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Spatial variability of soil properties under different land uses in the Koupendri catchment, Benin

Variabilidad espacial de las propiedades del suelo bajo diferentes usos del territorio en la cuenca de Koupendri, Benin

Variabilidade espacial das propriedades do solo sob diferentes usos da terra na bacia de Koupendri, Benim

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ABSTRACT

The knowledge of the spatial distribution of soil properties such as saturated hydraulic conductivity (Ksat), bulk density (BD), soil organic carbon (SOC), total nitrogen (TN) and available phosphorus (Avail. P) is fundamental to sustainable management of soil resources. A total of 291 surface soil (0-20 cm) samples were collected across three land use types: maize-sorghum (MS), rice field (Rice) and fallow shrub-grassland (FSG) in Koupendri, north-west Benin using a grid sampling of 25 m x 25 m. Additional soil samplings at 5 m x 5 m was carried out within the sampled area to capture small-scale variability. Data obtained were analysed using classical statistics, including Pearson's product moment correlation and analysis of variance and spatial statistics. The soil properties showed normal and non-normal distributions, and the coefficient of variation was high (75-126.7%) for Ksat, moderate (29-45%) for SOC, C/N and Avail. P, and low (7-15) for BD and TN across the different land use types. Land use had a significant ($P < 0.05$) effect on all the soil properties evaluated except C/N. The highest values of Ksat (151.6 cm/d), SOC (1.26%), BD (1.79 g/cm^3), TN (0.105%), Avail. P (4.66 ppm) and C/N (12.14) were obtained under the MS cropland whereas porosity was highest (43.7%) in the rice field. Highly significant correlation ($P < 0.01$) was observed among the soil properties irrespective of land use. The correlation length (65-300 m) and nugget effect ratio indicate high variation and strong spatially dependent soil properties. However, TN, BD, Avail. P and C/N were weakly spatially dependent. The variograms were fitted with mostly exponential and spherical models for mapping the variation in soil properties. The interpolation map could help in delineating different soil fertility and soil water management zones aimed at making good agronomic decisions.

RESUMEN

El conocimiento de la distribución espacial de propiedades del suelo como la conductividad hidraúlica (Ksat), la densidad aparente (BD), el contenido en carbono orgánico (SOC), nitrógeno total (TN) y fósforo disponible (Avail. P) es fundamental para el manejo sostenible de los recursos edáficos. Se recogieron un total de 291 muestras superficiales de suelo (0-20 cm) a lo largo de tres tipos de uso: maíz-sorgo (MS), un campo de arroz (Rice) y una

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zona de pastizal en barbecho (FSG)) en Koupendri, al noroeste de Benin, utilizando una red de muestreo de 25 m x 25 m. Se realizó un muestreo adicional de 5 m x 5 m dentro de la zona de estudio con objeto de determinar la variabilidad a escala detallada. Los datos obtenidos se analizaron mediante técnicas clásicas de estadística, incluyendo la correlación de Pearson, análisis de varianza y estadística espacial. Las propiedades de suelo mostraron una distribución normal y no normal, con un coeficiente de variación alto (75-126,7%) para Ksat, moderado (29-45%) para SOC, C/N y Avail. P, y bajo (7-15%) para BD y TN a lo largo de los usos del suelo. El uso del territorio tuvo un efecto significativo (P < 0,05) en todas las propiedades del suelo evaluadas excepto en la relación C/N. Los valores más altos de Ksat (151,6 cm/d), SOC (1,26%), BD (1,79 g/cm^3), TN (0,105%), Avail. P (4,66 ppm) y C/N (12.14) se obtuvieron bajo el uso MS, mientras que la porosidad fue mayor (43,7%) en el campo de arroz. Se observó una correlación significativa elevada (P < 0,01) entre las propiedades del suelo independientemente del uso del suelo. La longitud de correlación (65-300 m) y el efecto pepita indicaron una gran variación y fuerte dependencia espacial. Sin embargo, TN, BD, Avail. P y C/N se mostraron débilmente dependientes espacialmente. Los variogramas se ajustaron fundamentalmente con modelos exponenciales y esféricos a la hora de cartografiar las variaciones en las propiedades del suelo. El mapa de interpolación podría ayudar a delinear diferentes zonas de fertilidad y manejo de agua del suelo con objeto de tomar adecuadas decisiones agronómicas.

RESUMO

O conhecimento da distribuição espacial das propriedades do solo como a condutividade hidráulica (Ksat), a densidade aparente (BD), o conteúdo em carbono orgânico (SOC), nitrogénio total (TN) e fósforo disponível (Avail. P) é fundamental para a gestão sustentável dos recursos edáficos. Colheram-se um total de 291 amostras superficiais de solo (0-20 cm) sujeitos a três tipos de uso: milho-sorgo (MS), um campo de arroz (Rice) e uma zona de prados e arbustos de pousio (FSG) em Koupendri, noroeste do Benim, utilizando uma rede de amostragem de 25 m x 25 m. Realizou-se uma amostragem adicional de 5 m x 5 m dentro da zona de estudo com o objetivo de determinar a variabilidade a uma escala mais detalhada. Os dados obtidos foram analisados através de estatística clássica, incluindo correlação de Pearson, análise de variância e estatística espacial. As propriedades do solo apresentaram distribuição normal e não normal, com coeficiente de variação alto (75-126,7%) para Ksat, moderado (29-45%) para SOC, C/N e Avail. P, e baixo (7-15%) para BD e TN para os diferentes usos do solo. O uso da terra teve um efeito significativo (P < 0,05) em todas as propriedades do solo exceto na relação C/N. Os valores mais altos de Ksat (151,6 cm/d), SOC (1,26%), BD (1,79 g/cm^3), TN (0,105%), Avail. P (4,66 ppm) e C/N (12,14) foram obtidos para o uso MS, mas a porosidade foi maior (43,7%) no campo de arroz. Observou-se uma correlação significativa elevada (P < 0,01) entre as propriedades do solo independentemente do uso do solo. O comprimento de correlação (65-300 m) e o efeito pepita indicaram uma grande variação e forte dependência espacial das propriedades do solo. Contudo, TN, BD, Avail. P e C/N eram, espacialmente, fracamente dependentes. Para cartografar as variações nas propriedades dos solos, os variogramas ajustaram-se, fundamentalmente, com modelos exponenciais esféricos. O mapa de interpolação pode ajudar a delinear diferentes zonas de fertilidade e gestão da água do solo com o objetivo de tomar decisões agronómicas adequadas.

KEY WORDS
Soil fertility, variogram, heterogeneity, spatial dependence, agronomy.

PALABRAS CLAVE
Fertilidad del suelo, variograma, heterogeneidad, dependencia espacial, agronomía.

PALAVRAS-CHAVE
Fertilidade do solo, variograma, heterogeneidade, dependência espacial, agronomia.

1. Introduction

Soils are heterogeneous, diverse and dynamic in nature but are characterized by high spatial variability ranging from the point scale to the global scale. Such variability in both natural and managed ecosystems has been mostly driven by physical, hydrological and biological processes (Kumar and Remadevi 2006; Santra et al. 2008). Information on soil spatial variability may serve a range of different purposes. These purposes include modeling and understanding of hydrological processes at different spatio-temporal scales, and the production of sustainable soil and water resource management for improved agricultural productivity. In nature, complex pedological processes, their use and management drive soil variability at various spatial and temporal scales (Rodenburg et al. 2003; Viera and Paz González 2003). These complex pedological processes are classified as intrinsic (soil-forming), or extrinsic factors such as soil management practices, fertility status, crop rotation etc. (Cambardella and Karlen 1999). Generally, soil properties are known to exhibit high heterogeneity (Young et al. 2008) at different spatial scales and can also vary substantially under different land uses (Nadrowski et al. 2010). Burgos et al. (2006) noted that crop establishment and the type of vegetation also modifies soil variability through cultivation and implementation of agricultural soil management (Camacho-Tamayo et al. 2008). Recently, the importance of studies on spatial variability of soils across various land use types for sustainable agricultural productivity and the role of vegetation cover has been highlighted (Wei et al. 2008). The available data showed that soil spatial variability is high for temperate soils compared to tropical soils of the savanna region in West Africa. Idowu et al. (2003) reported that the West African savanna is one region with limited data on soil spatial variability across different land uses of the soil resources. Until now, little or no studies have been done on this subject in order to bridge this gap.

