VARIABILITY OF SOIL ORGANIC CARBON IN TWO RECLAIMEDSITES IN SOUTH EASTERN OHIO[1]

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Abstract: Knowledge of spatial variability is essential for assessing the true soil organic carbon (SOC) content and the sequestration potential of reclaimed minesoils (RMS). Two experimental sites were selected for determining the spatial variability of some soil properties including soil organic C (SOC) stock. Both sites located in Guernsey County of Ohio were reclaimed in 1978 with topsoil application and are under grass and forest cover, respectively. Soil bulk density (ρ_b), SOC, total nitrogen (TN) concentrations and stocks were determined for both sites for 0-15 cm, 15-30 cm, and 30-50 cm depths. In the Forest site, the statistical variability of ρ_b was low in all three depths. The ρ_b increased with depth and ranged from 0.88 Mg m^{-3} to 1.16 Mg m^{-3} for 0-15 cm, 0.91 Mg m^{-3} to 1.32 Mg m^{-3} for 15-30 cm, and 1.37 Mg m^{-3} to 1.93 Mg m^{-3} for 30-50 cm depths. The variability in ρ_b was also low in Grass site and ranged from 0.82 Mg m^{-3} to 1.18 Mg m^{-3} for 0-15 cm, 1.04 Mg m^{-3} to 1.37 Mg m^{-3} for 15-30 cm, and 1.18 Mg m^{-3} to 1.83 Mg m^{-3} for 30-50 cm depths. The ρ_b showed strong spatial dependence for 0-15 cm depth only in the Forest site (nugget:sill ratio = 20). The statistical variability of SOC concentrations and stocks were high for all depths in both sites (CV > 0.36). The SOC stocks also had strong spatial dependence for 0-15 cm and 30-50 cm depths (nugget:sill ratio < 17) and moderate to strong dependence for 15-30 cm depth in the Forest site (nugget:sill ration=24). In contrast, in Grass site, ρ_b was weakly and SOC stocks moderately spatially dependent for all depths. Variability did not follow a consistent trend and both short (mostly) and long range variability were observed. These results suggest that the management effects are important and assessment of spatial variability is necessary for the correct assessment of SOC accretion in reclaimed minesoils.

Additional Key Words: spatial scales, reclamation, management, soil organic carbon, soil Nitrogen

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Introduction

Soil is a dynamic, living, natural body and a key factor in the sustainability of terrestrial ecosystems. Soil quality has significant influence on the health and productivity of an ecosystem and the related environment (Larson and Pierce, 1991). However, soil quality varies in time and space, mainly because of the variability of soil physical and chemical properties. Soil properties manifest both short and long range variability and are multivariate in nature (Nielsen et al., 1973). This variation influences soil functions, water and nutrient movement through soil, root growth and sustenance.

Variability in soil properties can be expressed as a coefficient of variation (Wilding, 1985). However, it does not take into account the spatial covariance structure of the multivariate soil properties and can have high uncertainty. Geostatistics is a useful tool for analyzing the spatial variability, interpolating between point observations, and ascertaining the interpolated values with a specified error using a minimum number of observations (Burrough, 1991). Spatial dependence on soil properties are reported for scales ranging from a few meters (Trangmar et al., 1987) to several kilometers (Ovalles and Collins, 1987).

Surface mining is an anthropogenic activity that drastically changes the antecedent soil profile and soil quality. Mining leads to decline in soil structure, loss in aggregation and soil organic C (SOC) (Jansen, 1981; Shukla et al. 2004b). Reclamation of minesoils mitigates the negative environmental consequences associated with mining (Barnhisel and Hower, 1997). Reclamation curtails soil degradation and sets soil restorative process in motion (Daniels and Zipper, 1995; McSweeney and Jansen, 1984). Compaction associated with the reclamation processes results in initial increased soil bulk density and reduced porosity (Silburn and Crow, 1985). Restoration of minesoils is a viable option for terrestrial C sequestration. During 25 years following reclamation, Shukla et al. (2004a) reported a two-time increase in SOC stocks in two sites located in southeastern Ohio. Knowledge of spatial variability of SOC is important for assessing the true soil organic carbon (SOC) sequestration potential of reclaimed minesoils (RMS). It is also important for developing appropriate monitoring and verification protocols for carbon sequestration projects. Therefore, the objectives of this study were to classify some soil physical and chemical properties to capture optimally the total within field variability.

