Relationship Between Soil Texture and Soil Organic Carbon at Small Field Scale

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Abstract

The capacity of a soil to store organic carbon is related to its particle size distribution, or soil texture, mainly because the capacity of clay particles to stabilize organic materials. A study of the relationship of soil organic carbon (SOC) and particle size distribution at field level in two soils of Saskatchewan indicated that making broad assumptions about the relationship between soil texture and SOC in soils within a filed might lead to erroneous conclusions. At field scale dominant dynamic processes affecting the spatial distribution of soil texture, or other factors may create local conditions that override the fundamental texture SOC relationship of soils.

Introduction

The amount of organic C in soils is determined, by many factors, including particle size distribution, or texture, of the soil. Soils of fine texture tend to have either higher soil organic C, or the capacity to sequester more organic C under aggrading conditions than soils of coarser texture. This difference has been attributed to the capacity of clay particles to protect or stabilize organic substances in the soil (Neufeldt et al. 2002), as evidenced by a reduction in he rate of organic C mineralization observed in soils with elevated clay content compared to that observed in soils of coarser texture (Frauzluebbers and Arshad 1997, McInerney and Bolger 2000). Presently, with the inclusion of carbon sequestration in agricultural lands as a legitimate offset mechanism for greenhouse gases in the Kyoto Protocol agreement, there is considerable interest in developing verification and accounting methodologies to demonstrate that we can quantify accurately SOC stock changes. This could be achieved through repeated and extensive field measurements, but this avenue would be time consuming, tedious, and expensive. Most experts agree that a more feasible solution is to estimate SOC changes using simulation models. However for this avenue to be accepted, we must demonstrate the model's ability to estimate accurately observed SOC changes.

Among the many soil factors that affect the output of models, spatial variability of soil texture within a single field may play an important role in modifying the output of the model. The effect of soil texture on SOC described earlier is preponderant over relatively vast geographic areas, where there is a wide range in particle soil distribution. It is not well understood, however, if this relationship is valid for single fields, where particle size distribution is relatively uniform with a much narrower range of particle size distribution than regularly present over large geographic areas, or where the presence of soil processes particular to a given field might affect the generalized relationship between SOC and soil texture.

The objective of this study was to determine the effect of particle size distribution on SOC concentration at field scale in Brown and in Dark Brown Chernozemic soils in Saskatchewan.

Materials and Methods

As a reference, we used linear regression to determine the relationship between SOC and particle size distribution in the Ah or Ap horizon of Brown, Dark Brown and Black Chernozemic soils of Saskatchewan using data from the CANSIS database.

One hundred and sixty soil cores were taken at Scott, SK, in late spring 1994 in an area 400 x 450 m in a pseudo random pattern for determination of soil properties prior to the establishment of a long-term study of alternative cropping systems (Selles et al. 1999). Each core was divided into 0-7.5 and 7.5-15 cm for determination of inorganic and organic C. The two depth increments were combined for determination of particle size distribution by the hydrometer method (Sheldrick and Wang 1993), and GMD was calculated as outlined by Campbell (1985). Topographic elevation at each sampling point was measured with a surveyor's transit.

The soil at Scott was a Dark Brown Chernozem derived from modified glacial till (Clayton and Ellis 1952). The field had a gentle slope varying from 1 to 3% with a total 4.42 m elevation difference between the highest and lowest point.

In the fall of 2001, soil samples were taken from selected plots of the Swift Current long-term Old Rotation experiment (Zentner and Campbell 1988). The rotations sampled were continuous wheat fertilized with N and P as required [CW (NP)], continuous wheat fertilized with P alone [CW (P)], wheat and lentil phase of continuous cropped wheat-lentil fertilized with N and P (W-Lent). The experiment was laid out as a randomized complete block design with three replicates in plots 10.5 by 40 m. All phases (rotation-year) of each rotation were present every year (Zentner and Campbell 1988). From each plot, 12 cores were taken to a depth of 15 cm on a regular grid. The soil cores were sectioned into 0-7.5, and 7.5-15 cm depths, the soil was passed through a 2 mm sieve, air dried, and a subsample was withdrawn for determination of organic C and total N, using an automated combustion method (Carlo Erba™, Milan, Italy). Particle size distribution was determined by the pipette method after destroying organic matter and carbonates (McKeague 1978).

The soil at Swift Current was a mapped as Swinton silt loam, a Brown Chernozem derived from eolic materials overlying glacial till deposits (Ayres et al. 1985). The field has a very gently undulating topography with slopes not exceeding 2%.