The spatial distribution of soil properties at different spatial scales has been widely evaluated using geostatistical tools (Klatka et al. 2019; Rabbi et al. 2014; Paz González et al. 2000). This includes analysis of the spatial structure, interpolation between point observations, and map creation from the interpolated values. The approach is based on the theory of regionalized variables of Matheron (1971) that takes into consideration the spatial variability of a variable e.g. soil property as a random function represented by a stochastic model (McBratney et al. 2000). Among all geostatistical tools, kriging has become the most preferred and optimal interpolator because it minimizes unbiased estimation variance and provides the error term or variance for the prediction from a known variogram (Fu et al. 2010). The ability of kriging to optimally predict values at unknown locations with minimum variance and without bias has boosted its popularity (Oliver and Webster 2014). Kumar and Remadevi (2006) also reported that the preference of kriging over other interpolation methods e.g. distance weighted, arithmetic mean, nearest neighbour methods etc. is due to its ability to consider the spatial structure of the variable.

The main objective of this study was to evaluate and characterize the structure of spatial variability of some soil properties of the Koupendri catchment in northwest Benin under different land use/ land cover using a kriging method. The specific objectives were: (i) to evaluate the effect of land use on soil properties, (ii) to examine the spatial structure and variability of soil properties across each land use, and (iii), to map the spatial distribution of soil properties using the best model.

2. Material and Methods

2.1. Study area

This study was carried out in the Koupendri catchment located between latitudes 10° 44' to 10° 46' N and longitudes 1° 08' to 1° 11' E (**Figure 1**). It has a relatively flat physiography with few intermittent local hillslopes which influence the hydrology of the catchment.

The catchment can be characterized as an undulating pediplain relief overlying a Precambrian crystalline basement. The soils (**Figure 2**) are mostly Plinthosols with gravelly or plinthic horizons, Luvisols, Cambisols and Gleysols based on IUSS Working Group WRB (2015) classification system and correlated with FAO/Unesco soil legend (Azuka et al. 2015). It has a unimodal rainfall distribution pattern with a distinct wet (rainy) season and dry season. The rainy season lasts for about five months, from June to October with peak rainfall occurring in September while the dry season lasts for seven months, from November to May. Annual rainfall varies between 700 and 900 mm with a mean of 800 mm. Temperature varies between 25 ºC and 30 ºC, during the rainy season with a relative humidity above 90 percent in August. However, the temperature reaches a maximum of between

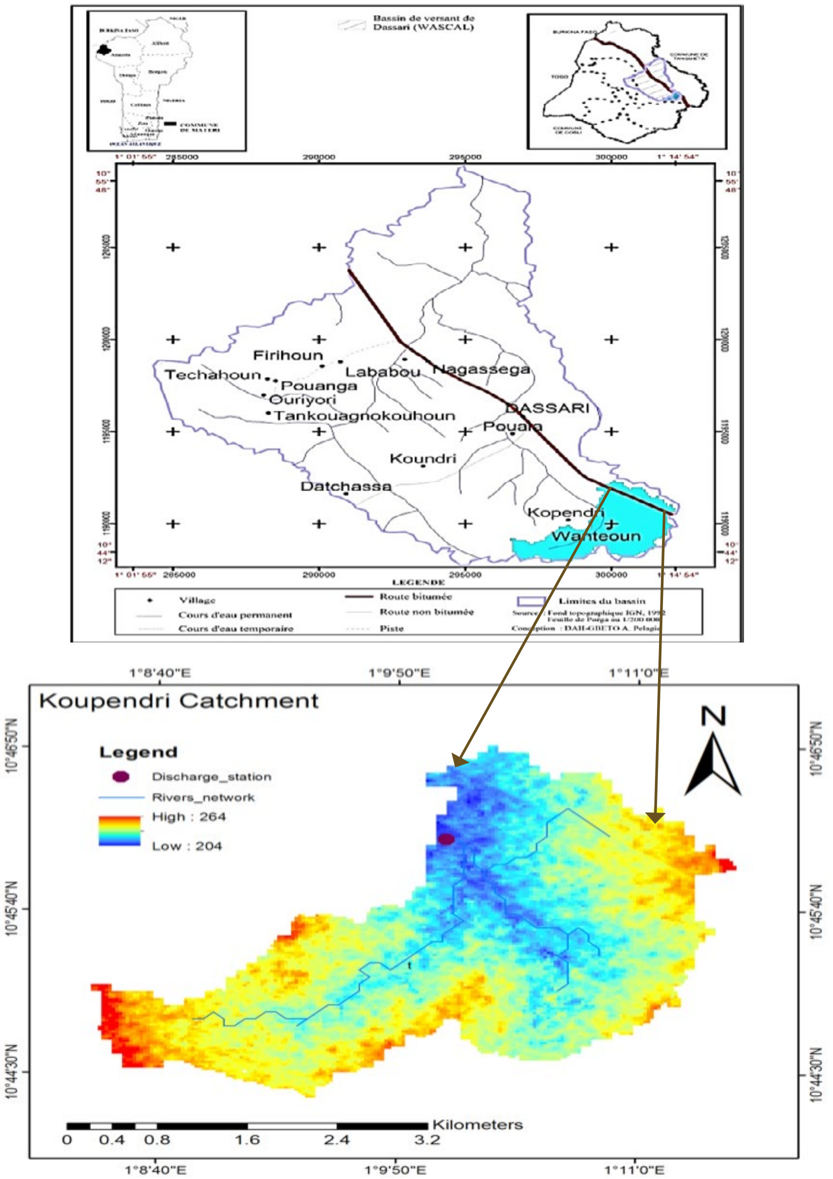

Figure 1. Location of Koupendri catchment in the Dassari catchment, North-West of Benin.

42 °C between March and April (Barry et al. 2005). The catchment is located within the northern (dry) Sudanian region according to the vegetation zone classification of Benin by Wezel and Bocker (2000). The Sudanian vegetation is dominated by a mixture of grassland and tree/shrub savannah of low density composed of *Combretum* spp., *Acacia gourmaensis* and *Crossopteryx febrifuga* (Idiéti 2012). The major land use in the catchment is agriculture and focused mainly on grain crops such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), etc.; tuber crops such as yam (*Dioscorea* spp.); and cash crops such as cotton. Pastoralism (livestock production) is also common in the area. Bush burning and burning of rice crop residue especially in the dry season is a usual practice in the catchment.

2.2. Soil sampling and analysis

Surface soil samples were collected from 0-20 cm depths using a systematic sampling approach within the three selected land uses in the catchment. The selected land use includes maize-sorghum cropland (MS), rice field and fallow shrub-grassland (FSG). In each of the selected land use types, a maximum of 60 soil sampling points were sampled using a regular grid size of 25 m x 25 m resolution, with an additional 40 points sampled at 5 m x 5 m