Methods and Materials

Experimental Sites

The experimental sites consisted of two fields reclaimed in 1978 with topsoil application in conformity to the 1977 Surface Mining Control and Reclamation Act (SMCRA). After reclamation both sites were seeded to grass to prevent soil erosion. In order to bring the Cumberland site back to its premined condition, trees were planted in the year 1982 (Fig. 1). According to the USDA classification, soil texture for both sites was silt loam.

A. Wilds grass site

B. Cumberland tree site

Figure 1. Experimental sites reclaimed in year 1978: (A) under grass, and (B) under forest cover owned by American Electric Power (AEP) Co.

Collection of Soil Sample

The core and bulk soil samples were collected from a 20 x 20 m grid size for 0-15 cm, 15-30 cm, and 30-50 cm depths. Altogether 90 cores and 270 (90 x 3) bulk soils samples were collected from three depths from each of the site. Core samples were obtained using 6 cm long and 6 cm diameter stainless steel cylinders.

Soil Bulk Density

All soil cores collected in the field were brought to the lab and trimmed at both ends. According to the method described by Blake and Hartge (1986), bulk density (ρ_b) was calculated as the ratio of dry soil weight to the total soil volume. The volume of soil inside the core was corrected by filling dry sand of known bulk density. The ρ_b was not corrected for the coarse fragments.

Soil Organic Carbon Concentrations and Stocks

Air-dried soil from each depth was ground separately to pass through 0.25 mm sieve. About 1 g of the soil was used for the determination of total carbon (TC) and total nitrogen (TN) concentrations by the dry combustion method (Elementar, GmbH, Hanau, Germany). Inorganic C concentration was determined using the procedure of Bundy and Bremner (1972). Briefly, 1.5 to 2 g of soil (< 2 mm) was weighed in a serum bottle that was crimp-sealed. A glass syringe was then used to inject 4- mL HCl (2 M) into the bottle to decompose the carbonates. The carbon dioxide (CO_2) produced was injected into gas chromatograph (Shimadzu, GC 14A). Using a thermal conductivity detector, the concentration of CO_2 was obtained and was converted to IC concentration. The TC was assumed to be the SOC because there IC concentration was very low (< 1 g kg^{-1}). The SOC and TN stocks were calculated as the product of SOC or TN concentration, ρ_b and the specific depth of soil layer. Soil C content after thermal pretreatment at 350^0C for 24 h was assumed to be coal C content (Schmidt et al., 2001).

Statistical Analysis

Descriptive statistics including mean, standard deviation, CV, maximum, minimum, skewness, and kurtosis were obtained for each measured soil variable using the Statistical Analysis System (SAS Institute, 1989). All measured soil physical and chemical properties were checked for normality. Using *Variowin* (Pannatier, 1996) and ArcGIS geostatistical Analyst (ESRI, 2004), variograms of each soil physical property and cross-variograms were obtained. The spherical models were fitted to the variograms (Fig 2):

$$\gamma(h) = C_0 + C_1\left[\frac{3h}{2a} - \frac{h^3}{2a^3}\right] \qquad \text{for } h \le a$$
$$= C_0 + C_1 \qquad \text{for } h \ge a \tag{1}$$

where C_0 is nugget, h is lag distance and a is range of spatial dependence to reach the sill ($C_0 + C_1$).

