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Land Use Change and Crop Production: Spatial Variability of Some Soil Physical and Hydraulic Properties of an Alfisol Grown to Cowpea (*Vigna unguiculata*)

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Abstract: Land use change could cause considerable variability of soil properties and processes at various scales. The objective of this study was to investigate the spatial variability and dependence of soil hydro-physical attributes of an Alfisol changed for cowpea (*Vigna unguiculata*) production in Southwest Nigeria during the 2015 late cropping season. A 1.01 ha cowpea field, divided into thirty-five (35) grids, each measuring 10 m x 10 m, was used. At two weeks after planting (2 WAP) and harvest, undisturbed and disturbed soil samples was collected from 0-20 cm surface layer at the center of each grid using core samples of known volume for the evaluation of spatial variability of soil water content (SWC), bulk density (BD), saturated hydraulic conductivity (Ksat) and total porosity (Pt). To ensure sampling of the same point at harvest, a global positioning system (GPS) equipment was used to record the coordinates of each point. The BD, SWC and Pt had coefficient of variation (CV) less than 12%, indicating low variability while Ksat, Ma and seed yield had CV between 12 and 60%, indicating moderate variability. Also, variables BD, Pt, EA, Ksat, Ma and seed yield were moderately spatially dependent while SWC was strongly spatially dependent.This soil had Ksat = 29.54 cm h^{-1}, BD = 1.63 g cm^{-3}, Pt = 0.3861 cm^3 cm^{-3} and Ma = 0.10 $cm^3 cm^{-3}$ as reference values, with more than 90% of the sampled points falling within the reference values, indicating that land use change has not significantly affected soil structural formation. The resulting maps of soil physical and hydraulic properties and crop yield could be used to support spatial sampling and thus facilitate site-specific soil management strategies with a view to saving cost and protecting the environment.

Key words: Spatial variability · Spatial dependence · Geostatistics · Geographical information system · Alfisol · Soil physical and hydraulic properties

INTRODUCTION

Soil properties vary spatially from plot to field scale even to a larger regional scale caused by both intrinsic (soil forming factors) and extrinsic factors (soil management practices including tillage, fertilization, irrigation and crop rotation) [1]. According to Buol *et al.* [2], the variation is a gradual change in soil properties with respect to landforms, geomorphic elements, soil forming factors as well as management practices. Therefore, monitoring, quantifying and digitization of the spatial variability of properties directly or indirectly related to the soil is vital for better understanding of the effects of land use and management systems on soils and allows better control of crop production and environmental monitoring [3, 4]. On a regional scale, the quantification of soil physical and chemical properties and estimation of their relative variation are among the fundamental steps to carry site-specific practices for ecological management, fertilization and irrigation scheduling.

Recent advances in geographic information system and geostatistical tools have strengthened investigations about the variability of soil properties [5,6] and based on the theory of regionalized variables,they have enabled the interpretation of results with respect to the structure of spatial dependence within the sample space. For example, Webster and Burgess [7] submitted

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that information on spatial variability for a variable of interest provided by the semi variogram, along with some known values of the variable, can be used by kriging to estimate the values at unobserved locations. Ersahin [8] stated that simple kriging in geostatisticsis a useful algorithm for estimating and mapping soil properties at unobserved sites in the agricultural fields with reasonable accuracy from easily measured soil variables. In this context, several studies have employed geostatistical techniques to verify that soil properties vary across farm fields as well as using the technique to estimate attributes in un sampled locations[9-19]. Mueller *et al.* [9] collected a large number of soil samples to yield more accurate kriging maps of soil properties and found that performance of kriging improved with increasing sampling intensity. lqbal *et al.* [10] generated fine-scale kriged contour maps with the help of semi variogram functions to describe the variability and spatial pattern of different types of soils and soil water retention properties in soil. Santos *et al.* [16] studied the spatial variability of physical attributes of a Distroferric Red Latosol after soybean crop in Brazil and found that all the attributes evaluated showed moderate to strong spatial dependence. More recently, Liptzin *et al.*[17] and Tavares *et al.* [19] used kriging method to estimate spatial pattern of total and available N and P in Alpine tree line at Colorado, USA and soil physical and mechanical properties in a sugarcane field in Brazil, respectively. Bi *et al.* [13] showed that the spatial dependence of soil moisture varied with time and soil depth in two watersheds within the hill-gully region of the Loess Plateau. However, Duffera *et al.* [12] found that total porosity (Pt), bulk density (BD) and saturated hydraulic conductivity (Ksat) were not spatially correlated in southeastern USA coastal plain soils. Despite this quantum of studies, there is dearth of information on spatial variability structure of physical properties of soils under managed soil in southwestern Nigeria. In addition, most of the studies neglected crop yield component in their analyses [14,16] despite quoting that spatial variation in soil properties causes variation in crop performance and yield.

The Crop Production Unit of the Teaching and Research Farm, Ekiti State University, Ado-Ekiti, South-western Nigeria, established over 15 years ago, has been under intensive cultivation every year, both rainy and dry cropping seasons, cropped predominantly with arable crops, maize and cassava. However, certain portions of the field have been converted to other land use, such as livestock, including poultry, piggery, sheep, goat and Moringa plantation and recently, about 1 ha of the field converted to grow cowpea. Although climate and geological history are considered to be prime factors affecting the variability of soil properties on regional and continental scales [5], however, land use is one of the dominant factors influencing soil properties at different scales, with changes in land use posing more significant effect on soil properties and processes. As a result, such changes modify the processes of transport and distribution of water and nutrients in the soil matrix. For instance, in a land under fallow, the type of vegetal cover is a factor influencing the soil organic carbon sequestration [20]. In addition, soils through indiscriminate land use change produce considerable alterations [21], with the quality diminishing [22] and subsequent decline in crop yield. For this land in question, the excessive cultivation over the years and changes in land use call for investigation. Such analysis becomes necessary to quantify the quality status of the soil and generate information for site-specific management options. Therefore, the objective of this study was to investigate the spatial dependence of some soil physical and hydraulic attributes of an Alfisol recently changed to cowpea (*Vigna unguiculata*) production in Southwest Nigeria.