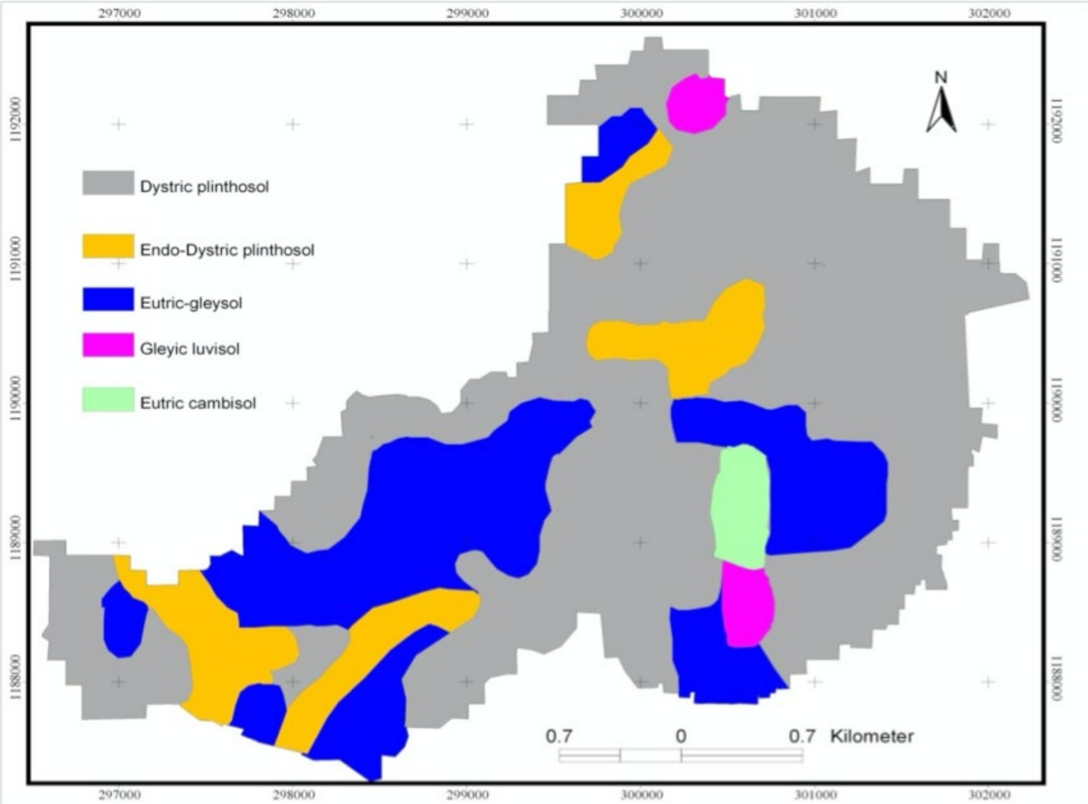

Figure 2. Distribution of soils in the Koupendri catchment at a scale of 1:25000 based on IUSS Working Group WRB (2015) classification system and correlated with FAO/Unesco soil legend (Azuka et al. 2015).

resolution within the initial sampling points (**Figure 3**). This was done to avoid missing the short-range variation crucial for estimating the most important part of the variogram (Oliver and Webster 2014). The coordinates of the sampling points were georeferenced and recorded with the aid of a GPS. Samples were taken in triplicate at each sampling point and bulked together to give one composite sample. This was done to overcome small scale variability and ensure that the collected soil samples were truly representative of the site or location. A total of 291 disturbed composite soil samples were collected from the three selected land use types and analyzed for soil organic carbon (SOC), total nitrogen (N) and available phosphorus (P). The soil samples were air-dried, sieve through a 2 mm mesh and analyzed using standard analytical procedures. The total N was determined using the Kjeldahl digestion procedure (Bremner 1996), SOC was analyzed using the dichromate oxidation method (Nelson and Sommers 1982), and available P was determined using the Bray I method (Bray and Kurtz 1945) for acid soils; and Bray II method (Bray and Kurtz 1945) for alkaline soils. Bulk density was determined by the core method as described by Blake and Hartge (1986). Saturated hydraulic conductivity (Ksat) was measured using the constant head permeameter method. Darcy's equation, as outlined by Youngs (2001) (**equation 1**) was used for the computation of $K_{sat;}$

$$K_{sat} = \frac{Q \,.L}{A \,.T \,.\Delta H} \quad (1)$$

Where Q = steady state volume of outflow from the entire soil column (cm^3), L is the length of soil column (cm), A is the interior cross-sectional area of the soil column (cm^2), ΔH is the change in hydraulic head or the head pressure difference causing the flow (cm), T is the time of flow (sec). Total porosity (%) was calculated from bulk

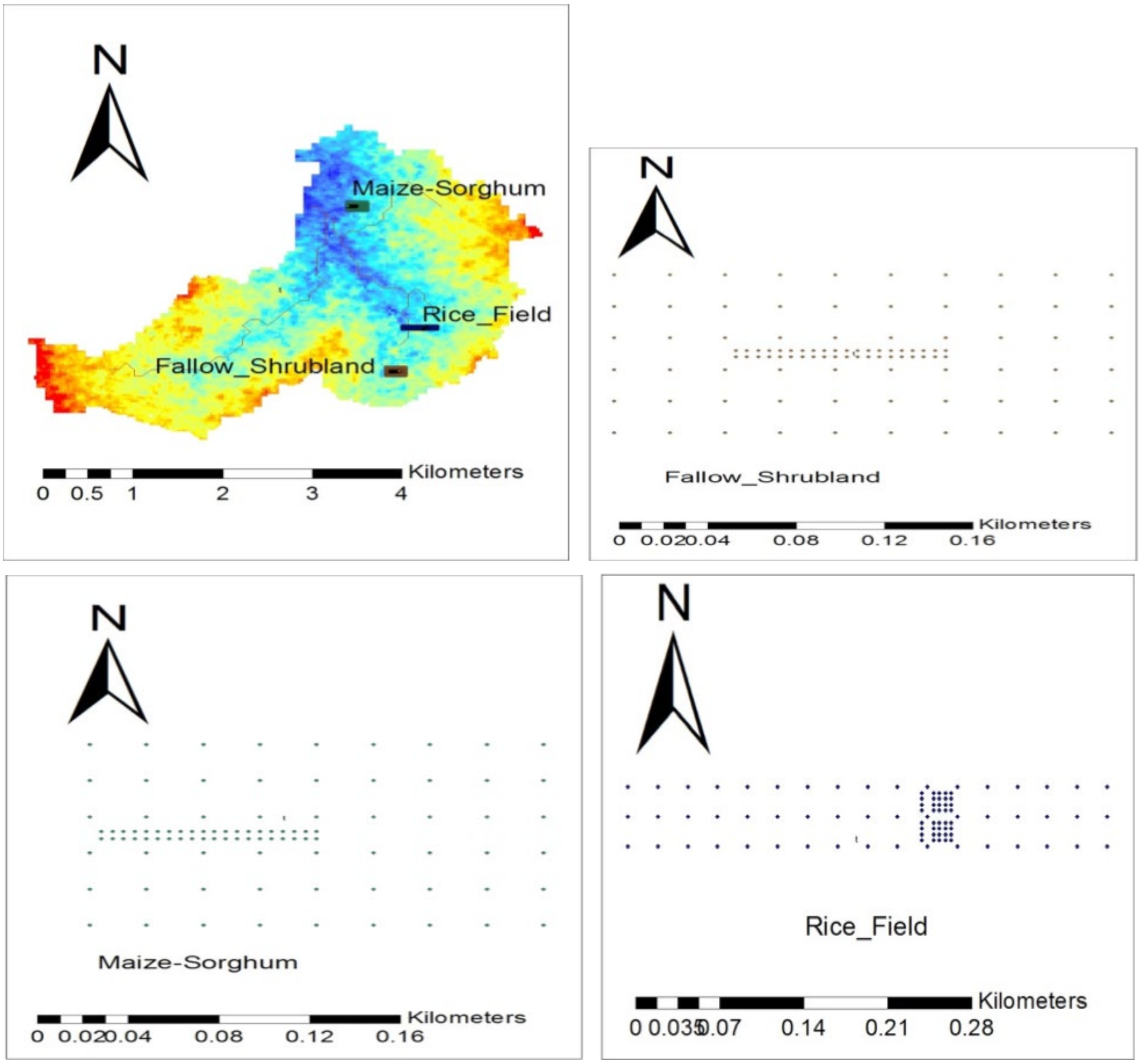

Figure 3. Sampling pattern for geostatistical analysis.

density (assumed particle density p_s = 2.65 kg m^{-3}) using the equation below (**equation 2**):

$$TP = \left(1 - \frac{P_s}{P_b}\right) x\ 100(2)$$

2.3. Statistical analysis

The data were subjected to one-way analysis of variance ANOVA using GENSTAT. Means for the main effects of land use on soil properties were compared for significant differences using the Fischer's least significant difference (F-LSD) procedure as described by Obi (2002). The relationship between the measured soil properties was evaluated using Pearson's r correlation analysis. Geostatistical analysis was done to characterize the spatial pattern or structure of the soil properties under different land use types. Normality and trend analyses were also carried out to check and correct the global trends in the data before geostatistical analysis. Non-normality or asymmetry in the distribution of the datasets has been reported to have an important effect on geostatistical analysis (Kerry and Oliver 2007). Some of the data which were not normally distributed were transformed before geostatistical analysis.

