Spatial Variability of Physical Properties in Lihen Sandy Loam Soil

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Introduction

Soil properties vary horizontally and vertically across agricultural fields, causing variability in crop yields. Knowledge of the spatial variability and relationships among soil properties is critical to the success of precision agriculture or site-specific management. Spatial variability of soil physical properties across the landscape has been examined and well documented (Camardella et al., 1994; Javed et al., 2005; and Mzuku et al., 2005). The researchers showed that soil bulk density, compaction, moisture content and texture can vary significantly within single farm.

The spatial variability of soil properties has been evaluated through classical statistics and geostatsitical techniques that verify relationships among several soil samples of a specific area or field using the study of regionalized variables (Davis, 1986).

Geostatistical analysis methods have also proven to be useful for mapping spatial variability of soil properties and have increasingly been utilized by soil scientists and agricultural engineers in recent years (Webster and Oliver, 2001). In this paper, geostatistical procedures were used to quantify spatial variability for cone index (CI), soil bulk density ($?_b$) moisture content (θ_v), and percentages of sand and clay.

Objectives

- Examine the field-scale spatial variability of CI, $?_b$, θ_v, and particle size distribution data using geostatitical methods.
- Determine whether these soil physical properties were correlated with each other.

References

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Fig. 1. *Isotropic semivariograms for (A) cone index (5-10 cm depth), (B) cone index at (20-25 cm), (C) bulk density, (D) moisture content, (E) percentage sand, and (F) percentage clay.*

