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Spatial Variability of Soil Properties along a Transect of CRP and Continuously Cropped Land

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ABSTRACT

Knowledge of soil spatial variability and relationships among soil properties is important for the evaluation of agricultural land management practices. This study was to characterize the spatial variation of selected soil properties along a transect across a field that was partially grassed Conservation Reserve Program land for 10 years (CRP) and partially continuously cropped land (CCL). The sample field, located at Zenith of Stafford County of Central Kansas, has Naron fine sandy loam (fine-loamy, mixed, thermic Udic Argiustolls). Forty soil samples both in 0-5 and 5-10 cm depths were collected along a 400-m transect across CRP and CCL. Soil chemical properties including pH, available phosphorus (P), and soil total carbon content (STC) were compared and geostatistically analyzed to construct semivariogram and estimate unsampled values. The semivariogram of STC and pH exhibited spherical model. One-dimensional pH for CRP and CCL showed separate patterns. Soil pH for CRP was higher than pH in CCL, and the differences of pH between the two depths were distinct in CRP, but not in CCL. Conversely, concentration of P was obviously higher in the CCL than in CRP, and showed increasing straight line along transect. Soil total carbon exhibited a periodic behavior along transect depending mainly on field topographic position and less on land use.

INTRODUCTION

Evaluating agricultural land management practices requires knowledge of soil spatial variability and understanding of the relationships (Buchter et al., 1991; Assadian et al., 1998; Diiwu et al., 1998). Usually, spatial variability is used to predict or estimate values at unsampled locations within the regions. Geostatistical methods are useful in quantifying spatial variability of soil properties (Warrick et al., 1986; Bourgault et al., 1997; Kutilek and Nielsen, 1994; Reese and Moorhead, 1996).

Mahinakbarzadeh et al. (1991) investigated the spatial variability of soil organic matter along several transects located within a soil map unit. They found that organic matter content showed a weaker trend. Buchter et al. (1991) measured soil properties, including soil-water-characteristic curves, particle size, saturated hydraulic conductivity, and bulk density along two parallel 100-m transects separated by 60 cm and found that the parameters had a strong periodic behavior with a main cycle of 50 m.

Moulin et al. (1994) studied the spatial distribution of soil properties, erosion and crop yield along a cultivated transect and an adjacent transect in virgin grassland. Erosion was affected by an interaction between elevation and surface curvature that affected the spatial and statistical distribution of soil properties and crop yield in the landscape.

The objectives of this study were to describe spatial variability and patterns of soil properties in an adjoining Conservation Reserve Program land (CRP) and continuously cropped land (CCL) transect and to evaluate the effects of CRP on soil properties.

MATERIALS AND METHODS

Field description and data collection

The sample field with Naron fine sandy loam (fine-loamy, mixed, thermic Udic Argiustolls) was located in Zenith of Stafford County of Central Kansas. Management practice in CCL for this field was conventional tillage with dry land winter wheat [*Triticum asetivium L.*] fallow, and/or wheat, grain sorghum [*Sorghum bicolor* (L.)] or corn [*Zea mays* L.] rotation. Native grasses were seeded in the CRP field in 1987. There were no grazing or burning in the CRP field until the contract expiration in spring 1998. The sample date for CRP was on 27 May 1998, a few days after10-yr grasses were burned. In the CCL site, the samples were taken after wheat harvest on 2 July 1998.

Forty soil samples were collected on a 10 m spacing along a 400 m long transect across the CRP and CCL field (Fig. 1). Each treatment accounted for 20 sites. The soils were collected from 0- to 5-cm and 5- to 10-cm depths for chemical property analyses of pH, available phosphorus (P), and soil total carbon (STC). The soil was air-dried and crushed to pass through a 2-mm sieve, and analyzed by the Soil Testing Laboratory of Kansas State University. Soil pH was measured on a 1:1 soil/distilled water paste. Available P was tested by the Bray 1 method. Total carbon concentrations were determined by dry combustion using LECO CNS-2000 automatic analyzer (LECO Corp., St. Joseph, MI).