Variations in soil properties were expressed by ranking the CV into different classes: least (<15%), moderate (15 to 35%) and most (>35%) (Wilding, 1985; Shukla et al., 2004c). Distinct classes of spatial dependence for soil variables were obtained by the ratio of the nugget to the total sill value (NSR). The variable was considered strongly spatially dependent when the NSR was $\le$ 25%, moderately spatially dependent for 25% < NSR < 75% and weakly spatially dependent for the NSR of $\ge$ 75% (Cambardella et al., 1994).

Results and Discussion

Variability of Soil Properties

Tables 1 to 3 list the descriptive statistics of the original data from Forest site including mean, median, coefficient of variation, skewness, kurtosis, maximum and minimum values for 0-15 cm, 15-30 cm and 30-50 cm depths, respectively. Despite some skewness in the data for ρ_b, TN, and SOC concentrations and stocks, the mean and median values for all these parameters were similar and median was either equal to or smaller than the mean for most of the parameters and data was normally distributed. The standard error of the mean as well as range (minimum-maximum) increased with depth for all the measured parameters. The CV was low for ρ_b (7% to 8%) and high for SOC concentrations and stocks (44% to 70%) for all depths. However, variability in TN concentrations and stocks was high (>35%) for 0-15 cm, and moderate (21% to 28%) for 15-30 and 30-50 cm depths.

For Forest site, the mean ρ_b ranged from 0.88 Mg m^{-3} to 1.16 Mg m^{-3} for 0-15 cm, 0.91 Mg m^{-3} to 1.32 Mg m^{-3} for 15-30 cm, and 1.37 Mg m^{-3} to 1.93 Mg m^{-3} for 30-50 cm depths. The SOC concentration was 23.7±10.4 g kg^{-1} for 0-15 cm, 17.5±2.2 g kg^{-1} for 15-30 cm, and 17.3±10.0 g kg^{-1} for 30-50 cm depths. The SOC stocks were 35.9±16.6 Mg ha^{-1} for 0-15 cm, 31.9±22.3 Mg ha^{-1} for 15-30 cm, and 44.8±26.8 Mg ha^{-1} for 30-50 cm depths. Mean ρ_b increased with depth and SOC stocks were higher for the 30-50 cm than for 0-15 and 15-30 cm depths. However, TN concentrations and stocks decreased with depth. This higher SOC stocks for 30-50 cm than other two depths were due to the presence of coal particles in the deeper soil layers. The coal C content in the soil increased with depth and ranged from 0.5% in 0-15 to 40% in 30-50 cm depth.

Table 1. Summary statistics for soil properties for the Cumberland site under forest for 0-15 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	1.00	1.33	2.00	23.7	35.9
Median	1.01	1.29	1.95	22.5	35.0
Std Error	0.01	0.08	0.13	1.9	3.0
Std Dev	0.07	0.46	0.73	10.4	16.6
CV	0.07	0.35	0.37	0.4	0.5
Kurtosis	0.03	0.87	0.56	-0.1	0.1
Skewness	0.02	0.80	0.72	0.6	0.6
Minimum	0.88	0.59	0.85	6.5	8.7
Maximum	1.16	2.41	3.92	49.0	72.2

where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

Table 2. Summary statistics for soil properties for the Cumberland site under forest for 15-30 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	1.20	0.57	1.02	17.5	31.9
Median	1.21	0.57	1.03	15.8	26.6
Std Error	0.02	0.03	0.05	2.2	4.1
Std Dev	0.09	0.16	0.28	11.8	22.3
CV	0.08	0.28	0.27	0.7	0.7
Kurtosis	2.11	-0.21	0.20	-0.1	-0.1
Skewness	-1.08	0.45	0.50	0.8	0.8
Minimum	0.91	0.29	0.50	1.3	2.3
Maximum	1.32	0.95	1.75	43.7	82.6