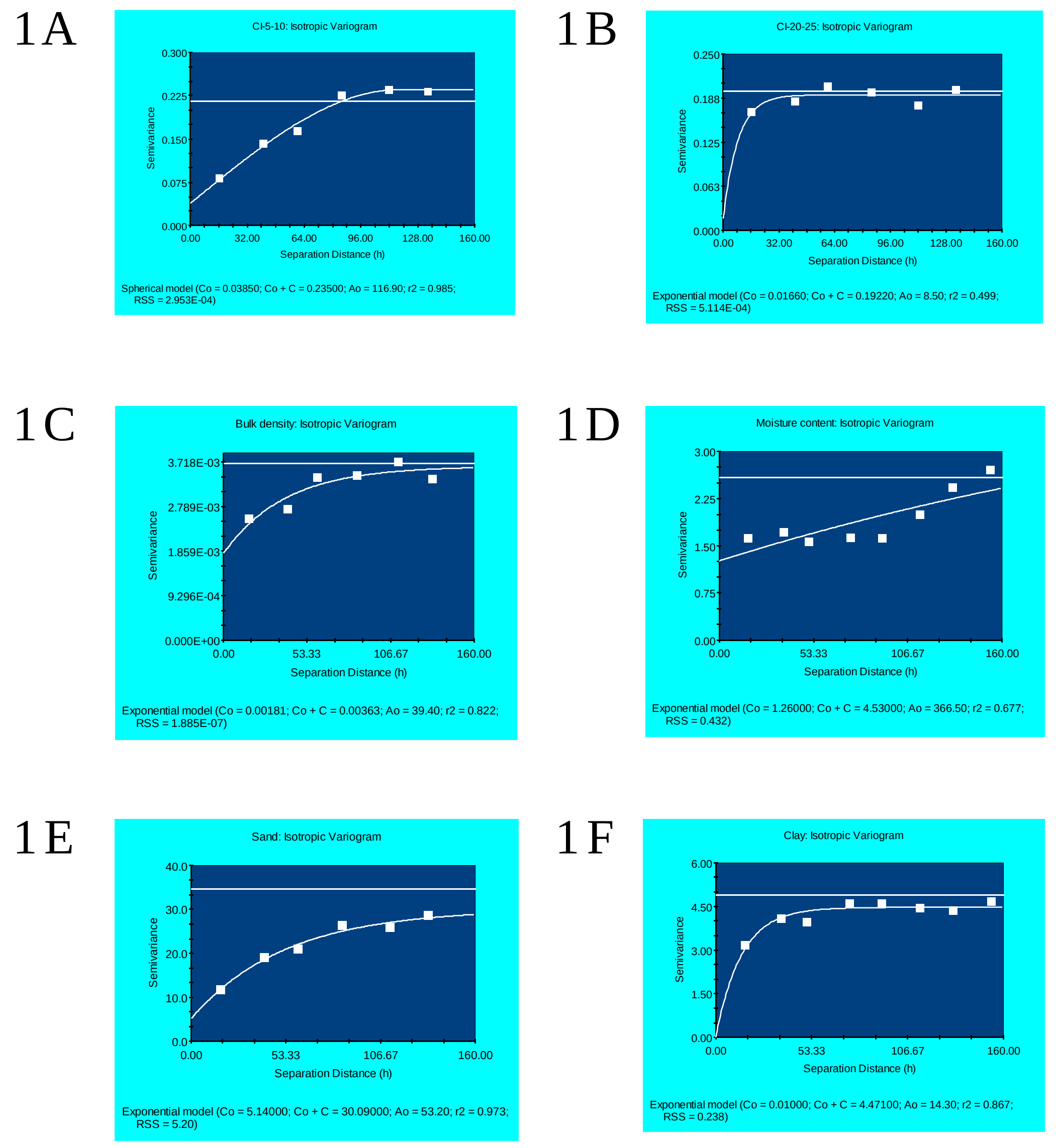
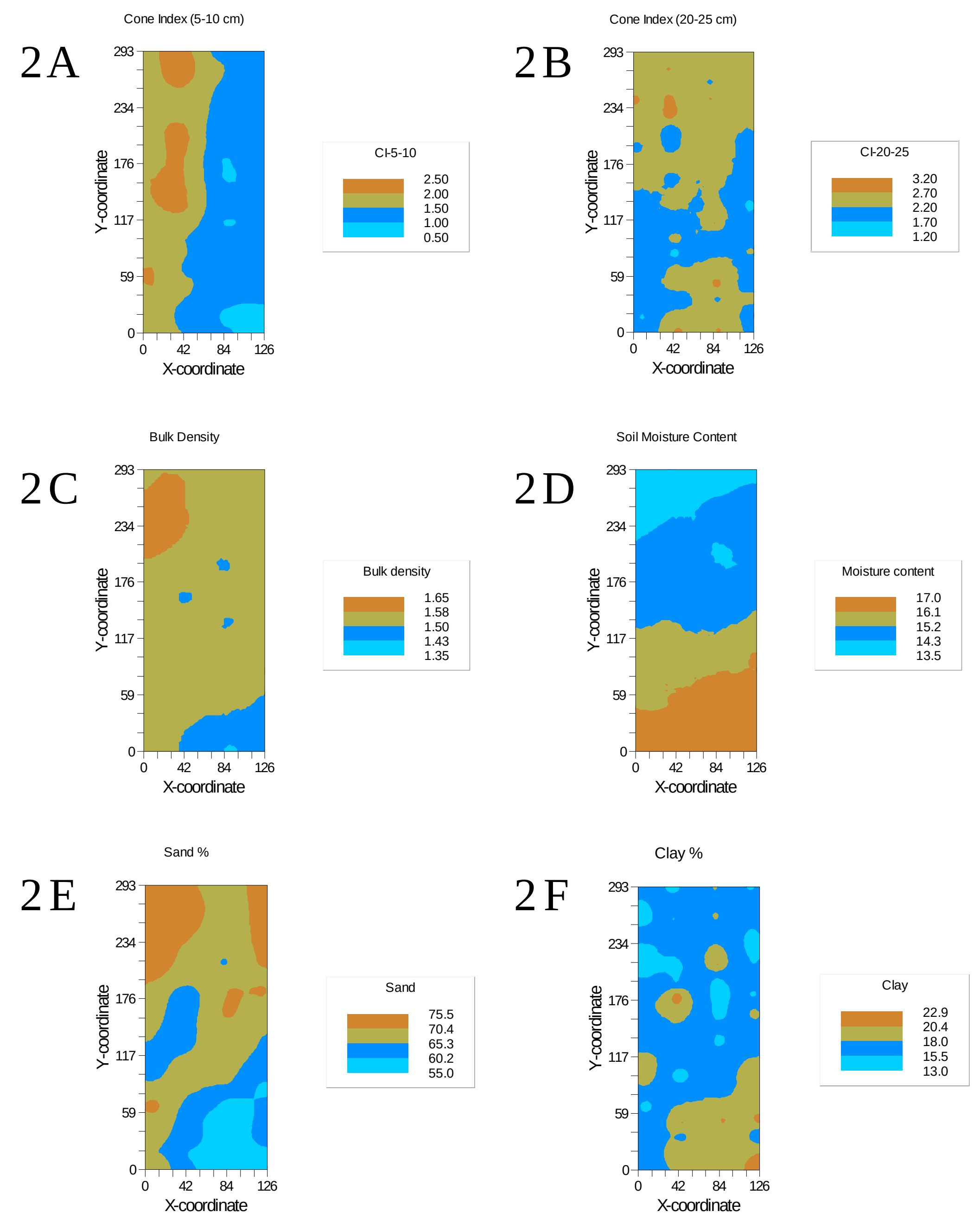