Geostatistical Analysis

Spatial variations with interdependence are commonly described with a variogram (Warrick et al., 1986). In geostatictics, the concept of variance from classic statistics is extended to semi variance. Considering a transect with

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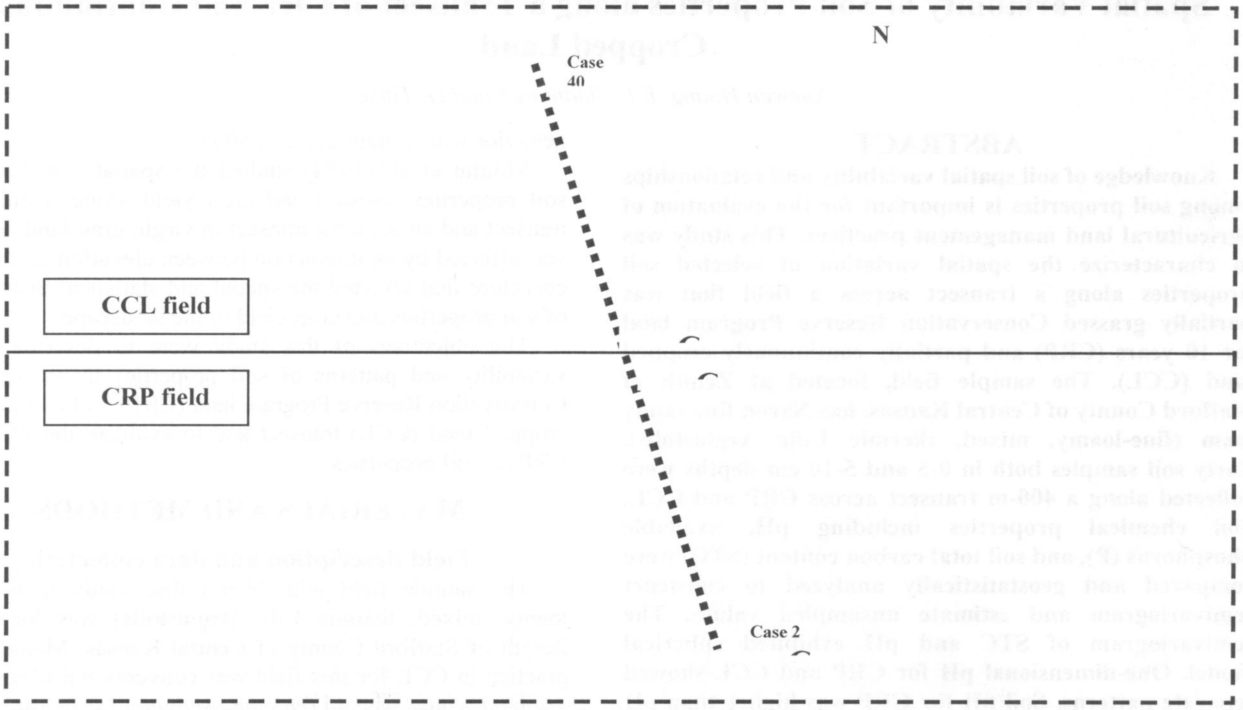

Figure 1. Layout of sample sites (solid squares) in Zenith of Stafford County in Kansas along a transect across Conservation Reserve Program (CRP) and continuously cropped land (CCL) fields.