MATERIALS AND METHODS

Description of Experimental Site: The field experiment was conducted during the 2015 late cropping season at the Crop Production Unit of the Teaching and Research Farm, Ekiti State University, Ado-Ekiti, south-western Nigeria, located on longitude latitude $7^0$42' 46" N and 5°14' 42"E and an altitude of 403 m above sea mean level (Fig. 1). The region is a humid tropical climate characterized by distinct dry and wet seasons with moderate mean annual rainfall of about 1367.7 mm while the mean annual temperature was not less than 12 °C during the winter period and more than 34 °Cduring the summer period. The soil of the study site belongs to the broad group Alfisol [23], with top sandy loam texture. The area has been under conventional tillage and maize/cassava intercropping for over five years before planting of cowpea. Some physico-chemical properties of the 0-20 cm surface layer of the field are shown in Table 1.

Land Preparation, Planting and Field Management: The maize field was 170 m x 205 m, giving an area of about 3.5 ha (Fig. 1). The field was ploughed to a depth of 20 cm.

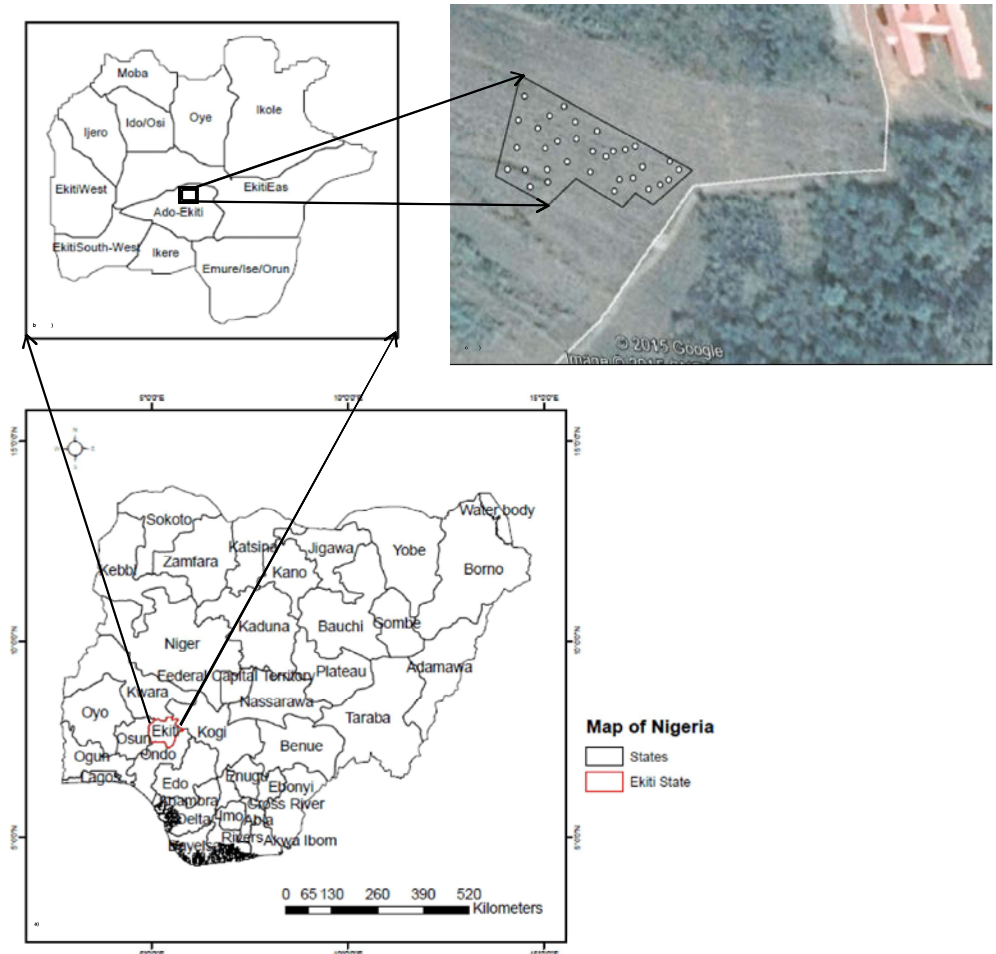

Fig. 1: a) Map of Nigeria showing the location of Ekiti State, b) map of Ekiti State showing the location of Ekiti State University and c) location of the experimental site, showing the sampling points.

Table 1: Some physico-chemical properties of the 0-20 cm surface layer of the cowpea field.

Chemical properties										
	OM	TN	Na	K	Ca	Mg	Av.P	H+Al	ECEC	BS
pH	--------------%--------------		-----------------------cmol kg^{-1}---------------------				mg kg^{-1}	-	cmol kg^{-1}	%
6.3	0.98	0.56	0.72	0.33	57.5	2.22	17.9	0.1	60.9	99.8

Physical properties			
Clay	Silt	Sand	
-------------------------------	--------------%--------------	-------------------------------	texture
12.2	14.8	73.0	SL

pH: alkalinity/acidity; OM: organic matter; TN: total nitrogen; Na: sodium; K: potassium; Ca: calcium; Mg: magnesium; Av. P: available phosphorus; H+Al: acidity, ECEC: effective cation exchange capacity; BS: base saturation; SL: sandy loam

Two weeks after ploughing, the field was harrowed and well pulverized. Cowpea seeds, at 2-3 seeds per hole, were planted manually at inter-row spacing of 60 cm and 30 cm between plants, giving a plant population of about 95,000 plants ha^{-1}. Until harvest, no fertilizer was applied and weeding was done manually by physically uprooting and hoeing of weeds. Crop protection was carried out on weekly basis shortly before flowering by spraying Karate 5 EC (active ingredient: lambda-cyhalothrin) at the rate of 400mL ha^{-1}.

Soil Sampling and Analysis: Immediately after land preparation, composite samples were collected from 0-10 cm layer from six representative locations of the field for the determination of soil physico-chemical properties. At two weeks after planting (2 WAP) and harvest, soil sampling was conducted for the evaluation of spatial variability of selected soil physical properties. For this analysis, the field was divided into thirty-five (35) grids, each measuring 10 m x 10 m, was used. To ensure sampling of the same point at harvest, a global positioning system(Garmin, model GPS 72H, Garmin International Incorp., USA) equipment was used to record the coordinates of each location and the boundaries of the field. The boundaries and the sampling points were georeferenced using the spatial analyst tool in ArcGIS (ArcGIS 10.1) (Figure 1c). At each sampling point, undisturbed soil samples (in 3 replicates) were collected from the middle of soil layer of 0-20 cm using core samplers, 57 mm diameter and 40 mm high to determine soil bulk density and saturated hydraulic conductivity. From the same soil layers, undisturbed samples were also collected to quantify the field gravimetric water content and granulometric composition.