Fig. 2. *Kriged contour maps for (A) cone index (5-10 cm depth), (B) cone index at (20-25 cm), (C) bulk density, (D) moisture content, (E) percentage sand, and (F) percentage clay.*



Results and Discussion

Descriptive statistics for each soil parameter is given in Table 1. The soil physical properties were modeled as normally distributed random variables using a probability analysis curve.

Isotropic Semivariance Analysis

Table 2 presents the semivariogram parameters for CI at two depths along with $?_b$, θ_v, and particle size distribution (percentages of sand and clay). Three classes of spatial dependence (structural variance) for soil properties were calculated based on the ratio of nugget (C_0) to the sill (C_0+C) (Cambardella et al., 1994). If the spatial class ratio was <25%, the variable was considered strongly spatially dependent; if the ratio was >25% and <75%, the variable was considered moderately spatially dependent; and if the ratio was >75%, the variable was considered weakly spatially dependent. A structural variance value close to zero indicates continuity in the spatial dependence.

Figures 1A through 1F show the isotropic semivariograms of CI at 5- 10 cm, CI at 20-25 cm, $?_b$, θ_v, percentage sand, and percentage clay, respectively. The ranges of spatial dependencies show a large variation ranging between 8.5 m for CI at 20-25 cm depth and 366.5 m for θ_v.

Further, the resulting semivariograms (*Figs. 1A to 1F*) indicate a strong spatial dependency for CI at both depths, and sand content (9-17%). The structural variance also showed moderate spatial dependency for $?_b$, θ_v (28-50%). However, the semivariogram for clay content shows a zero and small range of spatial dependence (*Table 2, Fig. 1F*). The zero (pure) nugget effect value indicates a very smooth spatial continuity between neighboring sample points. This small range of spatial dependence of clay content (14.3 m) indicates that this continuity diminishes rapidly over a short distance. The other soil variables have larger ranges of spatial dependence, except for CI at 20-25 cm depth (*Table 2*).

In general, spatial structure or dependence analysis from semivarinace results exhibited spatial variability across the field for CI at both depths, $?_b$, θ_v, and percentages sand and clay.

Tables

Table 1. Statistical summary of soil physical properties.

Statistics†	Cone Index (MPa) 5-10 cm	Cone Index (MPa) 20-25 cm	Bulk Density (Mg m^{-3})	Moisture Content (%)	Sand (%)	Clay (%)
Mean	1.499	2.259	1.54	15.2	66.7	17.1
Variance	0.212	0.196	0.003	2.6	34.4	5.9
CV	30.7	19.6	3.7	10.5	8.8	14.2
Range	1.898	1.858	0.27	6.4	24.0	14.6
Minimum	0.557	1.241	1.38	12.7	53.5	8.6
Maximum	2.455	3.099	1.65	19.1	77.5	23.2

† Number of measurements =72.

