Research Article

Variability of Soil Physical Properties in a Clay-Loam Soil and Its Implication on Soil Management Practices

Samuel I. Haruna and Nsalambi V. Nkongolo

Center of Excellence for Geospatial Information Sciences, Department of Agriculture and Environmental Science, Lincoln University, Jefferson City, MO 65102-0029, USA

Correspondence should be addressed to Nsalambi V. Nkongolo; nkongolo@lincolnu.edu

Received 26 August 2013; Accepted 17 November 2013

Academic Editors: R. K. Kolka and H. O. Liechty

Copyright © 2013 S. I. Haruna and N. V. Nkongolo. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

We assessed the spatial variability of soil physical properties in a clay-loam soil cropped to corn and soybean. The study was conducted at Lincoln University in Jefferson City, Missouri. Soil samples were taken at four depths: 0–10 cm, 10–20, 20–40, and 40–60 cm and were oven dried at 105°C for 72 hours. Bulk density (BDY), volumetric (VWC) and gravimetric (GWC) water contents, volumetric air content (VAC), total pore space (TPS), air-filled (AFPS) and water-filled (WFPS) pore space, the relative gas diffusion coefficient (DIFF), and the pore tortuosity factor (TORT) were calculated. Results showed that, in comparison to depth 1, means for AFPS, Diff, TPS, and VAC decreased in Depth 2. Oppositely, BDY, Tort, VWC, and WFPS increased in depth 2. Semivariogram analysis showed that GWC, VWC, BDY, and TPS in depth 2 fitted to an exponential variogram model. The range of spatial variability (A_0) for BDY, TPS, VAC, WFPS, AFPS, DIFF, and TORT was the same (25.77 m) in depths 1 and 4, suggesting that these soil properties can be sampled together at the same distance. The analysis also showed the presence of a strong ($\leq 25\%$) to weak ($>75\%$) spatial dependence for soil physical properties.

1. Introduction

Characterizing the spatial variability and distribution of soil properties is important in predicting the rates of ecosystem processes with respect to natural and anthropogenic factors [1] and in understanding how ecosystems and their services work [2]. In agriculture, studies of the effects of land management on soil properties have shown that cultivation generally increases the potential for soil degradation due to the breakdown of soil aggregates and the reduction of soil cohesion, water content and nutrient holding capacity [3, 4]. Cultivation, especially when accompanied by tillage, has been reported to have significant effects on topsoil structure and thus the ability of soil to fulfill essential soil functions and services in relation to root growth, gas and water transport and organic matter turnover [5–7]. Soil properties vary considerably under different crops, tillage type and intensity, fertilizer types and application rates. Consequently, the physical properties of the soil are also affected by many factors that change vertically with depth, laterally across fields

and temporally in response to climate and human activity [8]. Since this variability affects plant growth, nutrient dynamics, and other soil processes, knowledge of the spatial variability of soil physical properties is therefore necessary. To study the spatial distribution of soil properties, techniques such as classical statistics and geostatistics have been widely applied [9–11]. Geostatistics provides the basis for the interpolation and interpretation of the spatial variability of soil properties [9, 12–14]. Information on the spatial variability of soil properties leads to better management decisions aimed at correcting problems and at least maintaining productivity and sustainability of the soils and thus increasing the precision of farming practices [1, 15]. A better understanding of the spatial variability of soil properties would enable refining agricultural management practices by identifying sites where remediation and management are needed. This promotes sustainable soil and land use and also provides a valuable base against which subsequent future measurements can be proposed [14]. Despite the importance of this topic in agriculture, the literature is not abundant on the variability of soil physical properties in

FIGURE 1: Study area (Lincoln University's Freeman farm) showing the plots.

Central Missouri. Furthermore, existing studies on the spatial variability of soil properties have focused on the top soil (0–20 cm) with less or no studies at deeper soil depths (30–100 cm). The objective of this study was therefore to assess the spatial variability of soil physical properties at various depths (0–10 cm, 10–20, 20–40 and 40–60 cm) in a clay-loam soil cropped to corn and soybean, and determine how knowledge on this variability can affect soil management practices.