where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

Table 3. Summary statistics for soil properties for the Cumberland site under forest for 30-50 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	1.73	0.49	1.26	17.3	44.8
Median	1.77	0.48	1.28	16.7	45.0
Std Error	0.02	0.02	0.05	1.8	4.9
Std Dev	0.13	0.13	0.27	10.0	26.8
CV	0.07	0.26	0.21	0.6	0.6
Kurtosis	1.09	4.45	0.58	3.2	6.8
Skewness	-1.15	1.64	0.53	1.2	1.8
Minimum	1.37	0.32	0.83	1.1	2.9
Maximum	1.93	0.95	1.95	51.1	148.2

where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

Tables 4 to 6 present the descriptive statistics for the original data for the Grass site. The median values were again close to mean values and except for the ρ_b, median values were smaller than the mean. The standard error of the mean as well as range increased with depth for all the measured parameters. The variability was low in ρ_b (6 to 7%) and high in SOC concentration, TN and SOC stocks (>36%) for all depths. However, variability in TN concentration ranged from moderate for 0-15 cm and 15-30 cm depths (32% and 31%, respectively) to high (44%) for the remaining depth (>44%).

Table 4. Summary statistics for soil properties for the Wilds site under grass for 0-15 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	0.98	1.43	3.67	15.4	22.6
Median	0.01	0.09	0.44	1.0	1.5
Std Error	0.98	1.35	2.89	14.6	21.9
Std Dev	0.07	0.47	2.42	5.6	8.1
CV	**0.07**	**0.32**	**0.66**	**0.4**	**0.4**
Kurtosis	2.08	0.53	2.00	1.1	0.5
Skewness	0.42	0.02	1.31	0.4	0.1
Minimum	0.82	0.26	0.07	1.9	2.7
Maximum	1.18	2.50	11.24	30.0	40.3

where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

For the Grass site, mean ρ_b was 0.98±0.07 Mg m^{-3} for 0-15 cm, 1.24±0.07 Mg m^{-3} for 15-30 cm, 1.72±0.11 Mg m^{-3} for 30-50 cm depths. The SOC concentration was 15.35±6.63 g kg^{-1} for 0-15 cm, 8.77±8.83 g kg^{-1} for 15-30 cm, and 13.85±10.70 g kg^{-1} for 30-50 cm depths. The SOC stocks were higher for 0-15 cm than the remaining two depths. The higher SOC concentrations and stocks for 30-50 than 15-30 cm depth were due to the contamination by coal particles and ranged from 0.2% for 0-15 to 36% for 30-50 cm depth of the total C concentration in soil.

Table 5. Summary statistics for soil properties for the Wilds site under grass for 15-30 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	1.24	0.47	0.62	8.8	16.3
Median	0.01	0.03	0.10	1.6	3.0
Std Error	1.24	0.46	0.51	5.7	10.2
Std Dev	0.07	0.15	0.55	8.8	16.2
CV	**0.06**	**0.31**	**0.89**	**1.0**	**1.0**
Kurtosis	0.72	-0.27	5.30	10.1	8.2
Skewness	-0.39	0.33	1.86	2.8	2.6
Minimum	1.04	0.22	0.06	1.8	3.4
Maximum	1.37	0.77	2.68	45.7	81.3

where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

Table 6. Summary statistics for soil properties for the Wilds site under grass for 30-50 cm depth. The site was reclaimed in 1978

Property	ρ_b	*TNC*	*TNS*	*SOCC*	*SOCS*
Mean	1.72	0.41	0.90	13.9	35.6
Median	0.02	0.03	0.16	2.0	5.0
Std Error	1.75	0.37	0.62	10.6	28.1
Std Dev	0.11	0.18	0.89	10.7	27.5
CV	**0.07**	**0.44**	**0.99**	**0.8**	**0.8**
Kurtosis	18.53	6.57	5.41	-1.2	-1.1
Skewness	-3.90	2.35	1.95	0.5	0.5
Minimum	1.18	0.23	0.05	1.3	3.3
Maximum	1.83	1.07	4.20	33.6	89.1