Table 2. Geostatistical parameters of soil properties.

Soil Variable	Nugget C_0	Sill C_0+C	Structural Variance $\frac{C_0}{(C_0+C)}\times 100$	Range A_0 (m)	RSS	R^2	Model
Cone Index MPa (5-10 cm)	0.0385	0.235	16	116.9	0.00029	0.985	Spherical
Cone Index MPa (20-25 cm)	0.0166	0.1922	9	8.5	0.00051	0.499	Exponential
Bulk density Mg m^{-3}	0.0018	0.0036	50	39	1.89×10^{-7}	0.822	Exponential
Moisture Content, %	1.26	4.53	28	366.5	0.432	0.677	Exponential
Sand %	5.14	30.09	17	53.2	5.2	0.973	Exponential
Clay %	0.01	4.471	0	14.3	0.238	0.867	Exponential

Kriged Contour Maps

Contour maps of the individual soil attributes were generated by point kriging (*Figs. 2A to 2F*). The spatial distribution of $?_v$ probably follows the topographical feature of the field (*Fig. 2D*) where the land gradually slopes from NW to SE at approximately 2-3%. However, comparison of areas relatively high in water content to areas high in clay content generally shows the expected relationship.

Kriged contour maps indicated that soils with high $?_b$ were found in the NW part of the field extending mainly from NW to SE (*Fig 2. C*). However, the CI at 5 -10 cm depth map shows a different scenario where higher values of CI (2-2.5 MPa) are on the eastern half of the field and low values of CI (1 -1.5 MPa) are located on the western half.

Using spatial statistics indicated that CI, $?_b$, $?_v$, and particle size distribution were spatially structured explaining some trends in soil variability within the field. This spatial variability could be due to pedologic soil forming factors such as erosion and deposition processes. Soils at this research farm in ND are mixed of alluvial and eolian parent materials, originating from different rocks and unconsolidated sediments. Soil profiles of these soils exhibited stratification of different sediments deposited on top of each other. The top soil variations may be caused and affected by other factors such as vegetation, previous farming practices and weather conditions.

Correlation Among Soil Properties

Soil properties with strong and moderate spatial dependence were correlated with each other. The $?_v$ was positively related to clay content (r = 0.58, P < 0.01) and negatively correlated with sand content (r = - 0.68, P < 0.01) in the soil samples (*Fig. 3*). The basis of the positive relationship between $?_v$ and clay content is direct; that is, higher $?_v$ values are associated with finer rather that courser textured soil. In addition, a positive correlation described the relationship between $?_b$ and CI (r = 0.57, P< 0.01) at depth of 5-10 cm (*Fig. 4*). It would be expected that $?_b$ and CI would increase simultaneously; however, weaker correlations were detected among other soil physical parameters at both levels of soil depth.