Results and Discussion

The linear regressions between SOC and GMD for Saskatchewan soils explained 21% of the variability of SOC in soils of the Brown soil zone ($n = 999$, $P < 0.0001$), 22% of the variability in soil of the Dark Brown Soil Zone ($n = 343$, $P < 0.0001$), and 27% of the variability in soils of the Black soil zone ($n = 32$, $P = 0.002$) (Figure 1). These regressions indicated that SOC concentration in the soil decreased by 24.2, 78, and 460 g kg^{-1} per each mm of increase in GMD, for Brown, Dark Brown and Black soils, respectively. It is interesting to note that the magnitude of the slope of the regression was inversely proportional to the mean SOC of the soils in each soil zone.

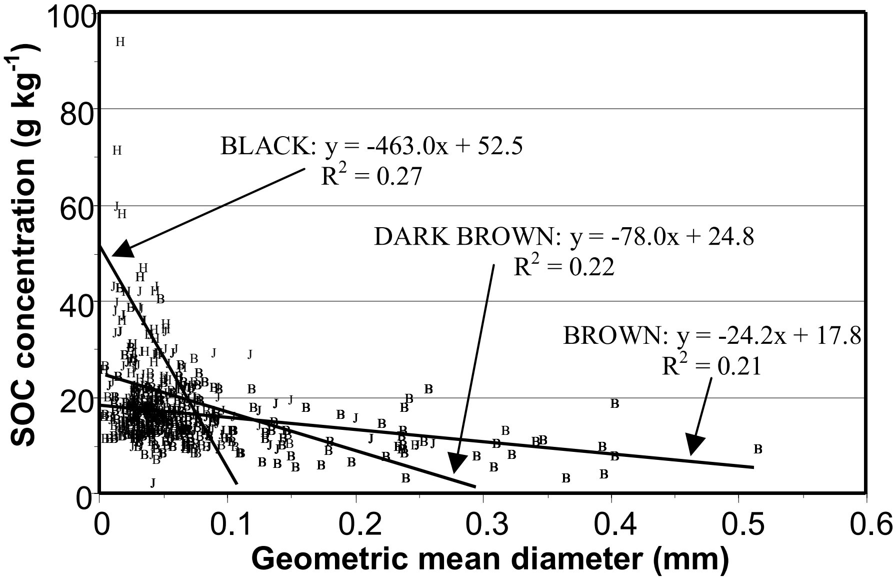

Figure 1. Relationship between soil organic carbon (SOC) and geometric mean diameter of soil separates in the Ah or Ap horizon of Chernozemic soils in Saskatchewan. Data from Agriculture and Agri-Food Canada, Land Resource Unit, Saskatoon.

Scott

Consistent with the soil description for Scott (Clayton and Ellis 1952), a paired t test of the GMD in the 0-15 cm and 15-30 cm depth confirmed that soil texture become finer with depth ($P < 0.0001$). On average the GMD of the surface 15 cm was 0.129 mm and for the 15-30 cm it was 0.109 mm. Particle size distribution in the surface 15 cm ranged from loam in the core with the smallest GMD to sandy loam the core with the largest GMD (Table 1). Sand and silt content between these two extremes varied by a factor of two, while clay content varied almost by a factor of five.

Table 1. Geometric mean diameter (GMD), and sand, silt, and clay content of the samples with the largest and smallest GMD in the surface 15 cm at Scott.

	GMD	**Sand**	**Silt**	**Clay**
	(mm)	----------------------	(%)	--------------------
Coarsest	0.327	72.0	24.5	3.5
Finest	0.063	37.5	47.5	15.0

Contrary to the general relationship between GMD and SOC described, at Scott SOC increased as soil texture became coarser. A linear regression between GMD and SOC indicated that SOC in the 0-7.5 cm depth increased by 4.7 g kg^{-1} for each 0.1 mm increase in GMD (Figure 2).

Parallel to this, we determined that SOC was inversely related to topographic elevation (Figure 3), increasing at a rate of 2.8 g kg^{-1} for each 1m increase in elevation. Simultaneously, the GMD of the surface 15 cm of soil decreased with an increase in elevation (Figure 4), indicating that at the highest reaches of the field soil texture was fines than in the lowest areas.

