.086 NS |
| Clay | 0.312 NS |

*NS not significant at 5 % level of probability

### *Management of soil organic matter*

Despite the low spatial variability of SOC, the management of organic materials to increase the soil organic matter (SOM) for the different spots with different SOC will still be practically noticed feasible. Therefore, to achieve relative homogeneity, for convenient application of organic materials in accordance with site-specific requirements, the field may be categorized based on SOC content into two relatively homogenous units of very low, 0-5 g kg$^{-1}$, designated as MU1 and low, 5-15 g kg$^{-1}$, designated as MU2 (Fig 2). Using the digital map, MU1 covered an area of 35.06 ha, while MU2 covered an area of 15.94 ha. This will reduce not only the overall quantity of organic materials to apply to cover the entire field, but also greatly reduce the time of application. Hypothetically, if the recommended rate is 10 t ha$^{-1}$ based on the SOC content, the whole field of 51 ha will require blanket application of 510 t of organic materials. But with the categorization, MU1 with low SOC content can receive the full dose of 10 t ha$^{-1}$, thus requiring 350.60 t of organic materials. The MU2 can receive half the recommended rate of 5 t ha$^{-1}$ due to its relatively higher SOC content, thus, requiring 79.75 t of organic materials. The entire field will require 430.35 t of organic material, instead of 510 t, thus, reducing the required organic materials by 79.65 t.

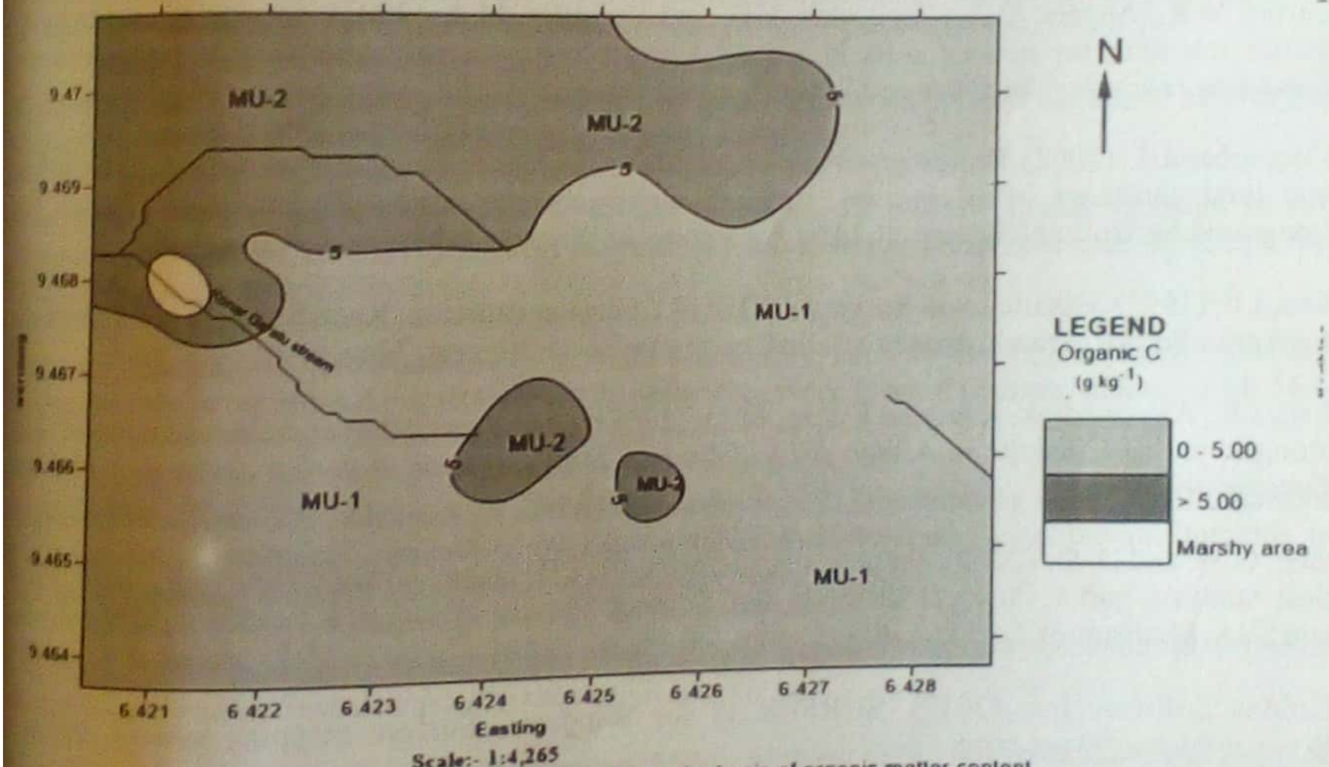


Figure 2 Map of the study site showing manamenet units on the basis of organic matter content

## CONCLUSION

The spatial variability of soil properties including the SOC in a field can be addressed by delineating e field into relatively homogenous units by using Geographic Information System (GIS) chnology. Specifically, in organic farming systems, where inputs of organic material into the soil o increase SOC are paramount, this technology helped to reduce the quantity of organic material eded to be applied to the soil to reduce the cost of production and enhance the SOC. Generally, this ill enable precision agriculture by site-specific management of soil properties that will not only duce cost of production, but also maximize yields, enhance soil productivity and conservation.

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