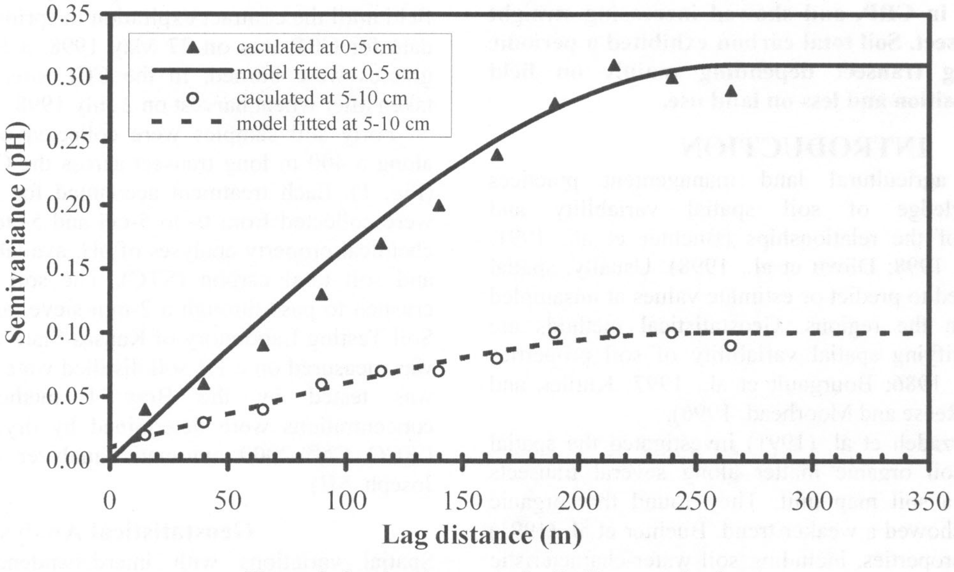

Figure 2. Semivariograms of soil pH at two depths.

equally spaced samples and measurements of soil property Z, a set of values $Z(x_1)$, $Z(x_2)$ … $Z(x_n)$ at location x_1, x_2 … x_n were obtained. The semi variance $\gamma(h)$ is estimated as:

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

where $N(h)$ is the number of pairs separated by lag distance h; $Z(x_i)$ is measured sample value at point i; and $Z(x_i+h)$ is measured sample value at point i+h.

A semivariogram, which graphs the semi variance between spatially separate data points as a function of the distance, is well documented to illustrate the spatial relationship of soil properties (Warrick and Myers, 1986; Buchter et al., 1991). In addition to indicating the spatial pattern, the modeled semivariogram can then be used in kriging interpolation.

There are several models to describe semivariogram. Here, spherical and linear models are briefly introduced. In those models, parameters C_0, C_0+C, and A_0 are defined as nugget variance, sill, and range, respectively. The spherical model is a modified quadratic function for which at some distance A_0, pairs of points will no longer be auto correlated and the semivariogram reaches an asymptote. The formula for this model is:

$$\gamma(h)=C_0+C[\frac{2}{3}\frac{h}{Ao}-\frac{1}{2}(\frac{h}{Ao})^3] \text{ for } \quad A_0 \qquad [2]$$

$$\gamma(h)=C_o+C \quad \text{for } h > A_0 \qquad [3]$$

The linear model describes a straight-line variogram. The formula used is:

$$\gamma(h)=C=[H(\frac{C}{Ao})] \qquad [4]$$

The best-fitted model then is used for kriging to interpolate unsampled locations. The kriging uses a linear combination of the observations to make unbiased predictions of unsampled values with minimum error variance. For better fitting, the model data frequency distribution was compared to a normal distribution. The skew ness and kurtosis coefficients are often used to describe the shape of data distribution. An absolute value of either coefficient is greater than 2, the distribution is considered as either skewed or kurtotic. A significant positive skewness coefficient indicates a long right tail; a negative value indicates a long left tail. A significant positive kurtosis coefficient shows a peaked distribution; a negative coefficient shows a flat distribution.

The data of P and STC were normalized by taking natural logarithm transformations in order to minimize the variation and meet the requirement of geostatistic analysis. Semivariogram models were best-fitted using GS^+ Gama Design software (Robertson, 1998). The puctual kriging with 3.9-m interval and 6 nearest neighbors was used to obtain point estimates of soil properties at unsampled locations.

RESULTS AND DISCUSSION

Statistical Parameters of Soil Property Data

Descriptive statistics for soil pH, P, and STC at 0- to 5-cm and 5- to 10-cm depths were presented in Table 1. Mean soil pH in the upper depth was greater than pH in the lower depth. Standard deviations at both depths were slightly different. Overall, pH ranged from 4.8 to 6.0 the upper depth, and 4.6 to 5.5 in the lower depth. Distribution of pH was kurtotic, but only in the upper depth.