2. Materials and Methods

2.1. Experimental Site. The study was conducted at Lincoln University's Freeman farm in Jefferson City, Missouri. The geographic coordinates of the study site are 38°58'116"N latitude and 92°10'53"W longitude. The soil of the experiment site is a Waldron clay-loam (Fine, smectitic, calcareous, mesic Aeric Fluvaquents). The study area is almost flat, with an average slope of 2%. The experimental field was made of 48 plots of 12.19 m width by 21.34 m length each. The 48 plots were arranged in a grid of 4 plots in the width by 12 plots in length as shown in Figure 1. One half of the plots was planted to corn (*Zea mays*) while the other half was planted to soybean (*Glycine max*). Soybean and corn plots all received 26.31 kg/ha of nitrogen, 67.25 kg/ha of phosphorus, and 89.67 kg/ha of potassium. Corn plots received 201.75 kg/ha of additional nitrogen in the form of urea.

2.2. Soil Sampling. Soil samples were collected in the middle of each plot after planting and full seeds emergence. Cylindrical cores of 3.15 cm radius and 10 or 20 cm height were used to collect soil samples at four depths: 0–10 cm, 10–20, 20–40 and 40–60 cm, corresponding to depths 1, 2, 3, and 4, respectively. The cylinders of 10 cm height were used for soil samples collection at depths 1 and 2 while the 20 cm height cylinders used for sampling at depths 3 and 4. A total of 576 soil samples were collected as follows: 48 plots $\times$ 4 depths $\times$ 3 replicates (at the middle of each plot). Collected samples were taken to the laboratory where they were weighed (fresh weight of sample; FWS) then oven dried at 105°C for 72 hrs. The weight was taken after oven drying (dry weight of soil; DWS). Soil physical properties were calculated as follows: Soil bulk density (BDY, $\text{g}\cdot\text{cm}^{-3}$) = (DWS/V), where DWS is the dry weight of soil and V the volume of cylinder (total volume of soil); Volumetric water content (VWC, $\text{cm}^3\cdot\text{cm}^{-3}$) = (FWS – DWS)/V, with FWS being the

fresh weight of soil; gravimetric water content (GWC, $\text{g}\cdot\text{g}^{-1}$) = [(FWS – DWS)/DWS] where FWS is the fresh weight of soil; total pore space (TPS, $\text{cm}^3\cdot\text{cm}^{-3}$) = $1 - (\text{BDY}/\text{PDY})$, where PDY is the soil particle density (taken as 2.65 g cm^{-3}); volumetric air content (VAC, $\text{cm}^3\cdot\text{cm}^{-3}$) = TPS – VWC; water-filled pore space (WFPS, %) = $100 * (\text{VWC}/\text{TPS})$; air-filled pore space (AFPS, %) = $100 * (\text{VAC}/\text{TPS})$; relative gas diffusion coefficient (Diff., $\text{cm}^2\cdot\text{s}^{-1}\cdot\text{cm}^{-2}\cdot\text{s}$) = $(\text{VAC})^2$, pore space tortuosity (Tort., $\text{m}\cdot\text{m}^{-1}$) = $(1/\text{VAC})$ [16].

2.3. Statistical and Geospatial Analysis. After calculation, data on soil physical properties was first transferred to Statistix 9.0 to compute summaries of simple statistics, then to GS+ (Geostatistics for environmental science) 7.0 for semivariogram analysis. A semivariogram (a measure of the strength of statistical correlation as a function of distance) is defined by the following equation [17]:

$$\gamma(h) = \frac{1}{2m(h)} \sum_{i=1}^{m(h)} [z(x_i + h) - z(x_i)]^2, \quad (1)$$

where $\gamma(h)$ is the experimental semivariogram value at a distance interval h , $m(h)$ is number of sample value pairs within the distance interval h , and $Z(x_i)$, and $Z(x_i + h)$ are sample values at two points separated by the distance h . Exponential and spherical models were the empirical semivariograms. The stationary models, that is, exponential (2) and spherical model (3) that fitted to experimental semivariograms were defined in the following equations [18]:

$$\gamma(h) = C_0 + C_1 \left[1 - \exp \left\{ - \left(\frac{h}{a} \right) \right\} \right], \quad (2)$$

$$\begin{aligned} \gamma(h) &= C_0 + C_1 \left[\left(\frac{3h}{2a} \right) - \left(\frac{h^3}{2a^3} \right) \right], \quad \text{when } h \leq a, \\ &= C_0 + C_1, \quad \text{when } h \geq a, \end{aligned} \quad (3)$$

where C_0 is the nugget, C_1 is the partial sill, and a is the range of spatial dependence to reach the sill ($C_0 + C_1$). The ratio $C_0/(C_0 + C_1)$ and the range are the parameters that characterize the spatial structure of a soil property. The $C_0/(C_0 + C_1)$ relation is the proportion in the dependence zone, and the range defines the distance over which the soil property values are correlated with each other [19]. A low value for the $C_0/(C_0 + C_1)$ ratio and a high range generally indicate that high precision of the property can be obtained by Parfitt et al. [19]. The classification proposed by Cambardella et al. [14], which considers the degree of spatial dependence ($\text{DSD} = C_0/(C_0 + C_1) \times 100$) as strong when $\text{DSD} \leq 25\%$; moderate when $25 < \text{DSD} \leq 75\%$; and weak when $\text{DSD} > 75\%$, was used in this study to classify the degree of spatial dependence of each soil property.

