CARBON LEACHING AND SPATIAL DISTRIBUTION ON AN ERODED LANDSCAPE IN SOUTHWEST WISCONSIN

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Abstract
Leaching and spatial distribution of carbon (C) within a soil profile and across a landscape is influenced by many factors such as vegetation, soil erosion, water infiltration, and drainage. Soil C distribution and leaching were measured for three levels of erosion slight, moderate, and severe, and a three-dimensional (3-D) map of the site was developed using data from a profile cone penetrometer (PCP). This map displays the distribution of the total depth of the Ap and Bt1 horizons and the upper part of the 2Bt2 horizon. Two-dimensional distribution of soil C was estimated for this landscape using C content information obtained from soil samples and the PCP data. Using C distribution for the upper two horizons, an assessment of soil C distribution for this eroded landscape was developed. The 3-D assessment of C distribution provides a better means of evaluating the impact of soil erosion on C fate. It was estimated that there were 52 Mg/ha of total C in the surface (Ap) horizon and 61 Mg/ha in the Bt1 horizon. This increase in C with depth in the soil can be attributed to an increase in clay content and C leaching resulting in stable carbon-clay complexes.

Additional Keywords: soil erosion, soil carbon distribution, 3-D soil map

Introduction
Soil erosion has a detrimental effect on soil physical, chemical, and biological properties throughout the eroded landscape. However, the erosional process is often only recognized at selected locations on a landscape. One of the key soil properties that is impacted by soil erosion is the amount C in the surface soil, as erosion is a selective process which removes the C rich topsoil. 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 C distribution and variability. This information could be used to explain how this distribution impacts crop yield and other soil properties at the landscape scale. The most realistic means of displaying soil variability would be with 3-D maps of various soil properties (Arriaga and Lowery 2004).

Penetrometers have been used widely by civil engineers to explore subsoil conditions such as relative density, shear strength, bearing capacity, and settlement. Penetrometers used in engineering applications are usually designed for penetrating to depths much greater than a meter. Agricultural applications of soil 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). Nevertheless, this technique has not been used to map eroded landscapes and related soil properties such as soil C distribution. Therefore, the objective of this study was to assess the use of this relatively limited invasive tool for mapping eroded soil and estimating erosion spatial patterns in an effort to relate soil erosion to soil C spatial variability.

Materials and Methods
This study was conducted in southwest Wisconsin, USA, at the University of Wisconsin-Madison, Lancaster Agricultural Research Station (42^o 52' N, 90^o 42' W). Soils in this area were developed in what is known as the driftless region, which covers parts of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois. 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, soils are generally characterized by steep slopes and are relatively vulnerable to erosion.

Soil at the research site is a Dubuque silt loam (fine-silty, mixed, mesic, Typic Hapludalfs), which formed in loess underlain by a clayey residuum. The study site was 120 by 60 m and located on a southwest facing slope ranging form 10 to 14 % steepness. Previous research was conducted at this location to establish three levels of erosion based on the depth of soil above the clayey residuum. In 1985 the site was intensively sampled with a bucket auger and push probe on a 5 by 5 m grid spacing to a depth of 1.2 m. Three levels of past erosion (slight, moderate, and severe) were identified using the depth to the clay residuum (2Bt2 horizon) as a baseline (Andraski and Lowery 1992). Three plots for each erosion level was then established.

In May of 2000 a PCP was used to collect profile data on a 10 by 10 m grid. The PCP consisted of a 30° cone with a 2.0 cm base diameter, threaded to a 1.25 cm diameter by 1.5 m long stainless steel rod. The rod was connected to a 1360 kg load cell (model LC101-3K, Omegadyne; Stamford, CT; 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.) to measure the penetration force. A string potentiometer (model HX-PA-150, Unimeasure; Corvallis, OR) was used to measure depth, while a truck mounted hydraulic soil probe was utilized to drive the PCP into the soil profile at a rate of 3 cm/sec. Data were measured every 0.05 sec with a 21-X electronic data logger (Campbell Scientific; Logan, UT). Surface elevation data were collected, under roving mode, with a differentially corrected global position system (GPS) attached to an all-terrain vehicle. These data were used to create a digital elevation model (DEM) of the site. A GPS with beacon differential correction was utilized to locate the PCP sampling points. At each recorded depth, there was an associated cone index (CI) value, thus creating a continuous curve for the entire profile at each PCP sampling location. These CI data from each PCP sampling point were then analyzed using the Cluster Observation procedure in Minitab (Minitab 2000), with the standardize variables option selected, and using the Squared Pearson and Ward method for distance measure and linkage method, respectively. The cluster procedure creates clusters, or group, of observations that are similar. Cone index data, from each sampling point, were clustered into one of three cluster groups that represented the three erosion levels, slight, moderate, and severe. This information was used to develop a 3-D map of the area (Fig.1).