Soil P ranged from 20 to 120 mg kg^{-1} in the upper depth and 14 to 120 mg kg^{-1} in the lower depth. Means and standard deviations of P at both depths were similar. Distribution of P was positively skewed, indicating that there were some few extreme high values in this transect.

Table 1. Statistical parameters of selected soil properties along the transect.

Soil properties	Soil depth (cm)	Mean	Min.	Max.	St.D.	Skewness coef.	Kurtosis coef.
pH	0-5	5.4	4.8	6.0	0.4	-0.73	-2.12
	5-10	5.1	4.6	5.5	0.3	-1.24	-1.43
P (mg kg^{-1})	0-5	57	20	120	28	2.00	-0.53
	5-10	53	14	120	30	2.44	-0.08
ln(P)	0-5	3.92	3.00	4.79	0.50	-0.04	-1.24
	5-10	3.83	2.64	4.79	0.57	-0.41	-0.57
STC (g kg^{-1})	0-5	8.26	3.40	33.40	5.94	6.53	10.45
	5-10	5.96	2.70	15.30	3.20	3.73	1.66
ln(STC)	0-5	1.94	1.22	3.51	0.56	2.20	0.20
	5-10	1.67	0.99	2.73	0.47	1.69	-0.64

Table 2. Comparison of pH, P and Total C between CRP and CCL.

Depth (cm)	Treatment	pH	P mg kg^{-1}	STC g kg^{-1}
0-5	CRP	$5.8^{§}$	38	9.18
	CCL	5.1	75	7.33
	Difference	0.7^{***}	-37^{**}	1.85NS
5-10	CRP	5.3	33	4.64
	CCL	4.9	74	7.28
	Difference	0.4^{***}	-41^{**}	-2.64^{**}

§ Mean value. Difference = CRP-CCL.

**, *** Significant at 0.01 and 0.001 probability level.

NS indicates no significant difference.

Soil total carbon was 2.3 g kg^{-1} higher in the upper depth than that in the lower depth. Moreover, STC varied about 10 times from 3.4 to 33.4 g kg^{-1} at upper depth and 5 times from 2.7 to 15.3 g kg^{-1} in the lower depth. Greater variation occurred in the upper depth. A few low spots near the middle of the transect had extremely high STC. Soil total carbon both depths was significantly positively skewed and also was kurtotic in the upper 5 cm depth. This meant that STC spanned a broad range, but most values were observed at the lower end of the range, with a few extremely large values. Logarithmic transformed values of P and STC had decreased standard deviation and reduced skewness and kurtosis coefficients.

Statistical comparison of CRP and CCL within each depth was done using a t-test. For both depths, pH was significantly higher in CRP than in CCL ($p<0.001$) (Table 2). Conversely, at both depths available P was significantly lower in CRP than in CCL ($p = 0.01$). However, STC at 0-5 cm depth did not differ, but at 5-10 cm, it was significantly higher in CCL than in CRP ($p = 0.01$). These results indicate that CRP lowered soil acidity and moved the soil environment towards a neutral pH. On the other hand, land in continuous production tended to acidify the soil environment. Also, CCL and accumulated P in the root zone, likely the result of intensive application of nitrogen and phosphorus fertilizers.

Semivariogram Models

The geostatistical parameters describing soil properties from a transect data set were listed in Table 3. Regression coefficients (r^2) suggested that all models were best fit. The semivariograms of soil pH and STC were best described by a spherical model (Figs. 2 and 4). The P data was best fit as a linear model (Fig. 3). Nuggets Co for all models were close to zero. Smaller nugget indicates the sampling interval is proper to reflect the variance (Nielsen, 1998).

The range in lag distance of pH and P were about 260 m. The range of STC was about 160 m. Within the range, the measurements of variable are correlated with each other. Soil total carbon had a narrower range than either pH or P and observations were correlated at shorter distances.