3. Results and Discussion

3.1. Summaries of Statistics for Soil Physical Properties. Overall, descriptive statistics for soil properties in this study showed moderate to high skewness for some of the properties

TABLE 1: Descriptive statistics for soil physical properties at four depths in a clay-loam soil.

	AFPS	BDY	Diff.	GWC	TPS	Tort	VAC	VWC	WFPS
D1 (0–10 cm)									
Mean	45.76	1.24	0.06	0.22	0.51	4.60	0.24	0.28	54.24
SD	10.61	0.11	0.03	0.03	0.04	1.50	0.07	0.04	10.61
C.V	23.18	8.99	56.29	15.25	8.36	32.60	29.64	15.26	19.56
Median	45.71	1.24	0.06	0.22	0.52	4.10	0.24	0.28	54.29
D2 (10–20 cm)									
Mean	26.54	1.47	0.02	0.21	0.42	12.46	0.12	0.31	73.46
SD	11.19	0.18	0.02	0.048	0.07	10.70	0.06	0.05	11.19
C.V	42.15	12.09	91.61	22.48	16.40	85.91	49.83	17.11	15.23
Median	27.32	1.46	0.01	0.22	0.43	9.04	0.11	0.31	72.68
D3 (20–40 cm)									
Mean	42.35	1.20	0.06	0.26	0.53	4.72	0.23	0.30	57.65
SD	8.19	0.12	0.03	0.04	0.05	1.29	0.06	0.03	8.19
C.V	19.33	9.75	53.22	13.92	8.68	27.30	26.27	11.48	14.20
Median	42.11	1.20	0.05	0.25	0.53	4.52	0.22	0.31	57.90
D4 (40–60 cm)									
Mean	39.34	1.18	0.05	0.28	0.54	4.94	0.21	0.32	60.66
SD	7.62	0.07	0.02	0.03	0.03	1.12	0.05	0.03	7.62
C.V	19.36	5.57	46.36	10.43	4.83	22.69	22.72	10.58	12.56
Median	39.74	1.18	0.05	0.27	0.54	4.67	0.22	0.33	60.27

AFPS: air-filled pore space (%); BDY: soil bulk density (g cm^{-3}); DIFF: relative gas diffusion coefficient ($\text{m}^2 \text{s}^{-1} \text{m}^{-2} \text{s}$); GWC: gravimetric water content of soil (g g^{-1}); TPS: total pore spaces ($\text{cm}^3 \text{cm}^{-3}$); TORT: Pore tortuosity factor ($\text{m} \cdot \text{m}^{-1}$); VAC: volumetric air content ($\text{cm}^3 \text{cm}^{-3}$); VWC: volumetric water content ($\text{cm}^3 \text{cm}^{-3}$); WFPS: water-filled pore space (%).

(Table 1). The highly skewed soil parameters included soil bulk density (BDY), diffusivity (DIFF), and volumetric water content (VWC), whereas total pore space (TPS) was moderately skewed. Air-filled pore space (AFPS) had a low skewness. Highly skewed parameters indicate that these properties have a local distribution; that is, high values were found for these properties at some points, but most values were low [20]. The other soil physical properties were approximately normally distributed on the field. The underlying reason for soil properties being normally or nonnormally distributed may be associated with differences in management practices, land use, vegetation cover, and topographic effects on the variability of soil erosion across the landscape of the field. These factors can be the sources for a large or very small variation of soil properties in some of the samples, which leads to the nonnormal distribution [21]. A wide range of spatial variability was observed for soil physical properties (Table 1). For instance, soil bulk density (BDY) ranged from 1.01 to 1.23 g cm^{-3} for depth 1, 1.15 to 1.46 g cm^{-3} for depth 2, 0.96 to 1.19 g cm^{-3} and 1.04 to 1.18 g cm^{-3} for depths 3 and 4, respectively (Figure 2). Soil bulk density was also significantly higher in the second depth (1.4 g cm^{-3}) than all the other 3 depths, where it varied between 1.18 g cm^{-3} and 1.24 g cm^{-3} . The mean value of AFPS was significantly lower in the second depth ($26.5 \text{ cm}^3 \cdot \text{cm}^{-3}$) than in all other 3 depths, where it varied from 39.34 to $45.7 \text{ cm}^3 \cdot \text{cm}^{-3}$. Soil pore tortuosity factor (TORT) and water-filled pore space (WFPS) were also significantly higher in the second depth ($12.46 \text{ cm} \cdot \text{cm}^{-1}$ and 73.46% , resp.). However, the relative gas diffusion