Evaluations

Soil Texture: The granulometric analysis was determined using the procedure described in EMBRAPA [24] from disturbed air-dried soil samples after passing through 2-mm sieve. The textural class for was obtained using the textural triangle of the USDA.

Bulk density: After preparation in the laboratory, the undisturbed core samples were oven-dried at 105°C for 48 h and the weight of dry soil was determined. The bulk density was determined according to the relation [25]:

$$BD = \frac{M_s}{V_s} \tag{1}$$

where BD is bulk density, g cm^{-3}; M_s is weight of dry soil, g; V_s is volume of soil, cm^3.

Soil water content: The initial weight of the soil samples was determined in situ using a sensitive weighing scale. In the laboratory, the samples were oven-dried at 105 °C for 48 hrs and the final weight was determined.

$$\theta_g = \frac{M_w}{M_{ds}} \tag{2}$$

where θ_g is the gravimetric water content, g g^{-1}; M_w is the amount of water in the sample, g; M_{ds} is the mass of oven-dried soil, g.

The soil volumetric water content, *SWC*, of each layer was obtained from the product of θ_g and the corresponding BD.

Total Porosity: It was determined using the relation:

$$Pt = 1 - \frac{BD}{Pd} \tag{3}$$

where P_t is the total porosity, cm^3 cm^{-3}; BD is the bulk density, g cm^{-3}; Pd is the particle density taken as 2.65 g cm^{-3}.

Macroporosity (Ma).): The soil *Ma* was estimated following the pedotransfer function proposed by Stolf, R., [26] for a similar soil as:

$$Ma = 0.693 - 0.465BD + 0.212Sa \tag{4}$$

where BD is the bulk density, g cm^{-3}; Sa is the sand content, kg kg^{-1}.

Aeration Porosity (EA): The EA was obtained as the difference between total porosity and soil volumetric water content.

$$EA = Pt - SWC \tag{5}$$

Soil Saturated Hydraulic Conductivity: Soil saturated hydraulic conductivity (*Ksat*) was determined by the constant-head permeameter [27] on undisturbed soil samples collected in metal cylinders (of known volume) after saturation by capillarity in a water bath for 48 hours. The determination of *Ksat* was performed by collecting and measuring the amount of water that percolates through the soil sample under a constant hydraulic head of about 3 cm in the water column, according to the methodology described by EMBRAPA [24]. From the data, soil *Ksat* was calculated according to Equation 6.

$$Ksat = \frac{Q * L}{A * H * t} \tag{6}$$

where *Ks*at is saturated hydraulic conductivity, cm/hr; Q is volume of water that flow through the soil column in a given time, cm^3; L is length of the soil column, cm; H is length of soil column + water head above the soil column, cm; A is area the soil column, cm^2; t is time, h.

Crop Yield: At physiological maturity, ripened pods from each grid (20 m^2) were harvested, shelled, cleaned and weighed. This procedure was repeated until all pods were harvested. The yields obtained were added together and converted to kg/m^2.

Data Analysis

Descriptive Statistics of Soil Properties: Descriptive statistics of minimum, maximum, average, standard deviation (SD), skewness, kurtosis and coefficient of variation (CV) of data on soil water content, bulk density, saturated hydraulic conductivity and porosity (total, macro and aeration). According to the classification proposed by Warrick and Nielsen [28], a parameter is considered to have low variability if the CV<12%, as moderate variability when12% < CV < 60% and high variability when CV >60%. In addition, the frequency distribution graph was plotted for each variable. All classical statistical analyses were carried out using SPSS (IBM version 20).

Geostatistical Analysis: Geostatistical analysis was done using the GS+ (Gamma Design Software, Version 5.2, 2005) to determine the spatial dependency and estimation of the soil properties evaluated. Isotropic semivariograms, including linear, power, spherical, exponential and Gaussian, were tested from omnidirectional semivariances, $\hat{\gamma}$ (h), of a set of spatial observations, Y_{xi}, expressed as Nielsen, D.R. and O. Wendroth, [29]:

$$\hat{\gamma}(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}(Y_{x+h}-Y_x)^2 \tag{6}$$

where $\hat{\gamma}(h)$ is the covariance; h is the spatial separation distance, known as the time lag; $N(h)$ is the number of pairs of observations separated by a distance; Y_x is soil variable observed at point x while Y_{x+h} soil variable observed at point $x+h$.

To characterize the spatial covariance structure of the variables, the best model was selected based on the coefficient of determination, R^2. From the models, basic spatial parameters such as nugget (Co), sill (C+Co) and range (a) were determined. Different classes of spatial dependence of the soil properties were computed using nugget to sill ratio (Co/(C+Co) as proposed by Cambardella, C.A. *et al*., [30]. For ratio < 25%, the soil property is considered to be strongly spatially dependent (SSD); for ratio between 26 and 75%, the soil property is said to be moderately spatially dependent (MDS) while for ratio >75%, the soil property is considered to be weakly spatially dependent (WSD). After selecting the best fit semivariogram model for each variable, contour maps were created through ordinary kriging of the Geostatistical Analyst extension in ArcGIS v. 10.1® (Esri, Redland, CA, USA). Cross-validation of the kriged results was made using validation statistics of mean absolute error (MAE) and mean square error (MSE) as:

$$MAE=\frac{\sum_{i=1}^{N}\left|Z^{*}-\bar{Z}\right|}{N} \tag{7}$$

$$MSE=\frac{\sum_{i=1}^{N}(Z^{*}-\bar{Z})^2}{N} \tag{8}$$

where Z^* is the predicted soil variable; $\bar{Z}$ is the mean of measured soil variable; N is the total number of sampling locations. The predicted values for each soil variable were obtained from the cross-validation procedure in the GS$^+$.