When the semi variance does not change significantly with increasing lag distance, the plateau reached, called the sill, reflects the magnitude of random variation (Nielsen, 1998). The sill for ln(STC) was approximately twice as high at 0-5 cm as at 5-10 cm. This implies that STC in the upper soil depth had greater variation. For the linear model of P, there was no sill reached across the 400 m transect. The semi variances for all samples were linearly dependent within the transect.

Variability of Soil Properties on a One-Dimensional Transect

Soil pH

Fig. 5 showed one-dimensional distribution patterns of pH between CRP and CCL. Within the CRP site, pH was apparently higher in the upper depth than that in the lower depth. However, within the CCL site, pH had greater variation, particularly in the upper depth. Distinct differences between the two depths was not observed. Soil pH in the CRP had less variation and a more consistent pattern for both depths compared to the CCL site. The pH stratification in the CRP site could be due to leaching and lack of mixing of soil profile. The great variation of soil pH in CCL could be attributed as non-uniform N fertilization and tillage operations. Moreover, pH for both depths was clearly lower in the CCL than that in the CRP. The pH exhibited a rapid decrease when it crossed the CRP/CCL boundary. These results indicate that CRP lowered soil acidity, on other hand, CCL tended to acidify the soil environment resulting from great amount of ammonia fertilizer.

Available P

Generally, available P displayed a linear increase with a small period along the entire transect (Fig. 6). Although P in CRP and CCL for both depths were highly variable, concentration of P was higher in CCL than in CRP. Within the CRP site, the high values were clustered in the beginning and end segments of the transect. Lower values occurred around 100 m. The trend of P within CCL was similar to that in CRP. Lower values occurred in the middle section and higher values occurred in the beginning and end segments. No depth difference in P was observed in the CRP or CCL sites.

Total Carbon

Soil total carbon showed periodic behavior with two cycles, like a W-shape along the transect (Fig. 7). The peak values occurred around the CRP/CCL boundary. According to field investigation, distribution of STC was related to field topography. Higher values of STC occurred in a concave area, and lower values occurred in a convex areas. Better soil water conditions resulting in higher biomass production in this depression area produced high soil total carbon. Soil total carbon within the CRP was least around 60 m and then steadily increased to the peak value at 190 m. In CCL, STC peaked as the transect crossed the border with CRP and gradually decreased, reaching the lowest values around 280 m, then steadily increased to the end of the transect. Soil total carbon exhibited a periodic behavior along the transect

Table 3. Geostatistical Model Parameters Describing Soil Properties along a transect

Soil Properties	Soil depth (cm)	Data Transformation	Model	Nugget Co	Sill Co+C	Range Ao	r^2
	0-5	none	Spherical	0	0.31	266	0.980
pH	5-10	none	spherical	0.01	0.1	254	0.976
	0-5	ln(C)	spherical	0.001	0.565	131	0.926
STC	5-10	ln(C)	spherical	0	0.303	125	0.926
	0-5	ln(P)	linear	0.036	0.455	285	0.946
P	5-10	ln(P)	linear	0.111	0.546	285	0.940

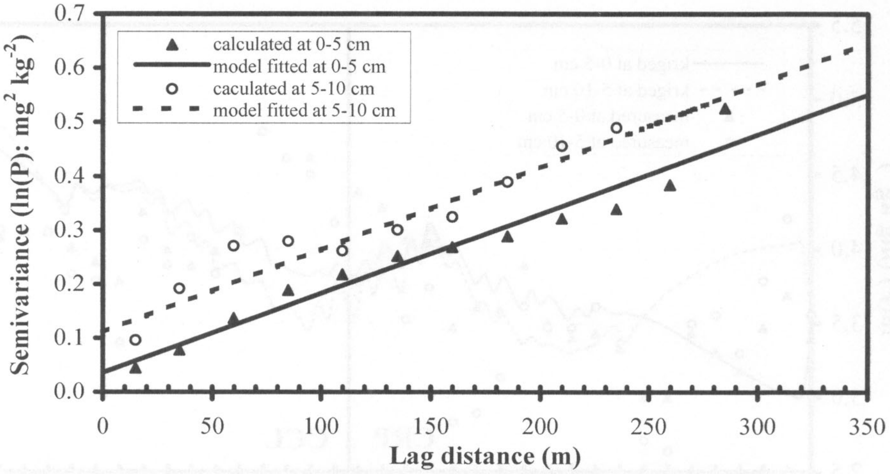

Figure 3. Semivariograms of ln(P) at two depths.