Geostatistical analysis was done using a semi-variogram to quantify the spatial patterns of regionalized variable and derives important input parameters used for kriging spatial interpolation and mapping (**equation 3**).

$$\gamma(\mathrm{h}) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 (3)$$

Where $z(x_i)$ is a measured sample at point x_i, $z(x_i+h)$ is a measured sample at point x_i+h, and $N(h)$ is the number of pairs separated by lag interval or distance h (Zhao et al. 2010). The semi-variogram was fitted or modeled with spherical, exponential, or Gaussian model (**equations 4-6**) respectively.

$$\gamma(h) = \begin{cases} C_0 + C_1\left[\frac{3}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^3\right] & for\ h \le a \\ C_0 + C_1 & for\ h > a \end{cases} (4)$$

$$\gamma(h) = \begin{cases} C_0 + C_1\left(1 - e^{-h/a}\right) & for\ h \le a \\ C_0 + C_1 & for\ h > a \end{cases} (5)$$

$$\gamma(h) = C_0 + C_1\left(1 - exp(h^2/a^2)\right)(6)$$

These models provide information about the spatial structure of the fitted models and the input parameters for kriging such as the nugget effect (C_0), which occurs at distances smaller than the sampling interval (e.g. 5 and 25 m in the present study), partial sill or structural variance C_1, and sill variance (C_0 +C_1, i.e. the total variance indicating the distance beyond which samples are considered to be spatially independent causing the semi-variogram not to be increasing with increasing distance). The correlation length or range (a) was derived from the fitted or modeled semi-variograms. The best-fitted model for each evaluated soil property under the different land use types was selected and presented in this study.

The kriging interpolations were mapped to reveal the overall trend of the data (Burgos et al. 2006). For the transformed data, the interpolation and mapping were done after converting them back to their original values. All geostatistical analysis and mappings were done using GIS software ArcMap (version 10.2; Esri, Redlands, CA) with its Geostatistical Analysts extension.

3. Results

3.1. Effect of land use on soil properties in Koupendri catchment

The results showed that land use has a very high significant ($p < 0.05$) effect on all the soil properties evaluated except the C/N ratio (**Table 1**). The highest mean values of Ksat (151.6 cm/d), SOC (1.26%), BD (1.79 g/cm^3), TN (0.105%), Avail. P (4.66 ppm) and C/N (12.14) were recorded in the maize-sorghum cropland; the highest value of 47.3% for porosity was recorded in the rice cropland. The lowest values of Ksat (32.6 cm/d), SOC (0.86%), BD (1.49 g/cm^3) were recorded in the rice cropland, while the lowest values for TN (0.077%), Avail. P (2.23 ppm) and C/N (11.10) were recorded in the fallow shrub-grassland.

Across the three land use types evaluated, the CV of Ksat was 126.7%, followed by Avail. P (CV = 36.6%) and SOC (CV = 35.2) respectively (**Table 1**).

3.2. Correlation analysis

The Pearson (r) correlation matrix for the soil properties evaluated under the different land uses/covers is shown in **Table 2**. Irrespective of land use, significant ($p < 0.01$) relationships amongst the evaluated soil properties were

Table 1. Effect of land use on soil properties in the Koupendri catchment

Land use	Ksat (cm/d)	BD (g/cm^3)	Porosity (%)	SOC (%)	TN (%)	Avail. P (ppm)	C/N ratio
FSG	36.5	1.55	41.57	0.99	0.077	2.23	11.10
MS	151.6	1.79	32.56	1.26	0.105	4.66	12.14
Rice	32.6	1.49	43.70	0.86	0.083	2.28	11.85
CV (%)	126.8	7.7	11.8	35.2	24.5	36.6	21.8
F-LSD$_{0.05}$	**33.6**	**0.044**	**1.67**	**0.13**	**0.008**	**0.403**	**NS**

Table 2. Pearson r correlation analysis results for the soil properties under different land uses

	Ksat	BD	Porosity	SOC	TN	C/N	Avail. P
Ksat	1						
BD	**-0.157****	1					
SOC	**0.429****	**-0.315****	**0.315****	1			
TN	**0.302****	**0.184****	**-0.184****	**0.766****	1		
C/N	**0.305****	0.050	-0.050	**0.692****	0.151	**1**	
Avail. P	**0.409****	**0.507****	**-0.507****	**0.572****	**0.557****	**0.256****	**1**

In bold, significant values at p-level of significance = 0.01 (two-tailed test) irrespective of land use.

highlighted in bold (Table 2). The results showed that SOC, TN and Avail. P had significant ($p < 0.01$) relationships amongst themselves and with other soil properties such as Ksat, porosity, bulk density (BD), and C/N ratio. SOC had significant ($p < 0.01$) positive relationships with Ksat ($r = 0.429$), porosity ($r = 0.315$), TN ($r = 0.766$), Avail. P ($r = 0.572$) but a significant ($p < 0.01$) negative relationship with BD ($r = -0.315$). Similarly, TN had a significant ($p < 0.01$) positive relationship with Ksat ($r = 0.302$), BD ($r = 0.184$) and Avail. P ($r = 0.557$), but a significant ($p < 0.01$) negative relationship with porosity ($r = -0.184$). Also, Avail. P had significant ($p < 0.01$) positive correlation with Ksat ($r = 0.409$), BD (0.507), C/N ($r = 0.256$) but significant ($p < 0.01$) negative correlation with porosity ($r = -0.507$).

3.3. Geostatistical analyses results of some selected soil properties under different land use types

The semi-variogram models and some geostatistical parameters of Ksat, BD, SOC, TN, Avail. P and C/N under different land use types in the Koupendri catchment is shown in Figures 4-9. The spatial correlation length (range) of SOC (94-286 m), Ksat (69-133 m), C/N (88-168 m), TN (88-180 m), BD (120-198 m) and Avail. P (132-231 m) was high across the three land use types indicating a longer distance over which these soil properties were closely related. There was no spatial autocorrelation beyond these ranges.

The variograms and the interpolated maps clearly revealed some patterns in the distribution of the soil properties evaluated in the Koupendri catchment. The semi-variance or variogram of the spatial distribution of Ksat, BD, SOC, TN, Avail. P and C/N ratio (Figures 4-9) revealed some differences in their spatial pattern or their distribution. The interpolated maps showed that SOC was highest from the southeastern part of the map under maize cultivation and decreased towards the west, with the northernmost part showing the lowest values (Figure 4). The distribution of SOC seemed to be homogenous across the entire sampled area, decreasing towards the northernmost part. For the rice field,