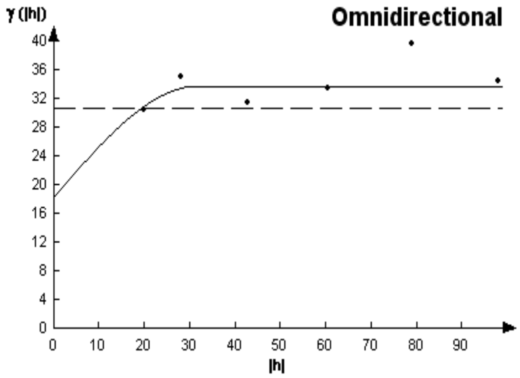
where ρ_b is soil bulk density (Mg m^{-3}), TNC and SOCC is total nitrogen and soil organic carbon concentration (g kg^{-1}), and TNS and SOCS is total nitrogen and soil organic carbon stocks (Mg ha^{-1})

Spatial Variability in Soil Properties

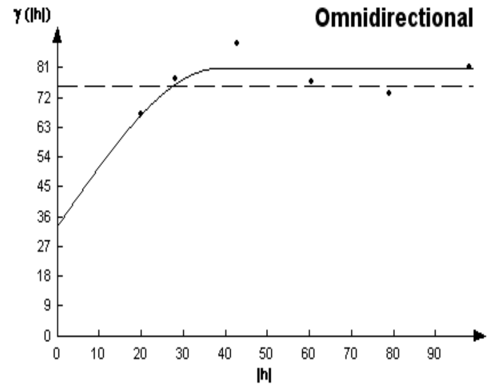
The measured soil properties showed differences in their spatial pattern in Forest site. The spatial dependence showed an isotropic behavior, which can be due to the low variability in soil management treatments and soil forming factors for the study area. Several different models were fitted to the variogram and the spherical model (Eq. 1) was the found to be the best with least sum of squares (Fig. 2). There was no anisotropy evident in the directional semivariograms for any soil property. Therefore, isotropic models were fitted using *Variowin*.

All variogram models of ρ_b, TN and SOC concentrations and stocks showed a positive nugget effect, which may be explained as the sampling error, random and inherent variability, or shorter-range variability of soil properties than the chosen grid size of 20 x 20 m. The relative size of nugget effect among different soil properties is described by expressing the nugget variance as a percentage of total semivariance or total sill (Trangmar et al., 1987).

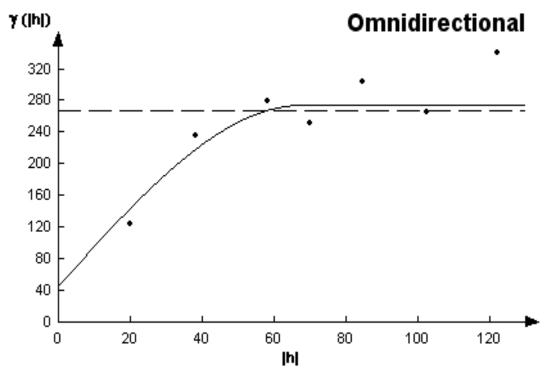
For Forest site, the nugget-sill ratio (NSR) of 20% showed strong spatial dependence for the ρ_b in 0-15 cm depth, and moderate (75% and 47%) for 15-30 cm and 30-50 cm depths, respectively (Table 7). The spatial dependence for TN concentrations and pools was moderate for all depths and ranged from 43% for 0-15 cm to 69% for 30-50 cm and 74% for 0-15 cm to 61% for 30-50 cm, respectively. The SOC concentration had moderate variability (42% to 61% for 0-15 cm and 30-50 cm depths, respectively), which was consistent with the observations made by Ovalles and Collins (1988). However, SOC stocks had strong spatial dependence for all three depths with nugget-sill ratios of 17% for 0-15 cm, 24% for 15-30 cm, and 17% for 30-50 cm depths. The moderate spatially dependent soil properties can be a function of intrinsic variations in soil texture and mineralogy. The extrinsic variations due to topography, and root distribution may result/cause strong variations in SOC stocks, and moderate variation in SOC and TN concentrations. The SOC concentration and stocks showed short range variability (from 22.5 to 67.6 m). Trangmar et al. (1987) also reported short range variability of SOC extending to several meters.