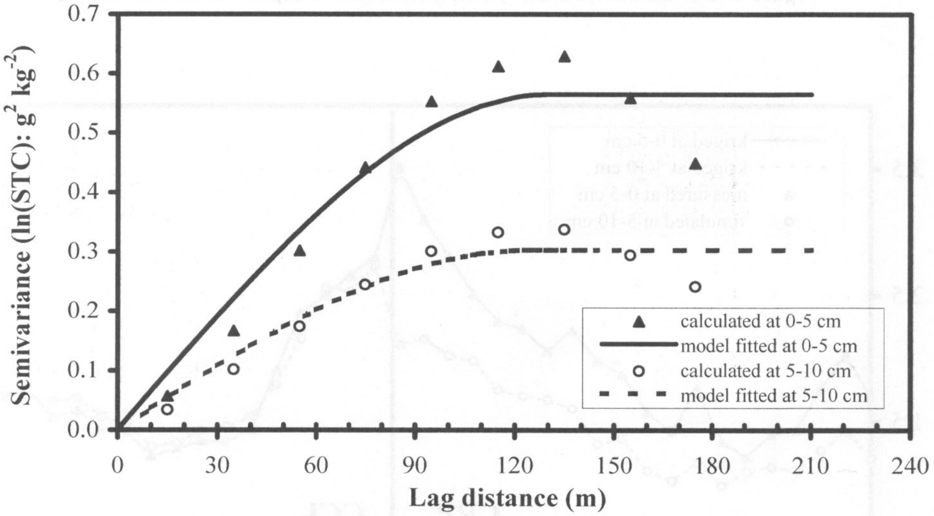

Figure 4. Semivariograms of ln(STC) at two depths.