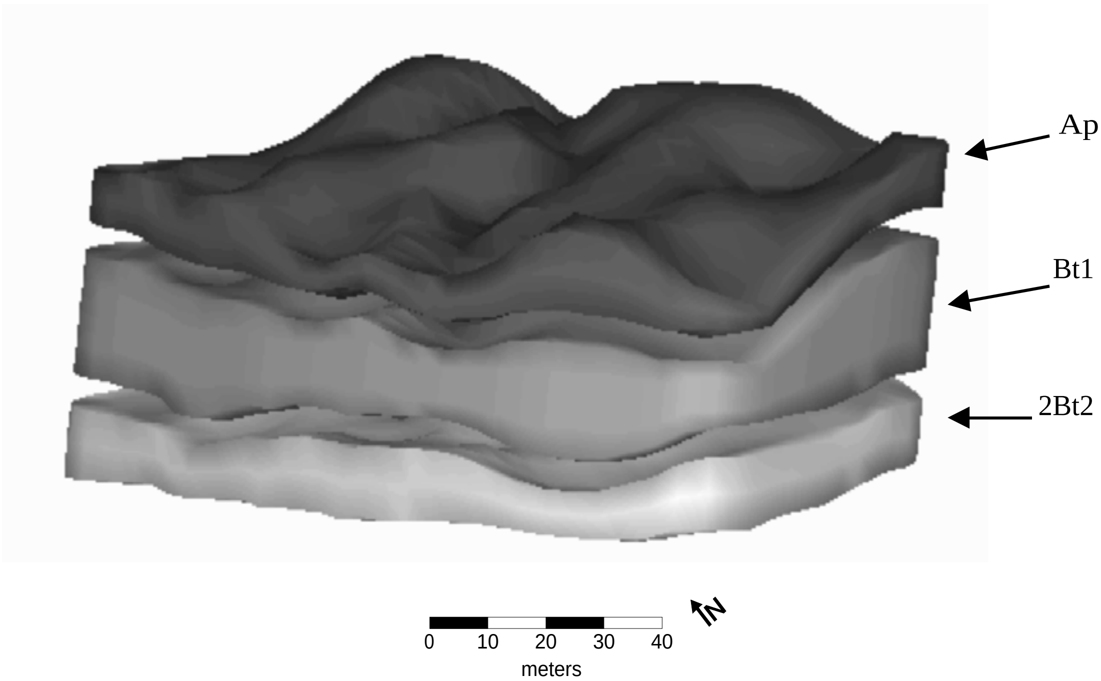

Figure 1. Three-dimensional representation of an eroded Dubuque soil on a 0.72 ha area.

Total C was determined on soil samples collected with a 1.9 cm diameter hand-push probe to a depth of 50 cm. Samples were sectioned into 10 cm increments. Five samples were taken from each erosion subplot at each depth increment and combined to form one composite sample per depth for each erosion plot. Soil samples were oven dried at 105°C for 24 hours. After drying, soil samples were ground by hand to pass 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.

Results and Discussion

Depth to the clayey residuum at the research site, which ranged from 0.45 to 0.95 m depending on the erosion level, was the key soil property used to delineate the different erosion levels across the landscape with the PCP. The CI of the clay residuum was much greater than that of the surface horizons. These characteristics and PCP data were used to develop a 3-D map of the site (Figure 1). Depth of soil displayed on the 3-D map was combined with existing data on erosion levels to get a distribution of the erosion levels. Soil C data for the various erosion levels were combined with these data to develop data on C distributions over the landscape.

In the top 20 cm of the soil profile total soil C content ranked severe > moderate > slight, but these differences were not statistically significant (Table 1) (Arriaga and Lowery 2004). This ranking is different from other eroded soils in the Midwestern section of the United States as reported by Lowery *et al.* (1995). The ranking of C in this soil is attributed to 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 result in greater C 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 2004).

When data from the 3-D representation (Figure 1) was combined with total soil C distribution data an estimate of the total amount of C for the various erosion levels and horizons was obtained. Although the slight erosion areas have less soil C in the respective horizons (Table 1) the total soil C for both horizons analyzed ranked slight > moderate > severe because the percentage of the land area at the site was greater for slight followed by moderate (44 % slight, 31 % moderate, and 25 % severe). The Ap horizon of the slight, moderate and severe erosion levels had 28, 14, and 10 Mg/ha of C, respectively. The Bt1 horizon of the slight, moderate and severe erosion levels had 31, 19, and 11 Mg/ha of C, respectively. Thus, it is important to consider not only soil C distribution by depth but also spatial distribution when assessing soil C credits.

Table 1. Soil C content for each erosion level (slight, moderate, and severe) at different depths. Numbers in the parenthesis represent standard deviations (from Arriaga and Lowery, 2004).

	Erosion Level		
Depth	**Slight**	**Moderate**	**Severe**
--- cm ---	------------------------ g/kg ------------------------		
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<0.10) (SAS, 1989).

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