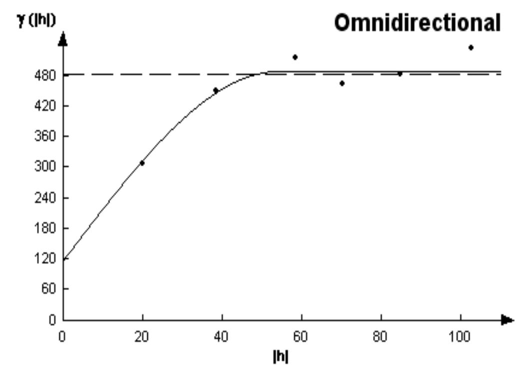
A. Soil organic C stock in 0-15 cm depth



B. Soil organic C stock in 15-30 cm depth



C. Soil organic C stock in 0-15 cm depth



D. Soil organic C stock in 15-30 cm depth

Figure 2. Sample variograms for soil organic C stocks for the Wilds grass site for: (A) 0-15 cm and (B) 15-30 cm depths, and for the Cumberland tree site for: (C) 0-15 cm and (D) 15-30 cm depths

For the Grass site, the nugget-sill ratio exhibited weak spatial dependence (>88%) for ρ_b at all depths. However, SOC and TN concentrations and stocks were characterized by moderate variability for all three depths (Table 8). The Grass site is well maintained and has a very gentle slope with dense grass cover. The moderate variability in SOC and TN concentrations and stocks may probably be due to the small variations in soil texture.

Table 7. The spatial variability of soil properties for the Cumberland site under forest. The site was reclaimed in 1978

Property	Model	SS	Nugget	Range (m)	Partial Sill	NSR (%)
			0-15 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.078	0.001	42.5	0.004	20
TN Concentration (g kg^{-1})	Spherical	0.079	0.09	28.6	0.117	43
TN Stock (Mg ha^{-1})	Spherical	0.109	0.39	36.0	0.138	74
SOC Concentration (g kg^{-1})	Spherical	0.190	52.80	123.0	73.70	42
SOC Stock (Mg ha^{-1})	Spherical	0.018	45.90	67.6	229.50	17
			15-30 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.054	0.006	23.4	0.002	75
TN Concentration (g kg^{-1})	Spherical	0.141	0.014	28.5	0.012	54
TN Stock (Mg ha^{-1})	Spherical	0.142	0.059	32.3	0.022	73
SOC Concentration (g kg^{-1})	Spherical	0.101	0.015	22.5	0.011	58
SOC Stock (Mg ha^{-1})	Spherical	0.003	117	53.9	372.4	24
			30-50 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.081	0.008	23.4	0.009	47
TN Concentration (g kg^{-1})	Spherical	0.575	0.011	19.5	0.005	69
TN Stock (Mg ha^{-1})	Spherical	0.053	0.043	22.1	0.027	61
SOC Concentration (g kg^{-1})	Spherical	0.026	0.0104	24	0.005	68
SOC Stock (Mg ha^{-1})	Spherical	0.011	133	44.2	630	17

where ρ_b is soil bulk density, TN is total nitrogen, SOC is soil organic C, SS is sum of squares, NSR is nugget-total sill ratio (%)

Table 8. The spatial variability of soil properties for the Wilds site under grass. The site was reclaimed in 1978