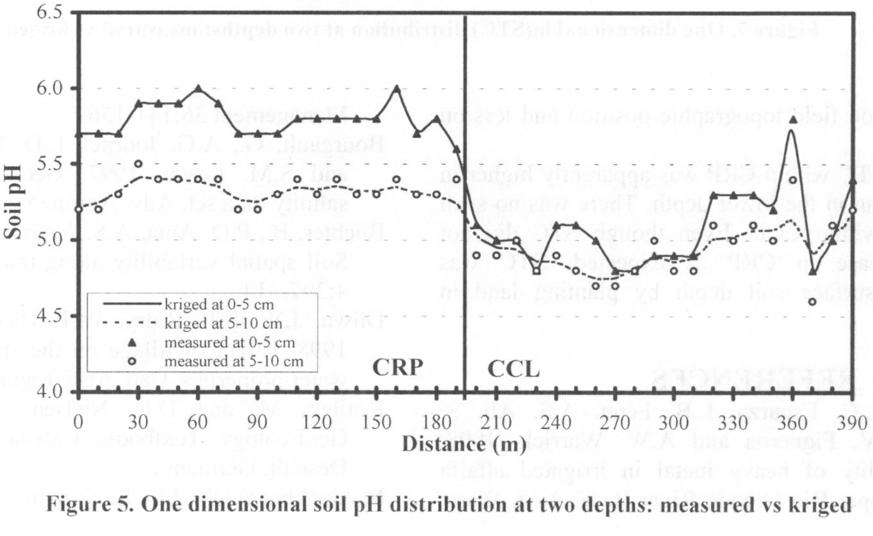

Figure 5. One dimensional soil pH distribution at two depths: measured vs kriged

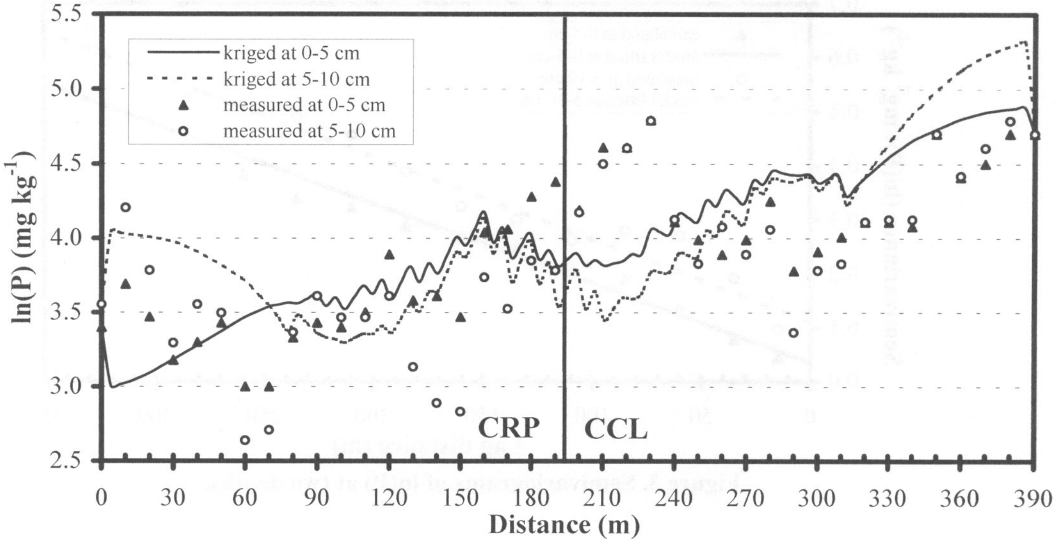

Figure 6. One dimensional ln(P) distribution at two depths: measured vs kriged

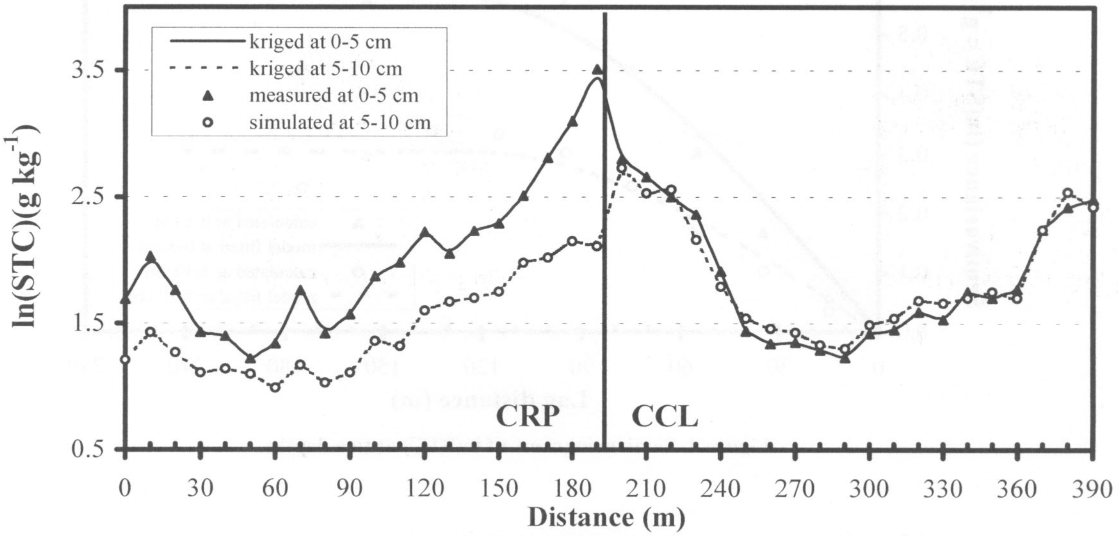

Figure 7. One dimensional ln(STC) distribution at two depths: measured vs kriged

mainly depending on field topographic position and less on land use.

Like soil pH, STC within CRP was apparently higher in the upper depth than in the lower depth. There was no such difference noted within CCL. Even though STC did not significantly increase in CRP as expected, STC was increased in the surface soil depth by planting land in permanent grasses.

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