coefficient (DIFF), gravimetric water content (GWC), total pore space (TPS), and volumetric air content (VAC) were significantly lower in the second depth ($0.02 \text{ m}^2 \text{s}^{-1} \text{m}^{-2} \text{s}$, 0.21 g g^{-1} , $0.42 \text{ cm}^3 \cdot \text{cm}^{-3}$, and $0.12 \text{ cm}^3 \cdot \text{cm}^{-3}$, resp.) (Table 1). The variability in soil physical properties is understandable since the soil of this site has a smectite layer (claypan) in the 10–20 cm, which corresponded to our second sampling depth. This layer of smectite is hard and compact, with very low pore space, high mass-volume ratio (bulk density) and high water retention capability (because of their large surface area). As a consequence of the presence of this smectite layer in depth 2, the mean of water-filled pore space (WFPS) was slightly lower in the first depth (54%) than in all four depths. In fact, air predominates the pore space in the first depth and cultivation loosened the soil, thereby allowing the water trapped in the pore space to evaporate. Higher GWC, VWC, and TPS at the lower depths (20–60 cm) mean that crops (especially corn and soybean grown in the field) were able to access water and dissolved nutrients through their roots. In fact, despite the claypan layer (10–20 cm), it has been reported by various researchers that crop roots were able to penetrate into and through this layer of smectitic clay [22–24] and that root growth may increase within the claypan layer [23] as a result of plant adaptation to water-limited soil layers. In general, the use of the coefficient of variation (CV) is a common procedure to assess variability in soil properties since it allows comparison among properties with different units of measurement. Overall, the coefficient of variation for all soil physical properties, in the four depths, ranged from 4.83 to

FIGURE 2: Variation of soil bulk density, gravimetric water content, total pore space, and volumetric water content with depth.

91.61% (Table 1). The pore tortuosity factor (TORT) showed the highest variation while soil bulk density (BDY) showed the least variation. The CV indicated that there was a strong spatial variability of the soil properties investigated. However, to have a better assessment of such spatial variability across the entire field, a geostatistical analysis was used.

3.2. Spatial Variability of Soil Properties. After computing summaries of simple statistics with Statistix 9.0, data on soil physical properties was transferred to GS+ (geostatistics for environmental science) 7.0 for semivariogram analysis. Semivariogram model fit was determined from the coefficient of determination (R^2) values, which range from 0 (very poor model fit) to 1 (very good model fit). Table 2 shows soil physical properties which mainly responded to exponential and linear variogram models, with the exponential model providing the best fit. In the 10–20 cm depth, exponential model provided the best fit for BDY ($R^2 = 0.93$), with the spherical model providing very poor model fit. Pore tortuosity also responded to an exponential variogram model in the 20–40 cm depth ($R^2 = 0.57$), although spherical model was noticed. Linear and exponential models were observed

in the 40–60 cm depth for TPS ($R^2 = 0.46$), with linear model providing a better fit (Table 2). In general, for all depths, model fit was not very strong with the exception of gravimetric water content and bulk density in the second depth. Overall, the exponential model provided the best fit with about 65% of the physical properties fitting this model. In geostatistical theory, the range of the spatial variability of the semivariogram is the distance between correlated measurements (the minimum lateral distance between two points before the change in property is noticed) and can be an effective criterion for the evaluation of sampling design and mapping of soil properties. The value that the semivariogram model attains at the range (the value on the y-axis) is called the sill. The partial sill is the sill minus the nugget [25, 26]. Theoretically, at zero separation distance (lag = 0), the semivariogram value is zero. However, at an infinitesimally small separation distance, the semivariogram often exhibits a nugget effect (the apparent discontinuity at the beginning of many semivariogram graphs), which is some value greater than zero. The nugget effect can be attributed to measurement errors or spatial sources of variation at distances smaller than the sampling interval (or both). Measurement error occurs because of the error inherent in measuring devices. To

TABLE 2: Variogram parameters for soil physical properties at four depths in a clay-loam soil.