RESULTS AND DISCUSSIONS

Descriptive Statistics: The descriptive statistics of soil variables of the cowpea field at 2 WAP and harvest is shown in Table 2. At 2 WAP, the BD ranged between 1.38 and 1.72 g/cm^3 (mean = 1.60 g/cm^3). The soil volumetric water content (SWC) had values between 0.1895 and 0.2461 cm^3 cm^3 (mean = 0.2148 cm^3 cm^3). For total porosity (Pt), the values were between 0.3501 and 0.4790 cm^3 cm^3 (mean = 0.3945 cm^3 cm^3). The aeration porosity (EA) ranged between 0.1107 and 0.2553 cm^3 cm^3 (mean = 0.1797 cm^3 cm^3); the saturated hydraulic conductivity (Ksat) ranged from 10.37 to 73.85 cm h^{-1}, with an average value of 34.09 cm h^{-1}, while Ma had values between 0.0656 and 0.1785 cm^3 cm^3 (mean = 0.1051 cm^3 cm^3). There was difference in the average values of the soil variables at harvest, with the BD and EA slightly increased by 2.5 and 3.4%, respectively while the SWC, Pt, Ksat and Ma decreased by 10.9, 4.4, 6.2 and 13.1%, respectively (Table 2). There was spatial variability in cowpea grain yield, as it varied between 0.292 and 0.486 kg m^{-2} (mean = 0.386 kg m^{-2}). In this study, the CVs for BD, SWC and Pt were less than 12%, indicating that these variables had low variability. On the other hand, Ksat, Ma and grain yield had CV between 12 and 60%, indicating moderate variability. The CV obtained in this study was similar to that of Wang and Shao [31] who reported low CV in BD and Pt. Duffera *et al.* [12] also reported that BD had low variability (CV = 0.08) in typical southeastern USA coastal plain soils. For Ksat, these results are in agreement with the findings of Stolte [32] and Zhao *et al.* [33], who found that Ksat had moderate variability in the hill-gully region and check dams of the Loess Plateau. In contrast, Shukla *et al.*[34] and Wang and Shao [31] reported high variability of Ksat. The moderate or relatively high variability of Ksat may be

Table 2: Descriptive statistics of grain yield and soil hydro-physical properties at 2 weeks after

	N	Min.	Max.	Mean	SD	CV	Skewness	Kurtosis
				2 WAP				
BD	33	1.38	1.72	1.60	0.103	0.064	-0.610	-0.944
SWC	33	0.1895	0.2461	0.2148	0.014	0.067	0.294	-0.415
Pt	33	0.3501	0.4790	0.3945	0.039	0.099	0.610	-0.943
EA	33	0.1107	0.2553	0.1797	0.045	0.249	0.373	-1.119
Ksat	33	10.37	73.85	34.09	17.423	0.511	0.827	-0.262
Ma	33	0.0656	0.1785	0.1051	0.032	0.309	0.802	-0.555
				At harvest				
BD	33	1.35	1.70	1.56	0.092	0.059	-0.285	-0.893
SWC	33	0.2013	0.2876	0.2383	0.019	0.081	0.177	0.004
Pt	33	0.3590	0.4888	0.4120	0.034	0.084	0.287	-0.917
EA	33	0.0781	0.2488	0.1736	0.038	0.218	-0.254	-0.135
Ksat	33	12.35	76.45	36.19	16.37	0.452	0.668	-0.390
Ma	33	0.0762	0.1966	0.1189	0.036	0.301	0.628	-0.906
GY	33	0.292	0.486	0.386	0.047	0.123	-0.079	-0.631

BD: bulk density, g cm^{-3}; SWC: soil volumetric water content, cm^3 cm^{-3}; Pt: total porosity, cm^3cm^{-3}; EA: aeration porosity, cm^3cm^{-3}; Ksat: soil saturated hydraulic conductivity, cm h^{-1}; Ma: macroporosity, cm^3cm^{-3} GY: grain yield, kg m^{-2}.

N: number of sampling points; Min.: minimum; Max.: maximum; SD: standard deviation, CV: coefficient of variation.

attributed to differences in soil pore geometry as a result ofsoil disturbance at planting. At harvest, the lower CV in Ksat may be due to rearrangement of soil particles and stabilization of the pore geometry. Also, the dispersion of Ma indicates that besides thepore volume, its continuity in the soil profileis very fundamental for drainage and distribution of water in thesoil [35], thus establishing critical values based only on porosity only becomes difficult, making it necessary to measure these variables with a view to assessing the real effects of management on soils.

The frequency and normal distribution curves for variables are shown in Figure 2. The variables, èv, Pt, Ksat and Ma had positive skewness, showing skewness to the right, while the BD, EA (harvest)and grain yiledhad negative skewness, showingskewness to the left (Table 2). According to Souza [36], where a variable is showing symmetry to the right or left, there is the tendency of high frequency of values below or above mean, respectively. Carvalho *et al.* [37] in a study on spatial variability of physical properties under different soil management in Brazil reported both positive and negative skewness values for the BD, Pt and èv. According to Ortiz [38], for a normal distribution, the kurtosis coefficients must be zero and the values between +2 and -2 are accepted. For this study, the kurtosis values were within the acceptable limit. Except for SWC at harvest, there was negative kurtosis for BD, Pt, EA, Ksat, Ma and grain yield (Table 2), indicating that the curves were flatter than normal (platykurtic). Where SWC had positive kurtosis, it indicates that the data were scattered and the distribution was narrower than normal (leptokurtic) (Fig, 2). These results also are in agreement with the findings of Carvalho, *et al*., [37].

Relationships Between Soil Physical Properties: The relationships between bulk density, soil water content and aeration porosity of the cowpea field at 2 weeks after planting (WAP) and harvest are presented in Fig. 3. At 2 WAP, the soil water content (SWC) increases with increase in BD whereas at harvest, opposite result was observed as the lower water content was observed with increase in BD. On the other hand, aeration porosity (EA) decreased with increasing BD both at 2 WAP and harvest of cowpea (Fig. 3). Although it is established elevated BD reduces macropores that are responsible for water dynamics and thus hinder soil water retention, making water unavailability to crops especially during droughts [39], however during periods of sufficient water supply by rainfall, increased micropores due to elevated BD by soil compaction favours higher water retention. Bamberg *et al.* [40] in a study on temporal changes in soil physical and hydraulic properties in strawberry fields in Brazil found increased water retention with time. The decrease in EA is expected because any measure that increases the BD leads to reduction in the volume of macropores which are responsible for air flow and gaseous exchange.