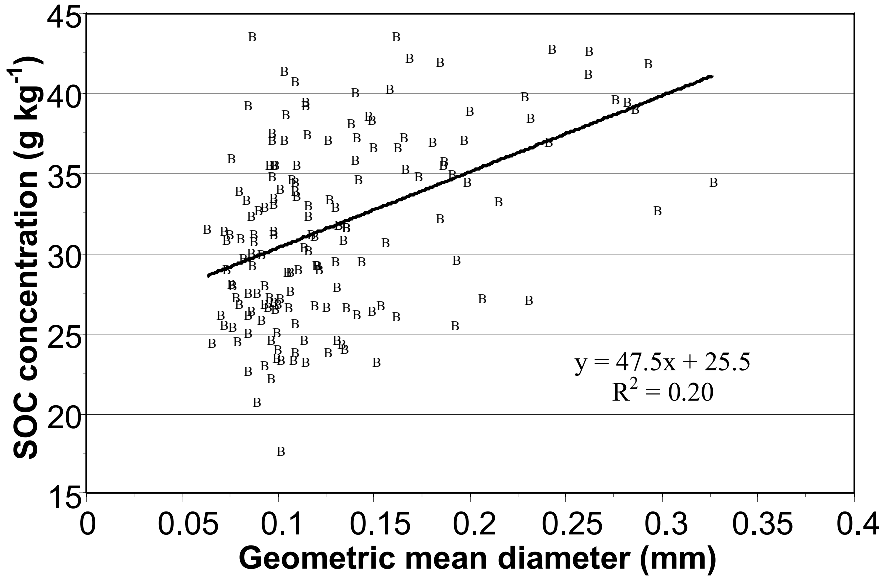

Figure 2. Relationship between soil organic carbon (SOC) and geometric mean diameter of soil separates in the surface 7.5 cm of soil at Scott.

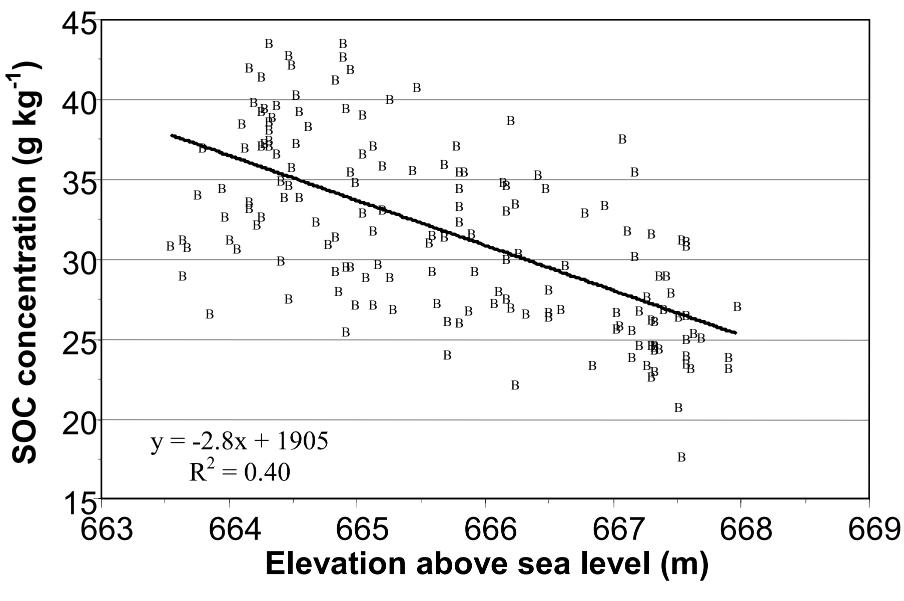

Figure 3. Effect of elevation on concentration of soil organic carbon (SOC) in the surface 7.5 cm of soil at Scott.

A stepwise regression procedure indicated that a regression model containing elevation and GMD would explain 46% of the observed variability in SOC. However, the variance inflation factor suggested that co-linearity between GMD and elevation might have invalidated the model. To avoid these problems we used GMD residuals from the elevation/GMD regression. This new model also explained 46% of the observed SOC variability, and furthermore indicated that elevation was a more important factor in determining the levels of SOC in the field. The studentized regression coefficients indicated that an increase in one standard deviation in elevation produced a decrease in SOC of 0.63 standard deviations, while a similar change in GMD produced and increase in SOC of only 0.24 standard deviations (Table 2).