Depth (cm)	Model	Nugget (C_0)	Sill ($C_0 + C$)	Range (A_0)	R^2	$(C/C_0 + C)$	DSD (%)
GWC							
0–10	Exponential	0.00	0.00	6.42	0.12	0.94	0.01
10–20	Exponential	0.00	0.00	64.26	0.75	0.52	0.29
20–40	Spherical	0.00	0.00	7.17	0.11	1.00	0.00
40–60	Exponential	0.00	0.00	4.56	0.01	0.99	0.00
VWC							
0–10	Exponential	0.00	0.00	6.21	0.31	0.94	0.01
10–20	Exponential	0.00	0.00	11.82	0.44	0.89	0.04
20–40	Exponential	0.00	0.00	5.88	0.17	0.97	0.00
40–60	Exponential	0.00	0.00	0.45	0.00	1.00	0.00
BDY							
0–10	Linear	0.01	0.01	25.77	0.07	0.00	1.18
10–20	Exponential	0.02	0.04	40.17	0.93	0.50	0.04
20–40	Spherical	0.00	0.01	7.42	0.20	0.95	0.07
40–60	Linear	0.00	0.00	25.77	0.39	0.00	0.44
TPS							
0–10	Linear	0.00	0.00	25.77	0.07	0.00	0.16
10–20	Exponential	0.00	0.01	14.64	0.79	0.81	0.13
20–40	Exponential	0.00	0.00	7.50	0.21	0.90	0.03
40–60	Linear	0.00	0.00	25.77	0.47	0.00	0.07
VAC							
0–10	Linear	0.00	0.00	25.77	0.25	0.00	0.48
10–20	Exponential	0.00	0.00	2.73	0.00	0.86	0.06
20–40	Exponential	0.01	0.00	7.62	0.35	0.92	0.07
40–60	Linear	0.00	0.00	25.77	0.21	0.00	0.23
WFPS							
0–10	Linear	107.28	107.28	25.77	0.15	0.00	10727.60
10–20	Spherical	10.80	135.30	5.38	0.00	0.92	1173.91
20–40	Exponential	3.50	66.49	7.47	0.27	0.95	369.59
40–60	Linear	55.49	55.49	25.77	0.07	0.00	5549.30
AFPS							
0–10	Linear	107.28	107.28	25.77	0.15	0.00	10727.6
10–20	Spherical	10.80	135.30	5.38	0.00	0.92	1173.91
20–40	Exponential	3.50	66.49	7.47	0.27	0.95	369.588
40–60	Linear	55.49	55.49	25.77	0.07	0.00	5549.30
DIFF							
0–10	Linear	0.00	0.00	25.77	0.10	0.00	0.11
10–20	Exponential	0.00	0.00	4.71	0.00	0.85	0.00
20–40	Exponential	0.00	0.00	4.53	0.05	0.93	0.01
40–60	Linear	0.00	0.00	25.77	0.19	0.00	0.05
TORT							
0–10	Linear	2.12	2.12	25.77	0.15	0.00	211.80
10–20	Exponential	17.80	126.10	8.10	0.19	0.86	2072.20
20–40	Exponential	0.18	1.74	13.20	0.58	0.90	19.44
40–60	Linear	1.24	1.24	25.77	0.16	0.00	123.68

DSD: degree of spatial dependence: strong DSD ($DSD \leq 25\%$), moderate DSD ($25 < DSD \leq 75\%$), and weak DSD ($DSD > 75\%$) according to Cambardella et al. (1994) [14].

