Increasing Soil Carbon as a Management Practice to Improve Soil Quality and Yield for Eroded Landscapes

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Abstract: Soil erosion has been a problem for agricultural systems since ancient times, with the main results of erosion being the loss of soil productivity because of degradation of soil quality stemming from loss of surface soil organic carbon (C). Erosion of the productive surface soil from a landscape reduces soil quality and crop production because it alters chemical, biological and physical properties of the soil, because of reductions in C and associated thickness of the surface soil horizons and the effective rooting depth. We developed a fast and reliable technique for mapping the thickness of soil horizons of an eroded landscape using a cone penetrometer and are now evaluating management practices to optimize agricultural production and environmental protection for eroded soils. Properties of eroded soil such as C content can be improved by addition of organic material, such as animal manure, and retaining crop residue on the soil surface. Animal manure was applied to both eroded and non-eroded areas. Crop yields were correlated to the amount of C in the surface soil, and manure applications resulted in an increase in soil C and crop yield, though not always significant.
Key words: soil erosion, soil carbon distribution, animal manure, yield.

INTRODUCTION and LITERATURE REVIEW

Soil erosion frequently has a detrimental effect on soil physical, chemical and biological properties throughout the soil landscape. However, the erosional process is often only recognized at selected locations such as the steep slopes on a landscape. A key soil property that is impacted by soil erosion is the amount of C in the surface soil, as erosion is a selective process which removes the C rich topsoil (Lowery et al., 1995). This removal is not constant across a given landscape however. Thus, there is a need to develop representative maps of eroded landscapes to better understand soil carbon distribution and variability. This information could be used to explain how this distribution impacts crop yield and other soil properties and quality at the landscape scale. The most realistic means of displaying soil variability would be with three-dimensional (3-D) maps of various soil properties (Arriaga and Lowery, 2005). These 3-D maps were developed using data collected with a cone penetrometer.

Penetrometers have been widely used by civil engineers to explore subsoil conditions such as relative density, shear strength, bearing capacity, and settlement (de Ruiter, 1988; Swedish Geotechnical Society, 1978; Sanlerat, 1972). Penetrometers used in engineering applications are usually designed for penetrating to depths much greater than a meter. Agricultural applications of penetrometers have mainly been used to investigate soil compaction, generally omitting characteristics of the soil profile below the root zone. However, recently a penetrometer has been used to map soil horizons (Rooney and Lowery, 2001), and develop 3-D soil maps for assessing soil variability (Grunwald et al., 2001). Arriaga and Lowery (2005) employed this technique to map eroded landscapes and related soil properties such as soil C distribution. However, more emphasis is needed to associate soil C amount and distribution with crop yields. Therefore, the objective of this study was to assess soil erosion and C spatial patterns, and relate these to crop yield. A second objective was to evaluate the impact of adding C as animal manure to eroded soil to improve soil productivity.

MATERIAL and METHOD

This study was conducted in southwest and southeast Wisconsin, USA. The southwest site was non-glaciated and located at the University of Wisconsin-Madison, Lancaster Agricultural Research Station (42^o 52' N, 90^o 42' W). The southeast site was located on a private farm in Walworth County, the Quinney Farm, (42^o 41' N, 88^o 38' W). Soils in the non-glaciated area, which is known as the driftless region, which covers parts of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois, were developed in deep loess deposits. The term driftless is applied because there was no glacial drift in this region during the last ice age. Given that the landscape in this region did not experience the leveling effects of glaciers, landscapes are generally characterized by steep slopes, with silt dominating the surface soil thus they are highly vulnerable to erosion.

Soil at the non-glaciated research site is a Dubuque silt loam (fine-silty, mixed, mesic, Typic Hapludalfs), which formed in loess underlain by a clayey residuum. The glaciated site soil is Miami silt loam (fine-loamy, mixed, mesic, Typic Hapludalfs). The study sites had slopes ranging from 2 to 14% steepness. Three levels of past erosion were identified based on the depth of soil above the clayey residuum at the non-glaciated and B-horizon at the glaciated site, respectively. The three levels of past erosion (slight, moderate, and severe) were identified using the depth to the clayey B-horizon or clay residuum as a baseline (Andraski and Lowery, 1992). A minimum of three plots for each erosion level were then established. Three-dimensional maps of the eroded landscapes were developed using cone penetrometer data, as described by Grunwald et al. (2001) and Rooney and Lowery (2001).