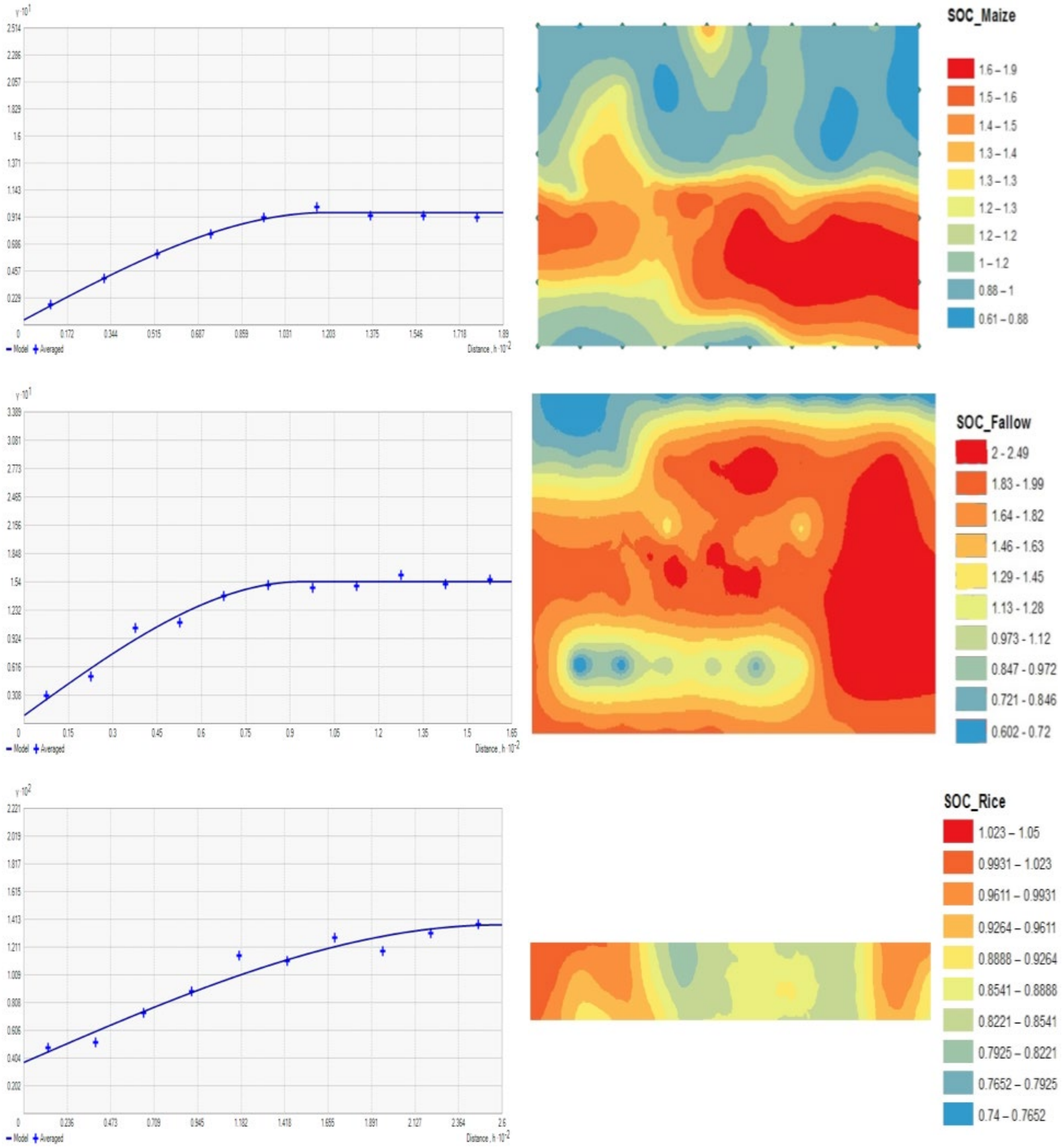

Figure 4. Variogram and map of soil organic carbon (SOC) under different land uses.

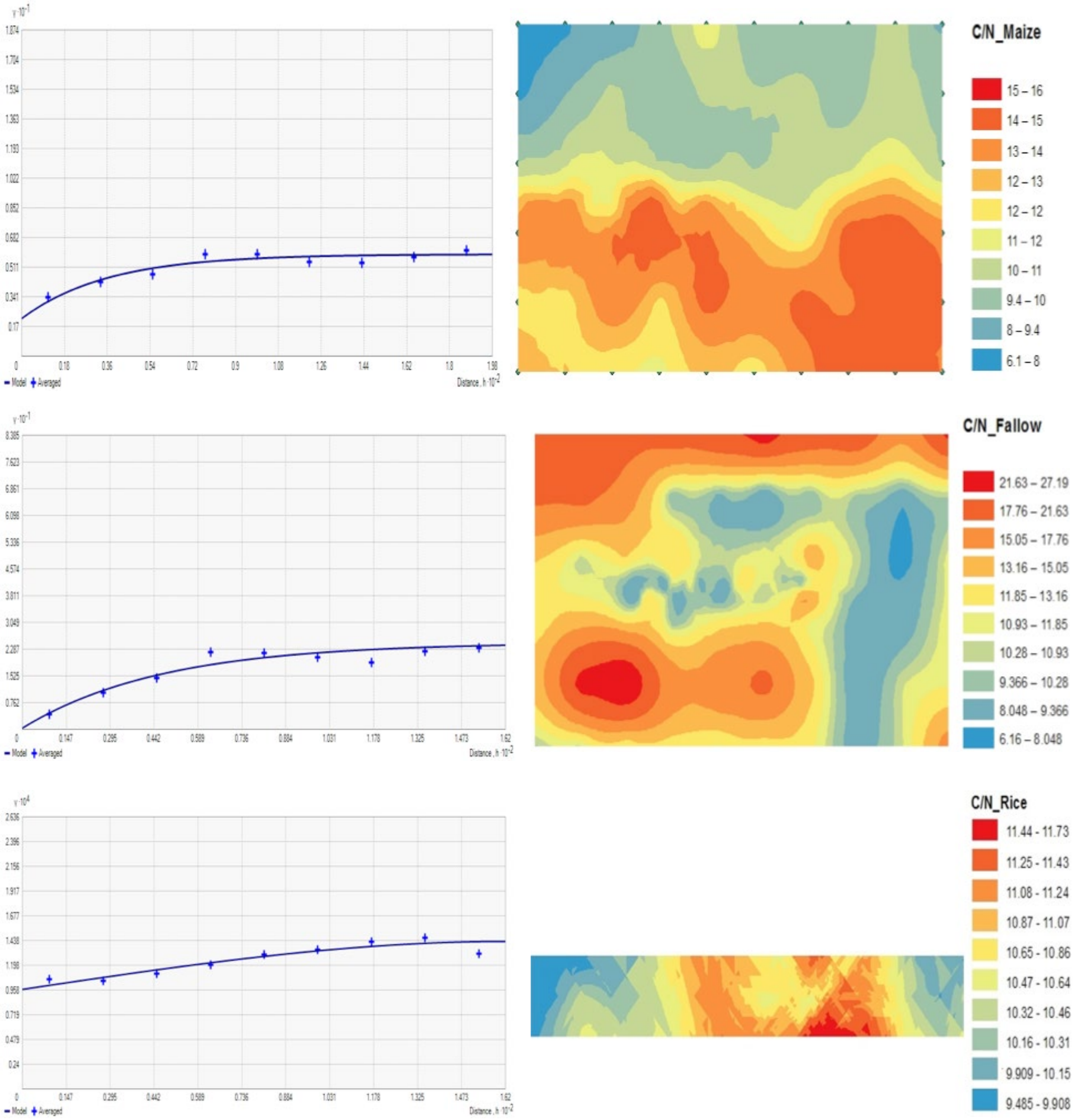

Figure 5. Variogram and map of carbon-nitrogen ratio (C/N) under different land uses.