Property	Model	SS	Nugget	Range (m)	Partial Sill	NSR (%)
			0-15 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.103	0.01	23.4	0.0003	94
TN Concentration (g kg^{-1})	Spherical	0.034	0.15	35.0	0.08	64
TN Stock (Mg ha^{-1})	Spherical	0.010	3.99	32.7	2.05	66
SOC Concentration (g kg^{-1})	Spherical	0.013	18.29	31.7	15.50	54
SOC Stock (Mg ha^{-1})	Spherical	0.023	30.72	28.6	41.60	42
			15-30 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.076	0.01	22.1	0.0007	88
TN Concentration (g kg^{-1})	Spherical	0.018	0.02	77.9	0.01	65
TN Stock (Mg ha^{-1})	Spherical	0.006	0.14	39.6	0.18	44
SOC Concentration (g kg^{-1})	Spherical	0.008	33.44	38.61	47.88	41
SOC Stock (Mg ha^{-1})	Spherical	0.064	166.4	51.8	114.4	59
			30-50 cm depth			
ρ_b (Mg m^{-3})	Spherical	0.158	0.02	23.4	0.001	94
TN Concentration (g kg^{-1})	Spherical	0.097	0.03	49.4	0.01	77
TN Stock (Mg ha^{-1})	Spherical	0.013	0.42	28.5	0.42	50
SOC Concentration (g kg^{-1})	Spherical	0.008	28.8	34.5	86.40	25
SOC Stock (Mg ha^{-1})	Spherical	0.013	270.1	42.0	481.80	36

where ρ_b is soil bulk density, TN is total nitrogen, SOC is soil organic C, SS is sum of squares, NSR is nugget-totalsill ratio (%)

The ρ_b was more spatially dependent in Forest site than Grass site for all three depths. The range was also higher in Forest than Grass site for 0-15 cm depth. Similarly SOC stocks were more spatially dependent in Forest than Grass site for all depths and for 0-15 cm depth the range was higher in Forest than Grass site. In spite of low variations in management practices over past 24 years, soil ρ_b and SOC and TN concentrations varied over a larger spatial distance in forest site than grass site. Therefore, this study clearly demonstrated the importance of management effects on soil properties and need to establish spatially explicit sampling design in forest and grass sites.

Conclusions

The statistical variability was low in soil bulk density and high in soil organic C concentrations and stocks for all depths for both Grass and Forest sites. For Forest site, soil bulk density was strongly spatially dependent for 0-15 cm depth but moderately to weakly spatial dependent for remaining depths. The soil organic C stocks showed strong spatial dependence for all depths in Forest site. For Grass site, soil bulk density was moderately to weakly spatial dependent for each depth. The SOC stocks showed moderate spatial dependence for all depths. Overall for 0-15 cm depth, bulk density and soil organic C were more strongly spatially dependent in Forest than in Grass site. These results suggest that the management effects are important, and that an explicit recognition of these sources of variability is essential to assessing the true soil C content and sequestration potential of reclaimed minesoils.

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Literature Cited

Barnhisel, R.I. and J.M. Hower. 1997. Coal surface mine reclamation in the eastern united states: the revegetation of disturbed lands to hayland/pasture or cropland. Adv. Agron. 61:233-275. http://dx.doi.org/10.1016/S0065-2113(08)60665-3.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. p. 363-376. *In* A. Klute (ed.) Methods of Soil Analysis, Part I, Second edition. ASA Monograph No. 9. Madison, WI.

Bundy, L.G., and J.M. Bremner. 1972. A simple titrimetric method for determination of inorganic carbon in soils. Soil Sci. Soc. Am. Proc. 36:273-275. http://dx.doi.org/10.2136/sssaj1972.03615995003600020021x.

Burrough, P.A. 1991. Sampling designs for quantifying map unit composition. P89-127. in (Eds.) M.J. Mausbach and L.P. Wilding. Spatial variabilities of soils and landforms. SSSA Spe. Publ. No. 28. Soil Sci. Soc. Am. Madison, WI.