eliminate this error, multiple samples were taken from each sampling point. Natural phenomena can vary spatially over a range of scales. Variation at microscales smaller than the sampling distances will appear as a part of the nugget effect. Table 2 shows that the spatial correlation (range) of soil properties widely varied from 1 m for volumetric water content (VWC) in depth four to 64 m for gravimetric water content (GWC) in depth 2. However, for the first and second depth (which are agriculturally more important), the range of spatial correlation varied from 3 m for volumetric air content (VAC) in depth 2 to 64 m for GWC in depth 2. Beyond these ranges, there is no spatial dependence (autocorrelation). The spatial dependence can indicate the level of similarity or disturbance of the soil condition. According to López-Granados et al. [27] and Ayoubi et al. [17], a large range indicates that the measured soil property value is influenced by natural and anthropogenic factors over greater distances than parameters which have smaller ranges. Thus, a range of about 64 m for GWC in this study indicates that the measured GWC values can be influenced in the soil over greater distances as compared to the soil parameters having smaller range (Table 2). This means that soil variables with smaller range such as VWC and VAC are good indicators of the more disturbed soils (the more disturbed a soil is, the more variable some soil properties become). The more variable properties have a shorter range of correlation. The different ranges of the spatial dependence among the soil properties may be attributed to differences in response to the erosion—deposition factors, land use-cover, parent material, and human interferences in the study area. The nugget, which is an indication of microvariability was significantly higher for water-filled pore space (WFPS) and air-filled pore space (AFPS) when compared to the others. This can be explained by our sampling distance which could not capture well their spatial dependence. The lowest nugget was for GWC (Table 2). This indicates that GWC had low spatial variability within small distances. Knowledge of the range of influence for various soil properties allows one to construct independent accurate datasets for similar areas in future soil sampling design to perform statistical analysis [17]. This aids in determining where to resample, if necessary, and design future field experiments that avoid spatial dependence. Therefore, for future studies aimed at characterizing the spatial dependency of soil properties in the study area and/or a similar area, it is recommended that the soil properties be sampled at distances shorter than the range found in this study. Cambardella et al. [14] established the classification of degree of spatial dependence (DSD) between adjacent observations of soil property > 75% to correspond to weak spatial structure. In this study, the semivariograms indicated strong spatial dependence (DSD ≤ 25%) for soil physical properties such as bulk density, gravimetric water content, volumetric water content, total pore space, and diffusivity. The rest of the soil physical properties (water-filled pore space, Air-filled pore space, and tortuosity) measured exhibited very weak spatial dependence (DSD > 75%) (Table 2). The strong spatial dependence of the soil properties may be controlled by intrinsic variations in soil characteristics such as texture and mineralogy, whereas extrinsic variations such as tillage and other soil and water

management practices may also control the variability of the weak spatially dependent parameters [14].

3.3. Spatial Distribution of Soil Properties across the Field.

Interpolated maps portraying the distribution of soil physical properties in various depths are shown in Figure 3 for soil gravimetric (GWC) and volumetric (VWC) contents and water-filled pore space (WFPS). Gravimetric water content showed a good spatial distribution across the field with the highest values located around the southwestern portion of the field. Volumetric water content also showed good spatial distribution across the field with high values located in the northern, central, and southwestern portions of the field. Water-filled pore has a distribution similar to that of volumetric water content. The other soil properties, however, showed very poor spatial distribution in the field. This is most probably due to their poor sill ($C_0 + C$), model fit and coefficient of determination (R^2). Even though the spatial variability was not very pronounced, there were areas on the field that had slightly higher values of these physical properties than the rest of the field. In general, bulk density, total pore space, volumetric air content, Air-filled pore space, diffusivity, and tortuosity were very high in the field even though they did not exhibit very distinguishable variability. This lack of visible spatial variability is supported because the sampling distance (range) is 26 m for these properties.

3.4. Implications of Spatial Variability of Soil Physical Properties on Soil Management.

Results of this study indicated that the spatial variability of soil water content (GWC and VWC) was high. This can be explained, among many other reasons, by soil type (clay-loam) which was able to hold more water. But with intensive tillage, this soil water content could be adversely affected. Studies have shown that tillage practices can alter soil physical properties and consequently the hydrological behavior of agricultural fields, especially when a similar tillage system has been practiced for a long period [15, 28–31]. Tillage intensity has also considerable effects on spatial structure and spatial variability of soil properties [15, 30]. Therefore, this study can help determine site-specific soil management and decision making. To do so, the spatial variability of soil properties developed through kriging will be an important tool. Different ranges of spatial dependence were noticed in the field. The different ranges of the spatial dependence among the soil properties may be attributed to differences in response to the erosion—deposition factors, land use-cover, parent material, and human interferences in the study area. The different ranges can also be used in future studies to determine the sampling distance of different soil physical properties on the field. Also, the sill ($C_0 + C$) can help determine where the variability or change in soil property stops. This will be useful especially for the irrigation purposes. Generally, with farmers facing the decision of whether or not to till and the intensity of tillage, a spatial variability study can help in this decision making. Maps produced in this study can also be used for irrigation purposes as they can clearly indicate which portion of the field needs irrigation (soil water content). To do this, soil water content

FIGURE 3: Spatial distribution of gravimetric (GWC) and volumetric (VWC) water contents in 0–10 cm depth and that of water-filled pore space (WFPS) in 20 cm depth.

information can be collected and analyzed geospatially to produce field maps. The process can be repeated frequently to obtain up-to-date soil water content information. To avoid frequent destructive sampling for water content analysis, equipment that allows insitu measurements such as TDR methods and water mark sensors can be used. Since a different range of spatial dependence among soil properties shows differences in response to human interferences and land use-cover, this will help reduce human activities that increase soil bulk density and cause soil compaction like the use of heavy equipment. It can also serve as a reference for the type of crop to be grown (cover crops for erosion susceptible areas).