The saturated hydraulic conductivity is a dynamic property of soil and its behavior is determined by the degree of compaction that the soil offers [41] as well as thequantity and continuity of pores, mainly macropores [42]. Fig. 4 shows the relationships between saturated hydraulic conductivity and other physical properties as well as the critical values of these properties at 2 weeks after planting (WAP) and harvest.

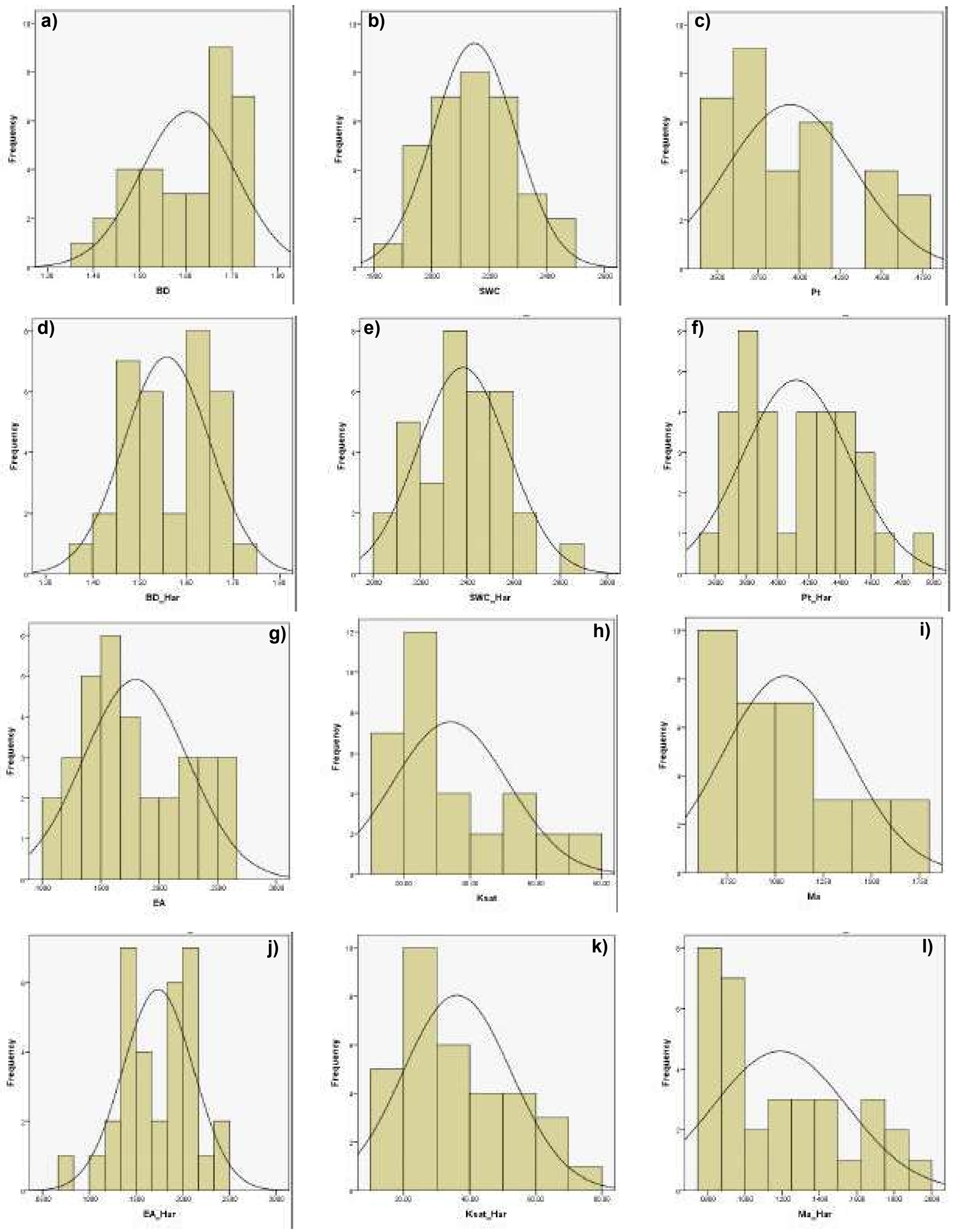

Fig. 2: Frequency and normal distribution of the selected soil physical properties at 2 weeks after planting (WAP) and harvest of cowpea.

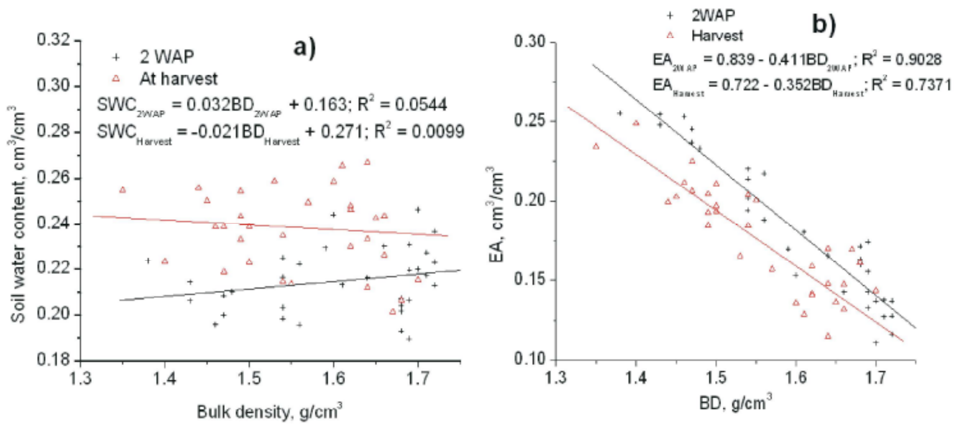

Fig. 3: Relationships between soil bulk density, water content and aeration porosity of the cowpea field at 2 weeks after planting (WAP) and harvest.