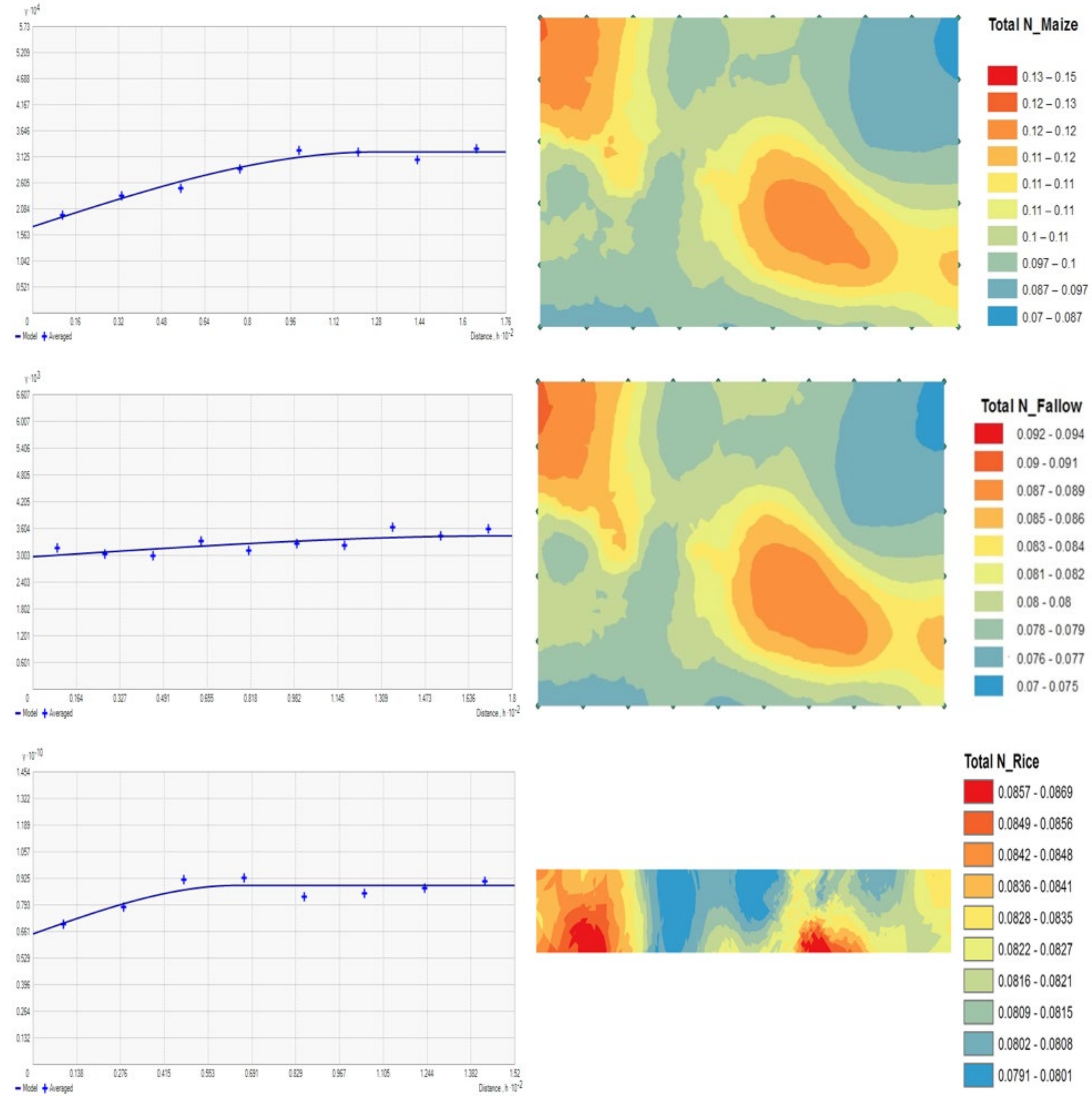

Figure 6. Variogram and map of total nitrogen (Total N) under different land uses.

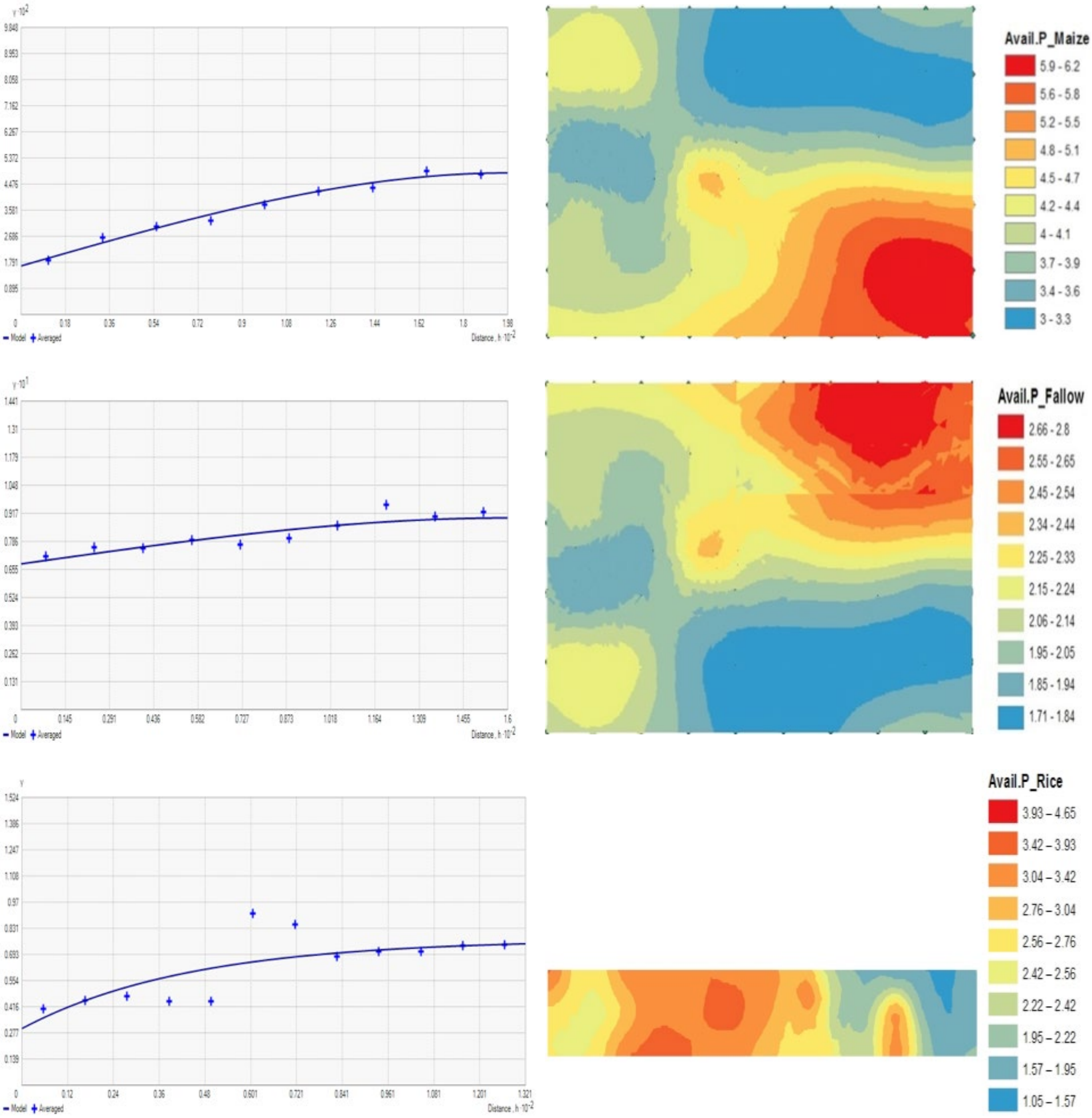

Figure 7. Variogram and map of available phosphorus (Avail. P) under different land uses.