Total carbon was determined on soil samples collected with a 1.9-cm diameter hand-push probe or truck mounted 6.0-cm diameter steel sampling probe to a depth of 50 to 100 cm. Samples were sectioned into 10-cm or 15-cm increments. Five samples were taken from each erosion plot at each depth increment and combined to form one composite sample per depth for each erosion plot. Soil samples were oven dried at 105^{o}C for 24 hours. After drying, soil samples were ground by hand to pass through a 100-mesh sieve. Total C was determined by dry combustion with a Tekmar-Dohrman DC-190 carbon analyzer (Rosemount Analytical Inc., Dohrman Division, Santa Clara, CA 95052) equipped with a solid sampler unit or a Leco CNS-2000 analyzer (Leco Corporation, 3000 Lakeview Ave., St. Joseph., MO)[1].

RESULTS and DISCUSSION

Depth to the clayey sub-horizons at both research sites ranged from 0.45 to 0.95 m and was used to delineate different erosion levels across the landscape. A cone penetrometer was used to map depth to clay rich sub-horizons and these data were then used to develop 3-D maps. Soil was sampled at the same sites as cone penetration measurements and these data were used to construct C distribution maps. Soil C distribution was combined with 3-D map to develop data on C distributions over the landscape (Figure 1).

In the top 20 cm of the soil profile, total soil C content at the non-glaciated site ranked severe>moderate>slight, but these differences were not statistically significant (Table 1). This ranking is different from other eroded soils in the Midwestern section of the United States as reported by Lowery et al. (1995), including soils derived from glacial parent materials. The glaciated soil in this study was similar to some reported by Lowery et al. (1995) in that there was no trend of increasing C with erosion level in the surface soil (0-15 cm) (Table 2). At this depth, the C content of the severe erosion level was significantly less than that of the moderate. However, there was a trend of increasing C content with erosion level deeper in the soil profile (15-30 cm). The ranking of C for the different erosion levels in the non-glaciated soil is attributed to the formation of organic clay complexes. As the soil erodes the clay content of the surface horizon increases, thus an interaction between clay particles and organic materials can result in greater C content in eroded soil. Soil C was found to leach as soluble C in this soil as well. Carbon leaching was increased when animal manure was added (Arriaga and Lowery, 2005).

Organic C has long been used as a fertilizer source. Thus, it is not surprising that there is a correlation between crop yields and the C content of the Miami silt loam soil at the glaciated site (Table 3). In general grain

[1] Mention of a company name does not imply endorsement by the University of Wisconsin-Madison or USDA-Agricultural Research Service. Names are only included for the benefit of the reader.

yields increased with organic C and the increase was significant when the C level increased to 15.7 g kg^{-1} soil. The R^2 for the regression equation relating yield to soil C was 0.54 (Table 3).

Animal manure and other organic materials have been suggested as a management strategy to increase the organic C content of eroded soils to improve their productivity (Arriaga and Lowery, 2003). While Arriaga and Lowery (2003) found manure to significantly increase soil C, there is a need to know how long this increase might persist without continuous additions of manure. Table 4 show results from sampling eight years after the last manure application to the Dubuque silt loam soil at the non-glaciated site. While there was greater C in the manure plots of some erosion levels compared to the no manure these differences were not significant.

CONCLUSIONS

Soil C is not evenly distributed over the landscape. As the non-glaciated soil eroded, the clay content of the surface horizon increased. Because C is more strongly bound to clay than to other soil separates, the C content in the surface horizon of the non-glaciated eroded soil increased. While animal manure or other organic materials can be used to increase the C content of eroded soils, this increase will not persist indefinitely without continuous inputs. Grain yields increased with increasing organic C content in the soil.