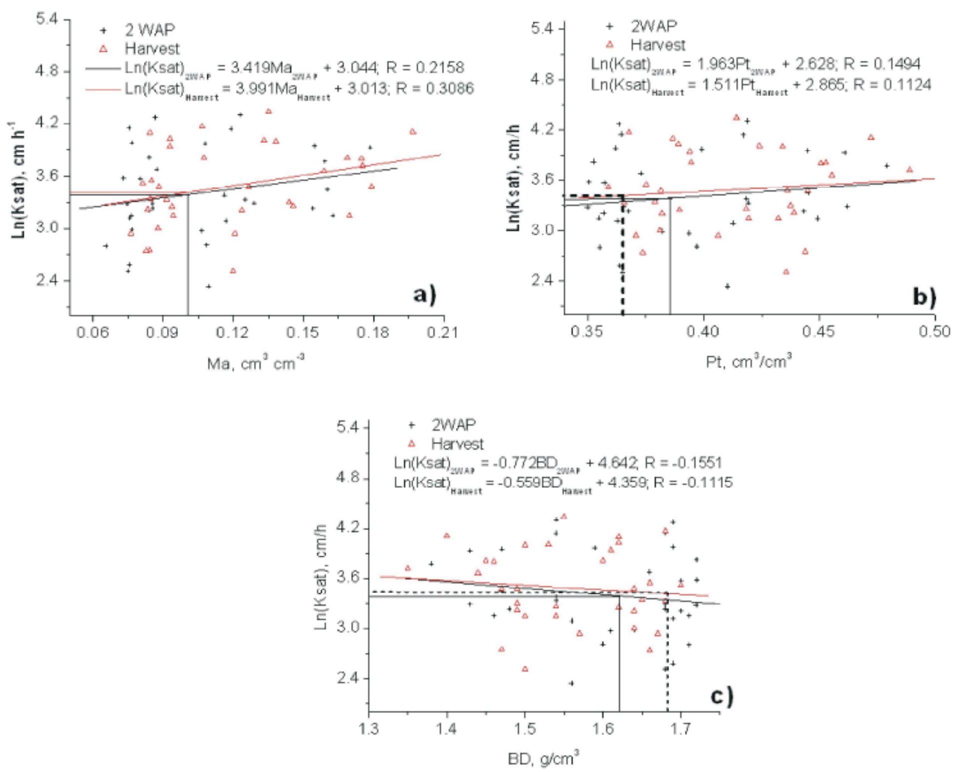

Fig. 4: Relationships between macroporosity, saturated hydraulic conductivity, total porosity and bulk density of the cowpea field at 2 weeks after planting (WAP) and harvest.

A soil is considered physically suited to crops when it has at least 0.10 $cm^3\ cm^{-3}$ macropores, which is considered [43], as the threshold for adequate soil aeration and gaseous exchange [44]. Below this value, the soil is faced with insufficient aeration and gaseous exchange. At 2 WAP, the soilunder studyshould have a minimum Ksat of 29.54 cm h^{-1} (Fig. 4) considering a threshold macroporosity value of 0.10 $cm^3\ cm^{-3}$. For the Ksat of 29.54 cm h^{-1}, the total porosity of thesoil should be at least 0.3861 $cm^3\ cm^{-3}$, while the maximum bulk density that the soil can present is 1.63g cm^{-3}.

At harvest, there were slight differences in the limiting as the minimum value of Ksat was 30.37 cm h^{-1}(Fig. 4) for this same Ma value of 0.10$cm^3\ cm^3$. For this Ksat of 30.37 cm h^{-1}, the Pt should be at least 0.3621 $cm^3\ cm^{-3}$ while the BD cannot be more than 1.69g cm^{-3}.

Table 3: Correlation between hydro-physical properties of the soil and grain yield.

	BD	SWC	Pt	EA	Ksat	Ma	GY
BD	1						
SWC	0.060	1					
Pt	-1.000**	-0.059	1				
EA	-0.932**	-0.417*	0.932**	1			
Ksat	-0.142	-0.098	0.142	0.165	1		
Ma	-0.924**	-0.112	0.924**	0.882**	0.229	1	
GY	-0.822**	0.421*	0.822**	0.733**	0.112	0.690**	1

BD: bulk density, g cm^{-3}; SWC: soil volumetric water content, cm^3 cm^{-3}; Pt: total porosity, cm^3cm^{-3}; EA: aeration porosity, cm^3cm^{-3}; Ksat: soil saturated hydraulic conductivity, cm h^{-1}; Ma: macroporosity, cm^3cm^{-3}; GY: grain yield, kg m^{-2}.

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Using these Ksat = 29.54 cm h^{-1}, BD = 1.63 g cm^{-3}, Pt = 0.3861 cm^3 cm^{-3} and Ma = 0.10 cm^3cm^{-3}as a reference, it appears that more than 90% of the sampled points had valuesless than (e.g. BD); equal to or above the reference values (e.g. Ma and Ksat), depending on the variable. This shows that the soil did not present some degree of limitation as regards soil physical quality. Nevertheless, the less than 10% of the sampled points that had values outside the reference values confirm the presence of spatial variability in these variables. The reference values of Pt and BD obtained in this study were comparable to those of Kaiser, [35], who studied similar soil in Brazil, although the minimum Ksat observed is considered higher. Abreu *et al.* [45] stated the mechanical tillage increases the Ksat of the soil surface layer, but over time, soil reconsolidation that makes the soil more compact reduces the Ksat. On the other hand, plant roots create biopores which have the tendency of increasing the Ksat[45]. Both conditions apply to the soil under study.

The results of the Pearson correlation analysis presented in Table 3 showed that the BD had significant negative correlation with EA, Ksat and Ma whereas there was no correlation between the BD and SWC. Santos *et al.* [16] reported significant negative correlation between BD and Ma. In addition, the authors found significant negative correlation between BD and SWC. The absence of correlation between BD and SWC is attributed to the contrasting behavior obtained at 2 WAP and harvest (Fig. 3a) which may be due to soil sampling conducted during periods of inadequate (2 WAP) and heavy rainfall (harvest). Except for Ksat, there was significant positive correlation between grain yield and SWC, Pt, EA and Ma. However, for BD, the correlation was significant but negative (Table3). Increased biological activity by cowpea root system and decomposing leaves reduces BD, leading to increase in the volume of macropores responsible for water and nutrient dynamics and aeration, hence better crop performance.