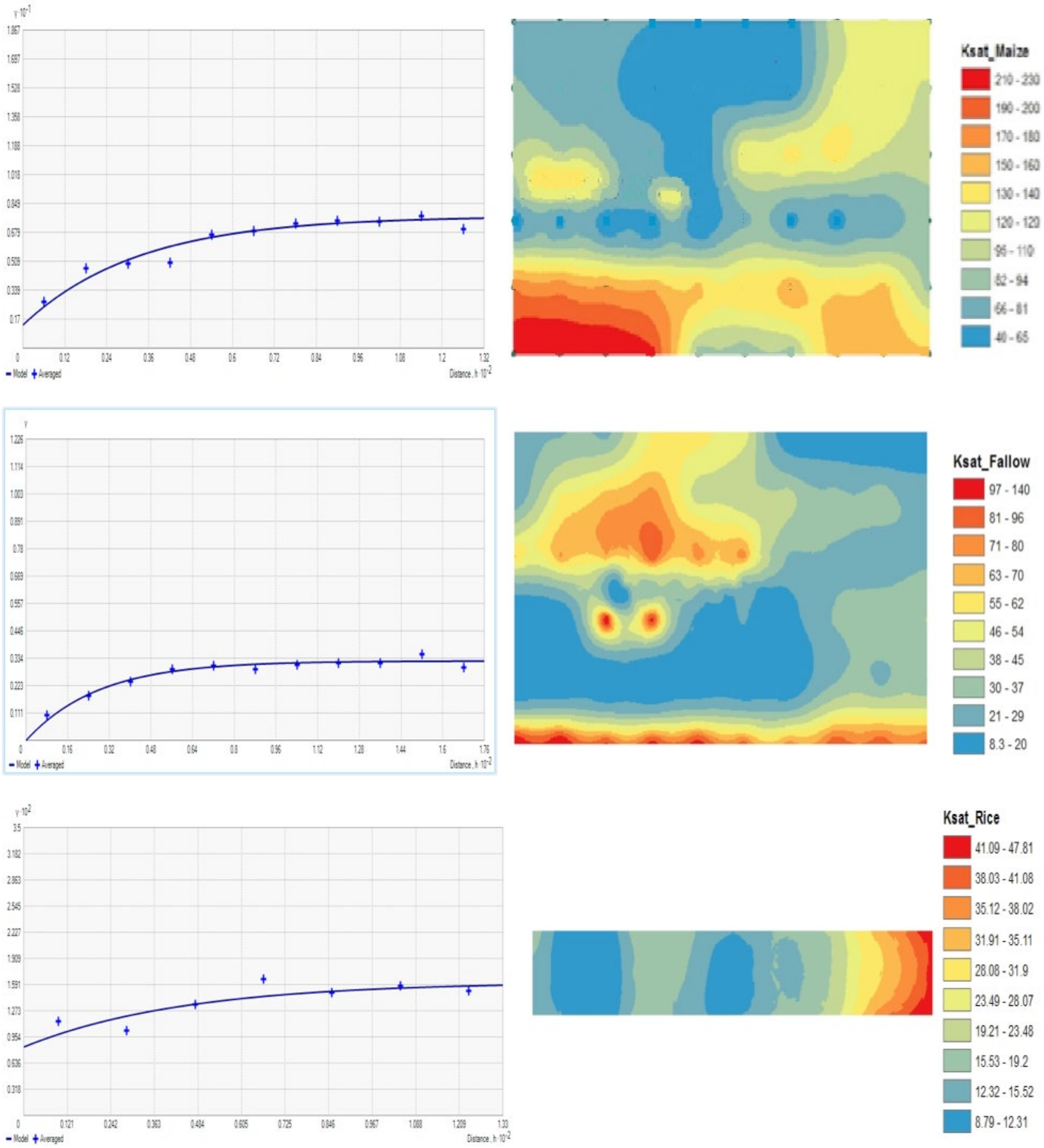

Figure 8. Variogram and map of saturated hydraulic conductivity under different land uses.

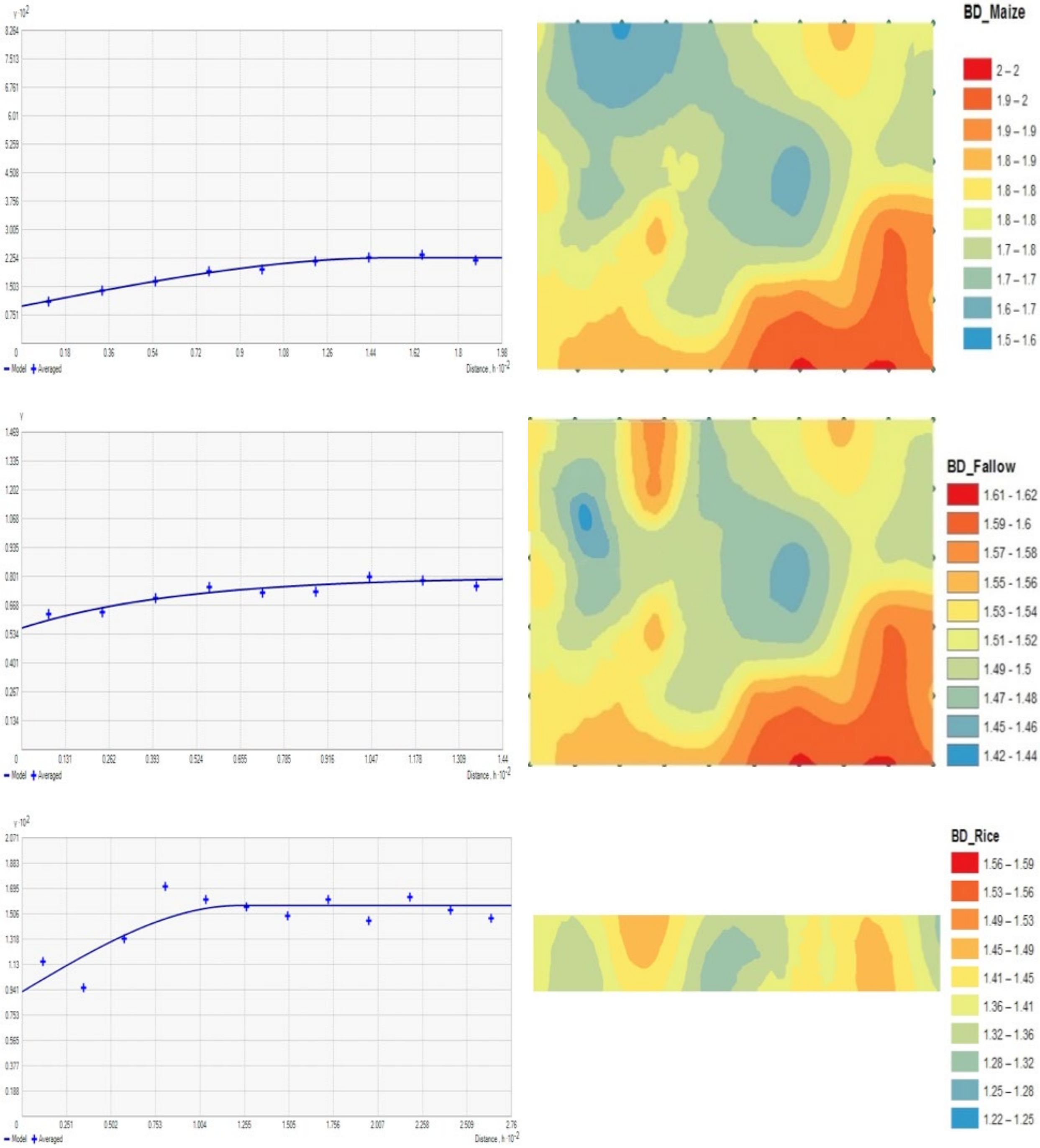

Figure 9. Variogram and map of bulk density (BD) under different land uses.

SOC was highest westward and eastward of the sampled area but decreased towards the central part. The map showed that C/N followed a similar trend or pattern of distribution with SOC and not with TN (**Figure 6**), indicating that C/N is strongly dependent on SOC. The map also showed a clearly defined pattern of distribution of soil Avail. P and BD within the different land use types, concentrated more on one side of the sampled area (**Figures 7, 9**). However, the distribution Ksat across the three land use types as shown by the maps (**Figure 8**) was rather random or discrete indicating the high variation exhibited by Ksat.

4. Discussion

Ksat, an important hydraulic property influencing flow and transport processes, was a highly variable property irrespective of land use as seen from the high CV of 48-126.8%. Agyare (2004) also reported a high CV of more than 100% for Ksat in the Volta basin. Such high variability in Ksat will elicit varied responses to hydrological processes such as surface runoff, flooding etc. across the various land use types investigated. Generally, MS land use with the highest Ksat value of 151.6 cm/d is expected to be less prone to surface runoff and flooding. Bulk density had the lowest CV (7-8.6%) across the three land use types and this fell within the range observed by Warrick and Nielsen (1980). A similarly low CV for BD was reported by Agyare (2004) for the Volta basin. Low CV often indicates uniformity in soil conditions in the area due to the parent material on which the soil is formed (Cambardella et al. 1994). The variability of SOC, TN, Avail. P and C/N showed low and moderate coefficients of variation. Several other researchers (e.g Wang et al. 2009; Wei et al. 2008) have reported moderate variability of TN and Avail. P. Denton et al. (2017) also reported high variability for Avail. P and moderate variability for TN and SOC. However, some of these studies did not put land use differences into consideration. The variability of the selected soil properties was higher in the fallow shrub-grassland land use compared to the other land use types. This clearly showed that apart from variability caused by geology, climate and vegetation type, land use and soil management practices such as tillage, fertilizer application etc. also influence the variation of these soil properties. It has been reported that addition of NPK fertilizers influences and reduces the variability of C/N (Zhang et al. 2016).