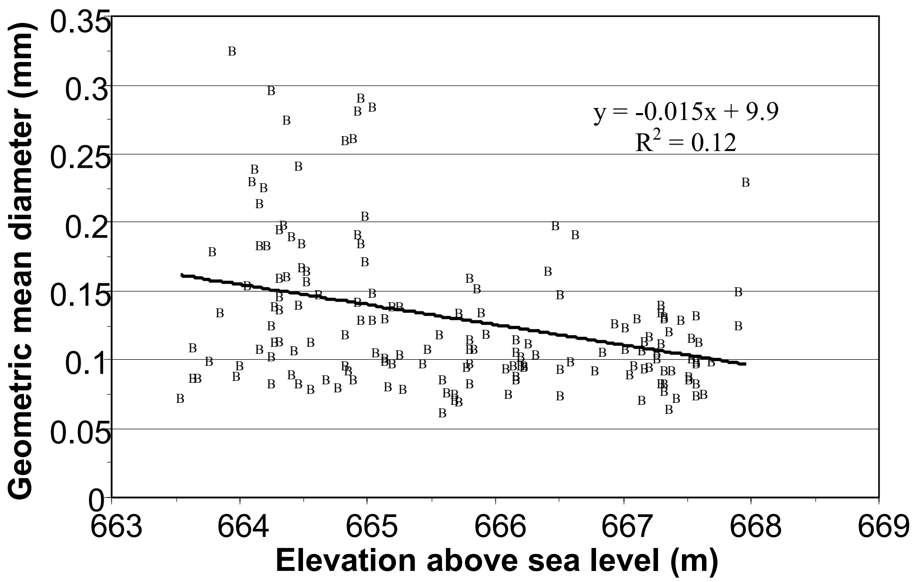

Figure 4. Effect of elevation on geometric mean diameter of soil separates in the surface 15 cm of soil.

As a result of this, elevation accounted for 40% of the explained SOC variability while GMD accounted for only 6%, as indicated by the semi-partial correlation coefficients (Table 2).
In order to obtain a better understanding of the effect of particle size distribution we determined the relationship between SOC and the proportion of each particle size classes. In this soil SOC was positively correlated with sand, and negatively correlated with silt and clay (Table 3). Clay explained the largest proportion of variability in SOC, and produced the largest change in this variable. The effect of sand was intermediate between that produced by clay and by silt, which explained just 3% of the variability of SOC, and had little effect on SOC levels.

Table 2. Effects of elevation and residual geometric mean diameter (rGMD) of the surface 15 cm on soil organic carbon (SOC) at Scott.

Parameter	Estimate	Studentized regression coeff.	Semipartial regression coeff.	Prob > |t|
Intercept	1904	--	--	<0.0001
Elevation	-2.81	-0.63	0.40	<0.0001
rGMD	27.33	0.24	0.06	<0.0001

In an earlier study Selles et al. (1999) indicated that at Scott there was evidence that erosion-deposition may have been active in the past removing surface SOC-rich soil and depositing it at lower elevations in the field, while exposing subsurface soil with lower SOC and higher clay content. Assuming that the original surface texture and SOC concentration of this soil was relatively uniform throughout the field, deposition of the eroded soil in lower parts of the field would tend to maintain the original SOC concentration and texture. This process would explain the reduction in SOC with elevation, the decrease of GMD with elevation, and the reduction of SOC as texture becomes finer.

Table 3. Simple linear regressions of soil organic carbon (SOC) with sand, silt, and clay content at Scott.

Particle size class	Slope	Studentized regression coeff.	r^2	Prob > F
Sand	0.26	0.36	0.13	<0.0001
Silt	-0.15	-0.18	0.03	0.02
Clay	-0.95	-0.53	0.28	<0.0001

Swift Current

The soil at Swift Current had finer texture than the soil at Scott. The silt and clay contents substantially higher, while the sand content was substantially lower. The textural classes at Swift Current ranged from silt loam to loam (Table 4). Similarly to Scott, the GMD in Swift Current at the surface of the soil (0-7.5 cm) was significantly larger ($P < 0.0001$) than in the 7.5-15 cm depth; the GMD was 0.036 mm in the surface layer and 0.033 mm deeper in the profile, but the difference between the two depths was 10 times smaller than that observed at Scott. Furthermore, the range in particle size distribution among the different samples at Swift Current was much narrower than at Scott. Sand and silt content between the core with the largest and smaller GMD varied by a factor of less than two, and clay content almost did not have a difference between the two extremes (Table 4).

Table 4. Geometric mean diameter (GMD), and sand, silt, and clay content of the samples with the largest and smallest GMD in the surface 15 cm at Swift Current.