Spatial Dependence and Mapping of the Soil Physical Properties: The results of the geostatistical analysis of the measured soil physical properties are shown in Table 4. The measured soil physical properties were fitted to exponential, gaussian and spherical models, with the coefficient of determination (R^2) ranging between 0.632 and 0.878. The grain yield was also fitted to spherical model, with R^2 = 0.745. Other researchers, Cavalcante, *et al*., [14] and Santos, *et al*., [16] have reported soil physical properties are best fitted to these models. The nugget effect or the semi variance at separation distance of zero ($h = 0$) ranged between 0.0001 $(cm^3\ cm^{-3})^2$ (from SWC) and 286.9$(mm\ h^{-1})^2$(from Ksat). According to Webster and Oliver [46], these values are indicative of field and experimental variability, or random variability that is undetectable at the scale of sampling. Except for Ksat, the close to zero nugget effect from the variables is an indication of very smooth spatial continuity between neighbouring points. With increase in separation distance (h), the semi variance increases to a more or less constant value, known as the sill or total semi variance at a given separation distance. In this study, the sill values ranged between 0.0010 $(cm^3\ cm^{-3})^2$(Ma) and 573.9 $(mm\ h^{-1})^2$ (Ksat). The semi variogram range is an important parameter as it represents the maximum distance by which pairs of variables are spatially correlated [29]. According to Yasrebi *et al.* [47], the knowledge of the range of influence for various soil properties enables one to construct independent datasets to conduct classical statistics. From Table 4, the semi variogram range varied from 8.76 m (EA) to 45.47 m (Ksat). The values of the semi variogram range of the soil physical properties obtained in this study were within the range obtained in previous studies [14, 16, 48]. All the variables evaluated showed

Table 4: Fitted models and estimated parameters of the experimental semi variograms of soil physical properties and grain yield.

Ppt	Co	Co+C	Ao	Co/C+Co	Model	R^2	MAE	MSE	Spatial class
					2 WAP				
BD	0.0089	0.0180	35.63	0.497	Exp	0.632	0.0051	0.00057	MSD
SWC	0.0001	0.0023	12.11	0.064	Gaus	0.878	0.00012	0.00002	SSD
Pt	0.0012	0.0024	27.30	0.498	Sph	0.736	0.0017	0.00010	MSD
EA	0.0016	0.0032	8.76	0.498	Sph	0.710	0.0018	0.00012	MSD
Ksat	286.9	573.9	45.47	0.500	Gaus	0.804	2.552	18.112	MSD
Ma	0.0004	0.0010	26.64	0.356	Sph	0.744	0.0022	0.00023	MSD
					At harvest				
BD	0.0073	0.0146	33.03	0.497	Exp	0.617	0.0036	0.0005	MSD
SWC	0.0004	0.0007	10.57	0.045	Gaus	0.831	0.0016	0.00002	SSD
Pt	0.0009	0.0019	27.22	0.497	Sph	0.737	0.0012	0.00007	MSD
EA	0.0012	0.0024	25.54	0.498	Sph	0.726	0.0022	0.00006	MSD
Ksat	256.8	513.7	45.13	0.500	Gaus	0.895	2.096	12.459	MSD
Ma	0.0010	0.0020	8.67	0.498	Sph	0.828	0.0016	0.00008	MSD
GY	0.0013	0.0023	24.04	0.565	Sph	0.745	0.0013	0.0004	MSD

BD: bulk density, g cm^{-3}; èv: soil volumetric water content, cm^3cm^{-3}; Pt: total porosity, cm^3 cm^{-3}; EA: aeration porosity, cm^3cm^{-3}; Ksat: soil saturated hydraulic conductivity, cm h^{-1}; Ma: macroporosity, cm^3cm^{-3}; GY: grain yield, kg m^{-2}

Co: nugget effect; C+Co: sill; Ao: range; Co/(C+Co): spatial ratio; R^2: coefficient of determination; MAE: mean absolute error; MSE: mean square error. Exp.: exponential; Gaus.: Gaussian; Sph.: spherical; MSD: moderate spatial dependence; SSD: strong spatial dependence.

spatial dependence, with the determined distinct classes of spatial dependence (nugget/sill ratio) ranging between 6.4 and 56.5%, only SWC having strongly structure spatial dependence (SSD) while other soil variables and grain yield showed moderate spatial dependence MSD), indicating that the distribution of these variables in space is not random. The Ksat had the highest CV and nugget effect compared to other physical variables, showing high discontinuity among samples. Vieira [49] stressed that the higher the nugget effect, the greater the discontinuity in samples. At harvest of cowpea, the same trend was obtained as regards the models and estimated parameters (range, nugget, sill, spatial dependence, etc) of the experimental semi variogram of the soil variables (Table 4). Strong spatial dependent in soil properties is an indication that such properties are controlled by variability in intrinsic soil properties such as geology, soil forming factors, texture and so on [47], whereas moderate spatial dependence may be due to management such as tillage, cropping system, irrigation, etc. According to Bijanzadeh *et al.* [50], understanding soil properties with their spatial dependence is of crucial importance for understanding the behavior of soil and hence provides better soil management.

By using the kriging algorithm of the geospatial analyst tool in ArcGIS, the spatial map of each soil indicator was plotted based on the semi variograms [51] as shown in Fig.5. The visualization of the distribution maps, at 2 WAP and harvest, showed that the soil varies in terms of physical properties, that is heterogeneity, indicating that the distribution of the variables are strongly influenced by both factors including geology, management practices, soil texture, among others. From the thematic maps, inverse relationship was also observed between BD and other variables (Pt, EA and Ma) because in the region where low BD was observed (Fig. 5a, b), higher values of Pt, EA and Ma were observed (Fig.5e, f, g, h, k, l). In addition, the low BD and high Pt, EA and Ma observed at northeastern region of the map (Fig. 5a, b, e, f, g, h, k, l) is attributed to better aggregation and improved pore space caused by the decay and decomposition of organic residue dumped from the sheep and goat pen that is located adjacent to the area. It was also observed that cowpea growth and development was rapid and vigorous in this region compared to other areas of the field.