4. Conclusion

We assessed the spatial variability of soil physical properties in a clay-loam soil cropped to corn and soybean. Results showed that soil physical properties either decreased or increased sharply in the second depth (due to the presence of a smectite layer) before leveling up or dropping off, but without reaching the first depth value in either case. In addition, depending on soil physical property, maps produced by kriging showed either good or poor spatial distribution. The semi-variogram analysis showed the presence of a strong ($\leq 25\%$) to weak ($> 75\%$) spatial dependence of soil properties. Our understanding of the behavior of soil properties in this study provides new insights for soil site-specific management in

addressing issues such as “where to place the proper interventions” (tillage, irrigation, and crop type to be grown).

Acknowledgment

This research is part of a regional collaborative project supported by the USDA-NIFA, Award no. 2011-68002-30190, Cropping Systems Coordinated Agricultural Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems. (Project website: <http://sustainablecorn.org/>).

References

- [1] D. Schimel, J. Melillo, H. Tian et al., “Contribution of increasing CO_2 and climate to carbon storage by ecosystems in the United States,” *Science*, vol. 287, no. 5460, pp. 2004–2006, 2000.
- [2] C. Kosmas, S. Gerontidis, and M. Marathianou, “The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece),” *Catena*, vol. 40, no. 1, pp. 51–68, 2000.
- [3] J. Iqbal, J. A. Thomasson, J. N. Jenkins, P. R. Owens, and F. D. Whisler, “Spatial variability analysis of soil physical properties of alluvial soils,” *Soil Science Society of America Journal*, vol. 69, pp. 1–14, 2005.
- [4] S. Zhang, X. Zhang, T. Huffman, X. Liu, and J. Yang, “Influence of topography and land management on soil nutrients variability in Northeast China,” *Nutrient Cycling in Agroecosystems*, vol. 89, no. 3, pp. 427–438, 2011.