	GMD	Sand	Silt	Clay
	(mm)	----------------------	(%)	----------------------
Coarsest	0.053	38.9	38.7	22.3
Finest	0.027	22.5	53.3	24.2

Table 5. Simple linear regressions of soil organic carbon (SOC) with sand, silt, and clay content at Swift Current.

Particle size class	Slope	Studentized regression coeff.	r^2	Prob > F
Sand	-0.61	-0.64	0.41	<0.0001
Silt	0.55	0.63	0.39	<0.0001
Clay	-0.52	-0.15	0.02	0.07

A linear regression between GMD and SOC revealed that at Swift Current the functional relationship between these two variables followed the general functional form described earlier for Saskatchewan soils. On average, SOC in this soil increased by 42 g kg^{-1} with a GMD reduction of 0.1 mm (Figure 5).

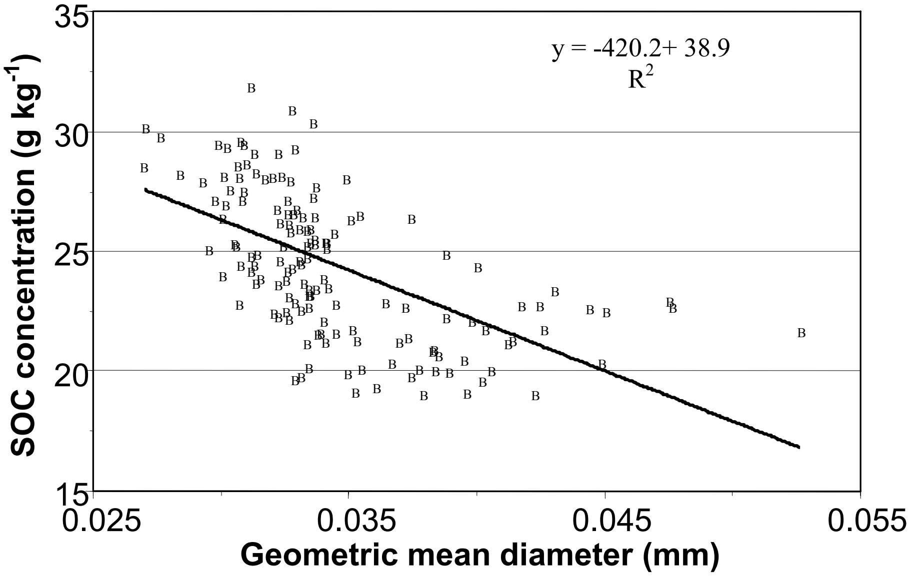

Figure 5. Relationship between soil organic carbon (SOC) and geometric mean diameter of soil separates in the surface 7.5 cm of soil at Swift Current.

The regressions of SOC with each of the soil separates (sand, silt, and clay) indicated that the bulk of the variability in SOC was associated with the variability in the sand and silt fractions (Table 5). The clay fraction in general had a weak association with SOC, explaining only 2% (P = 0.07) of the variability in SOC. Organic carbon concentration tended to show an inverse relationship with clay content, contrary to the generally accepted positive association often cited in the literature (Parton et al. 1987). Because of the negligible contribution of the clay fraction to the variability in SOC, most of the explainable variability at this site was related to the soil fractions coarser than 0.002 mm. Since the coarser fraction of the soil is a binary mixture of sand and silt, it follows that their proportions in the mixture are inversely related; that is when the proportion of sand increases, the proportion of silt must decrease, and vice-versa. As a result, one expects that the relations between SOC and sand or silt would be equal but opposite. Indeed this is what we observed, similar absolute value of the slope coefficients, but with opposite signs (Table 5). This conformed that although in this soil SOC concentration increased as the particle size distribution became dominated by finer particles, it was just the proportion of sand and silt and not the clay content that affected SOC.

One might speculate that in this soil derived from wind sorted and transported materials, the continued action of wind, because of size and shape factors, has co-sorted silt and particulate organic matter, transported them for short distances (from a few centimetres to a fraction of a metre), and then deposited them in shallow depressions, crevices, or sheltered areas at the soil surface. This dynamic process may have created small marginally more eroded areas with more sand and lower SOC concentration, and depositional areas of elevated silt content and SOC concentration.

Conclusions

Although there is a well established relationship between clay content and SOC that applies to soils with a wide variety of textures in relatively broad geographical areas, this study suggests that generalization of this relationship by applying it without verification to soils within a field may lead to erroneous conclusions because of dynamic processes operating locally, or specific soil conditions may override the generalized relationship between texture and SOC.

Acknowledgements

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