Figure 6 shows the spatial distribution of kriged cowpea grain yield. The spatial map of the grain yield was or less similar to thoseof BD, Ma, Pt and EA, however the yield was high where the Ma, Pt and EA were highand where the BD was low, strictly following the relationship already obtained. The inclusion of grain yield in this spatial analysis confirms that spatial variation in soil properties causes variation in crop performance and yield unlike previous studies reported by

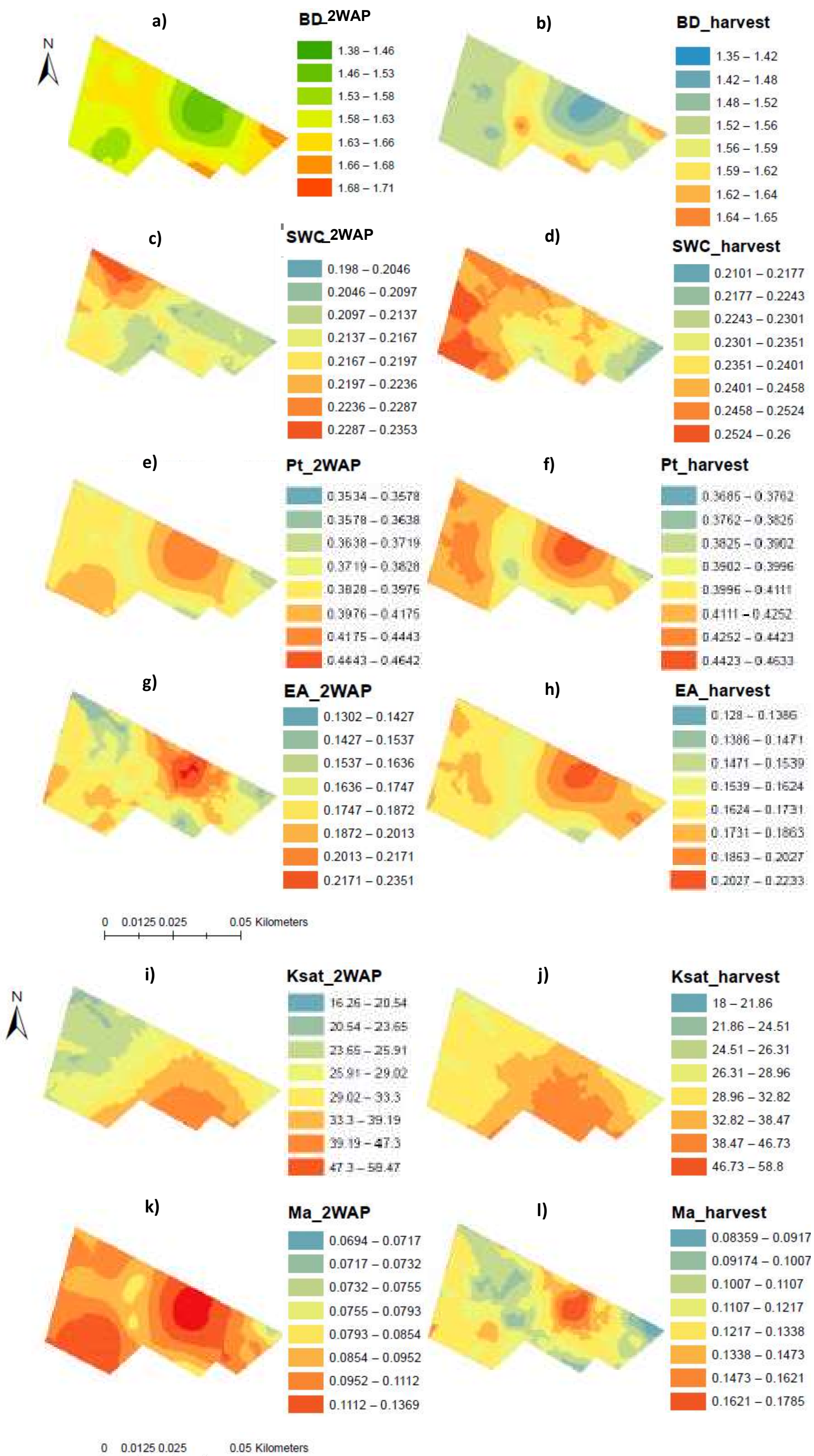

Fig. 5: Spatial distribution of kriged soil physical properties of the cowpea field at 2 WAP and harvest.

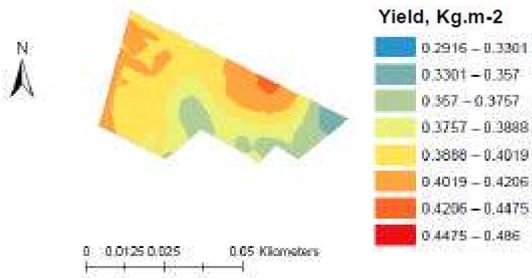

Fig. 6: Spatial distribution of kriged cowpea yield at harvest.

Santos, *et al*., [16] and Tavares, *et al*. [19]. The MAE indicates the bias while the MSE determines the prediction accuracy [52]. The results of test of cross-validation of the kriging procedure as checked by MAE and MSE statistics are shown in Table 4. Both the MAE and MSE values are close to zero, indicating that the kriging procedure was accurate. In this locality, this spatial analysis and mapping is the first of its kind, thus, the combination of yield and soil physical properties maps could be used to support spatial sampling and thus facilitate site-specific soil management strategies with a view to saving cost and protecting the environment.

CONCLUSIONS

Geographical information system (GIS) was combined with classical and geostatistical statistical methods to evaluate the spatial variability of physical properties of an Alfisol and cowpea grain yield on a land converted from continuous maize production.

The soil physical properties and grain yield showed varying degree of variation, with Ksat having the highest coefficient of variability.

All the soil physical propertiesand grain yield showed spatial dependence with properties BD, Pt, EA, Ksat, Ma and grain yield were moderate spatially dependent andSWC was strong spatially dependent.

The results showed that the spatial distribution of soil properties might vary even within a similar agricultural management, thus the findings of this study can be used to make recommendations for better management and modeling of soil and plant relationships in future studies.

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