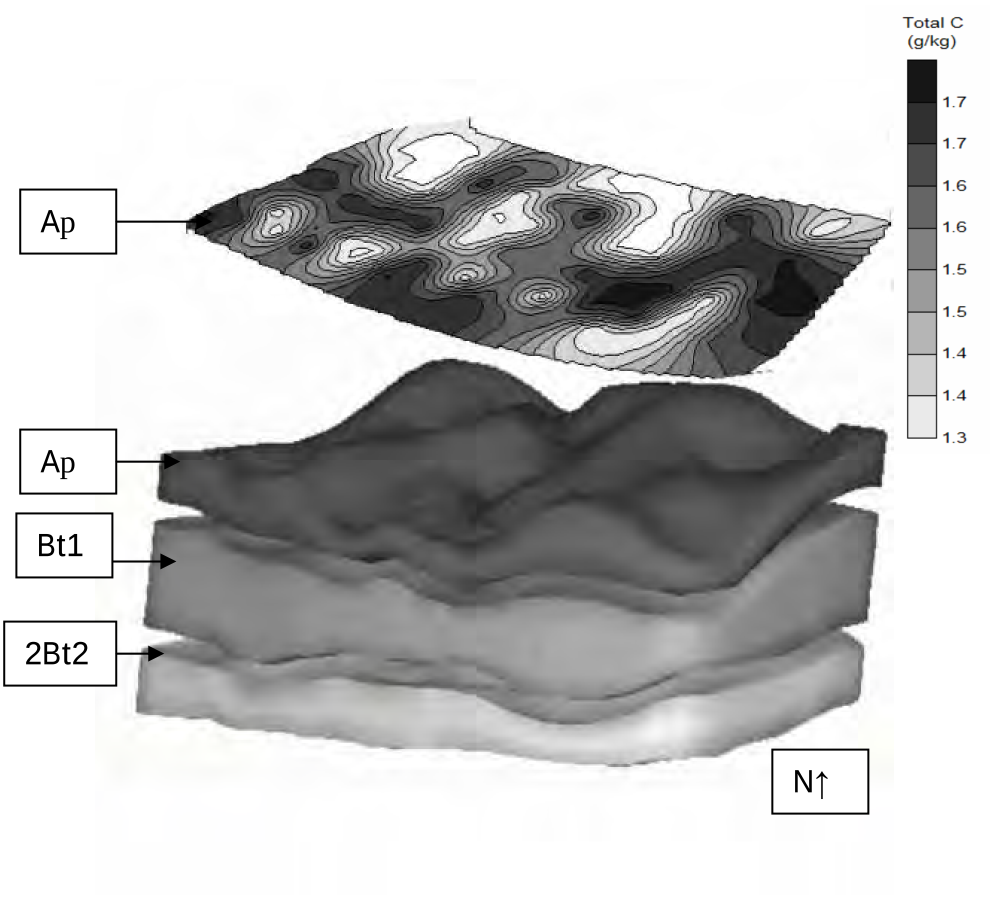

Figure 1. Soil carbon distribution of Ap horizon and three-dimensional representation of three soil horizons for the non-glaciated site (From Arriaga and Lowery, 2005).

Table 1. Soil carbon content for three erosion levels (slight, moderate, and severe) at different depths for a soil in the non-glaciated region of Wisconsin, USA in 1998. Numbers in the parenthesis represent standard deviations (From Arriaga and Lowery, 2005).

	Erosion Level		
Depth	Slight	Moderate	Severe
cm	------------------------ g kg^{-1} soil------------------------		
0-10	18.3 (3.5)	19.0 (3.0)	21.7 (2.1)
10-20	13.7 (1.2)	16.0 (1.7)	16.3 (3.5)
20-30	11.5 (1.0)	9.0 (1.7)	10.0 (3.0)

Differences between erosion levels at the same depth are not statistically significant ($P<0.05$).

Table 2. Soil carbon content for three erosion levels (slight, moderate, and severe) at different depths for a soil in the glaciated region of Wisconsin, USA in 2007. Numbers in parenthesis represent standard deviations.

	Erosion level		
Depth	Slight	Moderate	Severe
cm	------------------------g kg^{-1} soil--------------------------		
0-15	12.3ab (0.8)	13.5a (1.8)	11.3b (1.6)
15-30	9.2a (1.0)	9.3a (0.5)	10.3a (4.5)

Means followed by the same letter(s) in each row are not significantly different ($p<0.05$).

Table 3. Triticale (X *Triticosecale* Wittmack) **grain yield sampled from points with differing soil organic carbon (SOC) levels in the 0-15 cm depth of a silt loam from the glaciated region on Wisconsin, USA in 2007.**

SOC ($g\ kg^{-1}$ soil)	Grain yield ($Mg\ ha^{-1}$)
13.4	6.05 (0.5)a
14.5	5.98 (1.8)a
15.1	6.28 (2.5)a
15.7	8.83 (2.2)b

Means followed by the same letter(s) in each row are not significantly different ($p<0.05$). Regression equation: Grain yield ($Mg\ ha^{-1}$) = 1.33(SOC) - 12.6; R^2 = 0.54.

Table 4. Soil carbon content for three erosion levels (slight, moderate, and severe) at different depths for manure and no manure treatments in a non-glaciated region of Wisconsin, USA in 2007. (Manure was applied between 1988-1999 at 14.9±5.80 Mg ha^{-1})

		Depth (cm)		
Erosion Level	Treatment	0-10	10-20	20-30
Slight	Manure	19.6	13.6	7.8
	No manure	19.3	9.5	5.0
Moderate	Manure	19.4	14.4	11.2
	No manure	19.8	15.1	8.5
Severe	Manure	24.3	14.2	10.3
	No manure	18.2	18.5	11.0

Differences between erosion levels at the same depth are not statistically significant ($P<0.05$).

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