Most of the soil properties evaluated were not normally distributed. Other authors have also reported that some soil properties (e.g. SOC, TN, Avail. P) did not fulfil the normality requirement and transformed them before further analysis (Wang et al. 2009). Although natural, non-normal distribution of some soil properties has been reported (e.g. Webster and Oliver 2000), the principal reason for some soil properties not having normal distributions may be related to soil management practices and the temporal effect of tillage (Cambardella et al. 1994).

The result revealed that land use had a strong influence on the soil properties investigated. Other researchers have reported that different field management practices e.g. tillage and fertilizer application could influence soil physico-chemical and morphological properties of similar soil types (Fabrizzi et al. 2003). Wang et al. (2009) made similar findings for a small watershed on a loess plateau in China under different land uses. Kılıç et al. (2012) also found that increased soil tillage caused significant ($p < 0.01$) decreases or changes in soil properties e.g SOC, TN, Avail. P, etc. Celik (2005) also reported increased bulk density of surface soil due to deforestation and subsequent tillage practices. This result is consistent with the findings of other researchers (e.g. Abad et al. 2014; Ayoubi et al. 2011) who noted from their various studies that soils of agricultural land use had the highest bulk density in comparison to other land use types. The low SOC may be because of crop residue or biomass burning in the prevailing-slash-and burn land clearing method practiced in the Koupendri catchment. Saturated hydraulic conductivity (Ksat) is one soil property judged to be a sensitive indicator of land use change (Zimmermann et al. 2006). Several results showed that Ksat tended to be higher in forestland and decreased through agricultural lands, grassland and wetlands (Mainuri and

Owino 2013; Giertz et al. 2005). The higher Ksat value of 151.6 cm/day obtained in this study could also be attributed to the differences in soil types and landscape characteristics. The soil map of the catchment showed that MS land use was located within plinthosols characterized with the presence of plinthites and gravels while FSG and Rice field were located within Luvisols and Greysols respectively. Similarly, the MS land use type was located upslope while the FSG and Rice field land use types were located downslope and characterized by frequent flooding during some part of the rainy season.

Generally, the results showed that an increase in SOC lead to a decrease in soil BD across the land use types. More so, the carbon-nitrogen (C/N) ratio showed significant positive correlations with TN and SOC, indicating that C/N increased with increasing TN and SOC contents. This confirms the already known fact that besides the type of organic material involved, the rate of mineralization of organic materials is a function of the content of nitrogen in the soil. We also found that Avail. P increases with increasing SOC, TN and C/N. This result has shown that Avail P is strongly dependent on the SOC and TN content of the soil, and to some extent on the C/N.

Most of the soil properties were best fitted with an exponential and spherical model. This is similar to the findings of Agyare (2004) for the Volta basin. The nugget effect of SOC across the three land use types was lowest, implying strong spatial dependence or spatial continuity between neighboring points. In other words, near and distant samples have similar and different values respectively. The high nugget values obtained for TN in this study contradicts the findings of Denton et al. (2017), and Vieira and Paz González (2003) who reported very small nugget effect for TN. The high nugget effect of TN, especially under rice fields, could be attributed to the variation at smaller spatial scales not detected or captured at the present sampling scale. Additional sampling of these variables at smaller lag distances and in larger numbers might be needed to detect spatial dependence and characterize their spatial variability. However, research has also shown that the nugget effect could also be a result of soil and crop management practices e.g fertilizer application (Xu et al. 2013). Han et al. (2010) reported that the partial sill or structural variance C_1 component of the sill or total variance (C_0+C_1) is the variance caused or contributed by soil parent materials, climate, and terrain.

The majority of the soil properties investigated showed strong and moderate spatial dependence or distribution in patches across the three land use types. However, TN and BD showed a weak spatial dependence under the fallow shrub-grassland. Wang et al. (2009) also found a very weak spatial dependence (97.9%) for soil total phosphorus in a shrub land. Such information on the spatial dependence of the soil properties is particularly important in precision farming where inputs are limited to where they are needed. Generally, soil properties with strong and moderate spatial dependence tend to be conducive to site-specific management. On the contrary, soil properties with little (weak) or no spatial dependence will not be conducive to site-specific management and will be managed on the average (Pierce and Nowak 1999). The average extent of these distribution patches or spatial dependence is given by the range of the semivariogram. The range values showed considerable variation (10-260 m) among the soil properties investigated even within the same land use type. A similar high variation in the range of different soil properties was reported by López-Granados et al. (2002). The high range or spatial dependency of these soils is an indication of strong spatial dependence or spatial variability (Abu and Malgwi 2011). In other words, the measurements of these soil properties or variables are correlated with each other. The implication is that the observed values of the soil properties may be influenced by other values of the same property over greater distances than soil variables which have smaller ranges (Samper-Calvete and Carrera-Ramírez 1996). Similar high range observed for most of the soil properties especially Ksat investigated in this study corroborate the findings of other researchers (e.g. Abu and Malgwi 2011; Sharma et al. 2011; Cemek et al. 2007). Zimmermann and Elsenbeer (2008) also reported that spatial and temporal variability of Ksat is most pronounced under natural forest and under a regenerating fallow. According to Zimmermann and Elsenbeer (2008), agriculture seems to promote spatial Ksat patterns that are completely random, but with strong and extensive autocorrelations.

The differences in the spatial distribution of the soil properties investigated as shown by the clear patchy distribution in the interpolated maps could be attributed to land use and soil management practices. Similar findings were made by several authors (e.g., Tan and Lal 2005; Wang et al. 2009; Xu and Xu 2003) across various land use and vegetation types. Other authors (e.g., Williams et al. 2005; Cambardella and Karlen 1999; Kılıç et al. 2004) reported that fertilization and cultivation practices influenced spatial distribution of soil properties. Yuan et al. (2007) also reported that changes in farming practices and land use are thought to be the main reason for the temporal change in the spatial distribution SOC. More so, Denef et al. (2004) also reported that changes in the size of the secondary aggregates may be responsible for the variability of soil organic matter for agricultural soil. Wang et al. (2009), who observed moderate variability of TN and total P under different land use types, also reported significant changes in the spatial patterns of TN and total P under land use change in China. Since the spatial variability of these soil properties has implications for water flow and storage, nutrient management, and crop selection (Iqbal et al. 2005), the information provided here will be useful in making informed decisions with respect to site selection for improved crop production.

5. Conclusions

Sustainable use of soil resources and environmental management require an understanding of soil spatial variability. The results showed that the soil properties were significantly influenced by land use. Also, most of the soil properties, e.g. SOC, Avail. P and C/N, varied moderately across the various land use evaluated except Ksat that showed high variability. The variability of TN and BD were mostly low across the three land use types. The soil properties exhibited normal and non-normal distribution across the three land use types. The Pearson correlation analysis showed significant relationships amongst the soil properties which may influence their variability. Land use had a strong effect on these relationships. Avail. P had strong dependence on SOC, TN and C/N. The range values showed considerable variability amongst the measured soil properties, although TN and BD were weakly spatially dependent across the land use types based on their nugget effect values. This information is important for precise management of TN, Avail. P and SOC in terms of soil fertility management. SOC has the strongest spatial dependence among all the soil properties studied and across various land use. Land use and soil management practices such as tillage operations and fertilizer applications significantly influenced the soil properties, their distribution, and their spatial structure or patterns. The clear patchy distribution of the soil properties observed in this study has demonstrated that land use influenced their spatial distribution. The prediction maps provided useful information for site-specific management of these soil properties in precision agriculture for improved agricultural productivity.

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