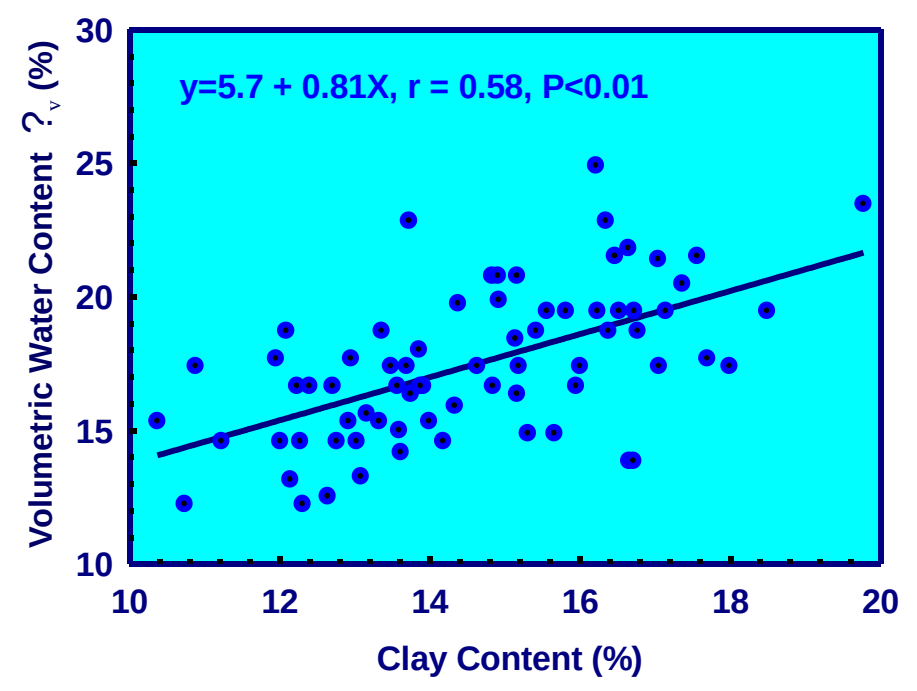


Fig. 3. *Relationship between moisture content and clay content.*

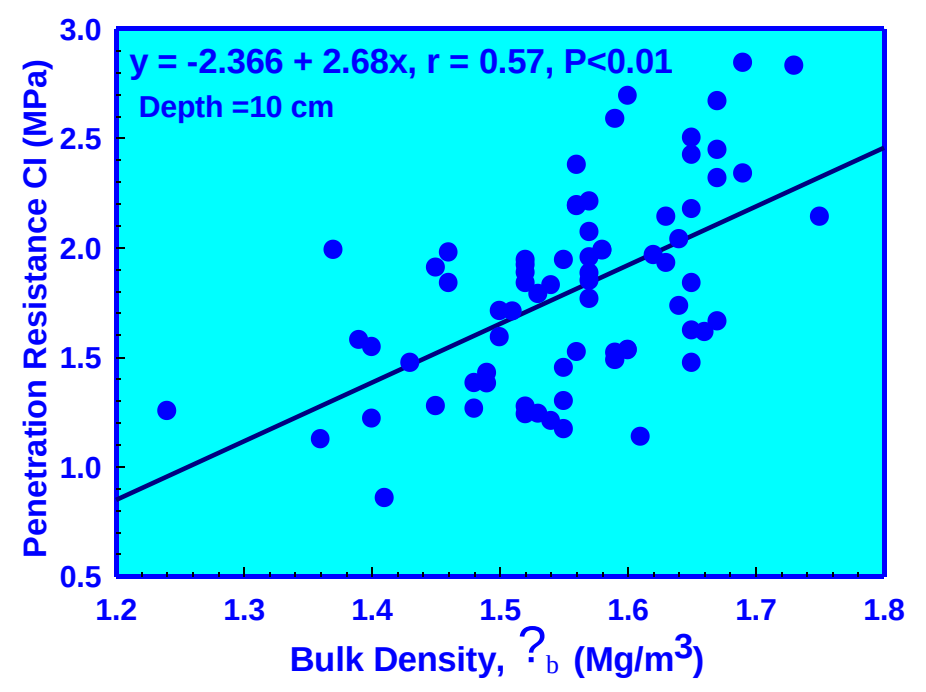


Fig 4. *Relationship between cone index and bulk density at 5-10 cm depth.*

Conclusions

The goestatistical methods revealed spatial variability in CI at 5-10 cm and 20-25 cm depths, $?_b$, θ_v, sand content and clay content across the field. The variability of these properties exhibited medium to strong spatial dependence that could be well described using either spherical or exponential models.

The semivariogram for clay content shows a small range of spatial dependence and zero nugget effect.

Spatial structure analysis indicated low to medium scales of spatial variability for soil physical properties.