Cambardella, C.A., T.B. Moorman, J.M. Novak, T.B. Parkin, D.L. Karlan, R.F. Turco and A.E. Konopka. 1994. Field scale variability of soil properties in central Iowa soils. Soil Sci. Soc. Am. J. 58:1501-1511. http://dx.doi.org/10.2136/sssaj1994.03615995005800050033x.

Daniels, W.L. and C.E. Zipper. 1995. Improving coal surface mining reclamation in the central Appalachian region. P. 187-217. In J. Cairns Jr. (ed.) Rehabilitating damaged ecosystems. Lewis Publ. Boca Raton, FL.

ESRI, 2004. ArcGIS software. Version 8.3. http://www.esri.com.

Jansen, I.J. 1981. Reconstructing soils after surface mining of prime agriculture land. Mining Eng. 33, 312-314.

Larson, W.E. and F.J. Pierce. 1991. Conservation and enhancement of soil quality, in evaluation for sustainable land management in the developing world. Vol. 2, IBSRAM Proc. 12(2). Bangkok, Thailand. Int. Board for Soil Res. And Management.

McSweeney, K. and I.J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. Soil Sci. Soc. of am. J., 48:607-612. http://dx.doi.org/10.2136/sssaj1984.03615995004800030028x.

Nielsen, D.R., J.W. Biggar and K.T. Erh. 1973. Spatial variability of field measured soil water properties. Hilgardia. 42:215-259. http://dx.doi.org/10.3733/hilg.v42n07p215.

Ovalles, F.A. and M.E. Collins. 1988. Evalluation of soil variability in northwest Florida using geostatistics. Soil Sci. Soc. Am. J. 52:1702-1708. http://dx.doi.org/10.2136/sssaj1988.03615995005200060036x.

Pannatier, Y. 1996. Variowin: software for spatial data analysis in 2D. Springer-Verlag. http://dx.doi.org/10.1007/978-1-4612-2392-4.

SAS Institute. 1989. SAS/STAT user's guide. Version 6. 4th ed. Vol. 1 and 2. SAS Inst. Cary, NC.

Shukla, M.K., R. Lal, J. Underwood and M. Ebinger. 2004a. Physical and hydrological characteristics of reclaimed minesoils in southern Ohio. Soil Sci. Soc. Am. J. 68: 1352-1359. http://dx.doi.org/10.2136/sssaj2004.1352.

Shukla, M.K., R. Lal and M. Ebinger. 2004b. Soil quality indicators for reclaimed minesoils in southestern Ohio. Soil Science. 169:133-142. http://dx.doi.org/10.1097/01.ss.0000117785.98510.0f.

Shukla, M.K., R. Lal, and M. Ebinger. 2004c. Principal component analysis for predicting biomass and corn yield under different land uses. Soil Science. 169:215-224. http://dx.doi.org/10.1097/01.ss.0000122521.03492.eb.

Silburn, D.M. and F.R. Crow. 1985. Soil properties of surface mined lands. Trans. ASAE 27:827-832.

Schmidt, M. W.I., J. O. Skjemstad, C.I. Czimezik, B. Glazer, K. M. Prentice, Y. Gelinas, and T. A.J. Kuhlbusch. 2001. Comparative analysis of black carbon in soils. Global Biogeochem. Cycles. 15:163-167. http://dx.doi.org/10.1029/2000GB001284.

Trangmar, B.B., R.S. Yost and G. Uehara. 1987. Spatial variation of soil properties and rice yield on recently cleared land. Soil Sci. Soc. Am. J. 51:668-674. http://dx.doi.org/10.2136/sssaj1987.03615995005100030059x http://dx.doi.org/10.2136/sssaj1987.03615995005100030021x.

Wilding, L.P. 1985. Spatial variability: its documentation, accommodation, and implication to soil surveys. p.166-194. In: D.R. Nielsen and J. Bouma (Eds.): Soil spatial variability. Pudoc, Wageningen.