- [5] L. J. Munkholm, A. Garbout, and S. B. Hansen, "Tillage effects on topsoil structural quality assessed using X-ray CT, soil cores and visual soil evaluation," *Soil & Tillage Research*, vol. 128, pp. 104–109, 2013.
- [6] A. J. Franzluebbers, "Soil organic matter stratification ratio as an indicator of soil quality," *Soil and Tillage Research*, vol. 66, no. 2, pp. 95–106, 2002.
- [7] L. J. Munkholm, P. Schjønning, K. J. Rasmussen, and K. Tanderup, "Spatial and temporal effects of direct drilling on soil structure in the seedling environment," *Soil and Tillage Research*, vol. 71, no. 2, pp. 163–173, 2003.
- [8] A. Swarowsky, R. A. Dahlgren, K. W. Tate, J. W. Hopmans, and A. T. O'Geen, "Catchment-scale soil water dynamics in a mediterranean-type oak woodland," *Vadose Zone Journal*, vol. 10, no. 3, pp. 800–815, 2011.
- [9] R. Webster and M. A. Oliver, *Statistical Methods in Soil and Land Resource Survey*, Oxford University Press, Oxford, UK, 1990.
- [10] A. Saldaña, A. Stein, and J. A. Zinck, "Spatial variability of soil properties at different scales within three terraces of the Henares river (Spain)," *Catena*, vol. 33, no. 3–4, pp. 139–153, 1998.
- [11] Z. M. Wang, K. S. Song, B. Zhang et al., "Spatial variability and affecting factors of soil nutrients in croplands of Northeast China: a case study in Dehui county," *Plant, Soil and Environment*, vol. 55, no. 3, pp. 110–120, 2009.
- [12] R. Webster, "Quantitative spatial analysis of soil in the field," *Advances in Soil Science*, vol. 3, pp. 1–70, 1985.
- [13] H. Pohlmann, "Geostatistical modelling of environmental data," *Catena*, vol. 20, no. 1–2, pp. 191–198, 1993.
- [14] C. A. Cambardella, T. B. Moorman, J. M. Novak et al., "Field-scale variability of soil properties in central Iowa soils," *Soil Science Society of America Journal*, vol. 58, no. 5, pp. 1501–1511, 1994.
- [15] E. Özgöz, "Long term conventional tillage effect on spatial variability of some soil physical properties," *Journal of Sustainable Agriculture*, vol. 33, no. 2, pp. 142–160, 2009.
- [16] N. V. Nkongolo, R. Hatano, and V. Kakembo, "Diffusivity models and greenhouse gases fluxes from a forest, pasture, grassland and corn field in Northern Hokkaido, Japan," *Pedosphere*, vol. 20, no. 6, pp. 747–760, 2010.
- [17] S. H. Ayoubi, S. M. Zamani, and F. Khomali, "Spatial variability of some soil properties for site-specific farming in northern Iran," *International Journal of Plant Production*, vol. 2, pp. 225–236, 2007.
- [18] T. M. Burgess and R. Webster, "Optimal interpolation and isarithmic mapping of soil properties. I. The semi-variogram and punctual kriging," *Journal of Soil & Science*, vol. 31, no. 2, pp. 315–331, 1980.
- [19] J. M. B. Parfitt, L. C. Timm, E. A. Pauletto et al., "Spatial variability of the chemical, physical and biological properties in lowland cultivated with irrigated rice," *Revista Brasileira de Ciencia do Solo*, vol. 33, no. 4, pp. 819–830, 2009.
- [20] C. R. Grego, S. R. Vieira, and A. L. Lourenção, "Spatial distribution of *Pseudaletia sequax* Franclemont in triticale under no-till management," *Scientia Agricola*, vol. 63, no. 4, pp. 321–327, 2006.
- [21] G. B. Tesfahunegn, L. Tamene, and P. L. G. Vlek, "Catchment-scale spatial variability of soil properties and implications on site-specific soil management in northern Ethiopia," *Soil and Tillage Research*, vol. 117, pp. 124–139, 2011.
- [22] S. J. Grecu, M. B. Kirkham, E. T. Kanemasu, D. W. Sweeney, L. R. Stone, and G. A. Milliken, "Root growth in a claypan with a perennial-annual rotation," *Soil Science Society of America Journal*, vol. 52, no. 2, pp. 488–494, 1988.
- [23] D. B. Myers, N. R. Kitchen, K. A. Sudduth, R. E. Sharp, and R. J. Miles, "Soybean root distribution related to claypan soil properties and apparent soil electrical conductivity," *Crop Science*, vol. 47, no. 4, pp. 1498–1509, 2007.
- [24] P. Jiang, N. R. Kitchen, S. H. Anderson, E. J. Sadler, and K. A. Sudduth, "Estimating plant available water using the simple inverse yield model for claypan landscapes," *Agronomy Journal*, vol. 100, pp. 1–7, 2008.
- [25] A. Utset, M. E. Ruiz, J. Herrera, and D. P. De Leon, "A geo-statistical method for soil salinity sample site spacing," *Geoderma*, vol. 86, no. 1–2, pp. 143–151, 1998.
- [26] W. Fu, H. Tunney, and C. Zhang, "Spatial variation of soil nutrients in a dairy farm and its implications for site-specific fertilizer application," *Soil and Tillage Research*, vol. 106, no. 2, pp. 185–193, 2010.
- [27] F. López-Granados, M. Jurado-Expósito, S. Atenciano, A. García-Ferrer, M. Sánchez De La Orden, and L. García-Torres, "Spatial variability of agricultural soil parameters in southern Spain," *Plant and Soil*, vol. 246, no. 1, pp. 97–105, 2002.
- [28] R. L. Hill, "Long-term conventional and no-tillage effects on selected soil physical properties," *Soil Science Society of America Journal*, vol. 54, no. 1, pp. 161–166, 1990.
- [29] D. E. Buschiazzi, J. L. Panigatti, and P. W. Unger, "Tillage effects on soil properties and crop production in the subhumid and semiarid Argentinean Pampas," *Soil and Tillage Research*, vol. 49, no. 1–2, pp. 105–116, 1998.
- [30] T. Tsegaye and R. L. Hill, "Intensive tillage effects on spatial variability of soil physical properties," *Soil Science*, vol. 163, no. 2, pp. 143–154, 1998.
- [31] J. A. Gómez, J. V. Giráldez, M. Pastor, and E. Fereres, "Effects of tillage method on soil physical properties, infiltration and yield in an olive orchard," *Soil and Tillage Research*, vol. 52, no. 3–4, pp. 167–175, 1999.