A positive correlation indicated the relationship between $?_b$ and CI at 5-10 cm depth and between θ_v, and percentage of clay in the soil.

Weaker correlations were detected between CI and θ_v, at both depths as well as among other soil parameters.

Spatial variability of soil physical properties could be due to pedologic soil forming factors or may be caused by factors such as vegetation, previous farming practices and weather conditions.

Abbreviations Used In This Poster:

CI = cone index
$?_b$ = bulk density
$?_v$ = moisture content

Materials and Methods

Soil, Description, Data Collection and Site Characterization

This study was initiated on April 6, 2005 on a grassland site of approximately 4.75 ha at the USDA-ARS Nesson Valley Research farm located approximately 23 miles east of Williston, ND (48.1640 N, 103.0986 W). The topography of land is rolling from NW to SE, with 2-3% slope. The soil is classified as Lihen sandy loam soil (sandy, mixed, frigid Entic Haplustoll) consisting of very deep, somewhat excessively or well drained soils that formed in sandy alluvium, glacio-fluvial, and eolian deposits.

Soil physical properties measured at the site include $?_b$, $?_v$, particle size distribution, and CI as an indicator of soil strength or compaction. Bulk density and $?_v$, were measured by collecting soil cores using a soil core sampler approximately 20 cm in length and 5 cm in diameter. The core sampling process was repeated twice such that two cores at depths of 5-10 and 20-25 cm were collected for each sampling location within the study area. Particle size distribution for each core was determined by the hydrometer method. Cone index was measured by inserting a hand-held digital penetrometer into the soil at three different locations within a 30-cm radius of where soil cores for bulk density were extracted. Measurements were made based on a 16 m by 36 m grid sampling pattern, which created 72 individual grid cells. Soil properties were measured at the center of each grid cell at depths of 5-10 and 20-25 cm.

Statistical Methods

Descriptive statistics, including mean, variance, coefficient and variation (CV), range, maximum, and minimum were obtained for each measured soil property using SAS software (SAS Institute, 2003). A student t-test showed that there were no significant differences between the two depths for all measured soil variables except for CI, thus allowing the two depths to be averaged.

Geostatistical analyses, including semivariance model fitting and kriged mapping were performed using GS$^+$ (Gamma Design Software, 2004). Measurements of CI, $?_b$, $?_v$, and particle size distribution were point-ordinary kriged to produce interpolated spatial maps. Prior to applying geostatsitical procedures, each soil variable used in this study was checked for normality, for presence of trends in the data, and for anisotropy at various directions (0, 45, 90 and 135 degrees). Isotropy semivariogram models were best fitted to the experimental data. A residual sum squares (RSS) was used to select the exact form of the semivariance model. A trial and error procedure was used to minimize the RSS value until the model providing the best fit between actual and fitted values was found for each soil property. Spherical or exponential models provided the best fit for the semivariograms of all soil physical properties used in this study.

Semivariance is expressed in Equation [1] as described by Journal and Huijbregts (1978).

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

Where *(h) is semivariance for the interval distance class, h is the lag distance, Z(x_i) is the measured sample value at point i, Z(X_i+h) is the measured value at point i+h, and N(h) is the total number of pairs for lag interval h.

Spherical models defined in Eq. [2] provided the best fit for the experimental semivariances of soil bulk density.

$$\gamma(h) = C_0 + C\left(\frac{3h}{2a} - \frac{1}{2}\left(\frac{h}{A}\right)^3\right) \qquad \text{for } h \leq A \qquad [2]$$

and

$$\gamma(h) = C_0 + C \qquad \text{for } h > A \qquad [3]$$

where C_0 is nugget effect value, C is the spatial variance, $\underline{A}$ is the range, and *h* is the distance.

The exponential model (Eq. [4]) provided the best fit for the experimental semivariances for all other remaining soil properties.

$$\gamma(h) = C_0 + C\left(1 - \exp\left(-\frac{h}{A}\right)\right) \qquad [4]$$