Aggregate Wettability and Stability in an Eroded Landscape

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Abstract

Spatial patterns of soil loss within a field are often the result of several erosion agents acting in concert. The intensity of soil loss from specific erosion agents is spatially different, for example high tillage erosion rates are mostly found on the crest and shoulders of hills while the most intense water erosion is found in the mid to lower backslope. However, there is a significant overlap of influence between erosion processes within regions of soil loss and deposition. Erosion processes also interact indirectly, for example, tillage erosion may change soil erodibility properties associated with water and wind erosion. Transects were established on relatively noneroded-grass and eroded-cultivated hillslopes. The pattern of current erosion rates on the cultivated field was established using a water and tillage erosion model (WATEM). Aggregate wettability and stability were compared between land use and within erosion zones in the cultivated field. Aggregate wettability and stability were related to soil organic carbon distribution within the landscape. Soil organic carbon distribution within the landscape was strongly influenced by past erosion and soil forming factors which in turn influences patterns of aggregate wettability and stability.

Keywords: tillage erosion, soil organic carbon, water erosion, soil erodibility

Introduction

Spatial and temporal variability of soil properties affect soil hydrology and erodibility. The distribution of soil properties within fields are a result of natural soil forming processes and accelerated changes caused by soil management practices. Water and tillage erosion contribute significantly to soil property variation (Schumacher et. al., 1999). The peak intensity of the two erosion processes occur in different topographical positions on a hillslope. Tillage erosion typically is most severe on the shoulder while water erosion is most severe in the mid to lower backslope positions (Schumacher et al., 2005). The activities of the two erosion processes overlap and interact. Soil organic carbon, inorganic carbon, horizonation, nutrient content, rooting depth, water storage capacity, infiltration rates, texture, aggregate stability are examples of soil properties that have been documented as changing due to erosion processes (de Alba et al., 2004, Papiernik et al., 2005, Olson et al. 1999). Several of these properties influence the propensity of soil aggregates to disperse and erode.

Susceptibility to soil water erosion is often related to the ability of the soil to intake water. The spatial and temporal variability of soil wetting properties makes the development of functions predicting soil losses in the field difficult (Shakesby et al., 2000). Soils with ≥ 150 to 200 g kg^{-1} smectitic clay minerals, such as Mollisols, are not likely to become water repellent through hydrophobic natural compounds because the structure of hydrophobic natural organic compounds is not suitable for attaching to ion-exchanging clay minerals (Farmer, 1978). Therefore, in the absence of contamination, Mollisols are not likely to contain large amounts of hydrophobic components. However, some degree of water repellency (subcritical water repellency, Tillman et al., 1989) may be present in any soil and may contribute to aggregate stability (Eynard et al., 2005).

The past literature is dominated by the study of soils expressing severe water repellency, such as soils rich in volcanic ash (Andosols), sandy soils, soils contaminated by oil spills, or soils covered by forests or bushes, especially in xeric or aridic moisture regimes favorable to fire (DeBano, 2003). Many previous studies dealt with the wettability of Inceptisols and Spodosols with low pH and high C/N ratios (Chenu, 2000, Ellerbrock et al., 2005), whereas prairie soils (Mollisols) have received less attention. Detailed research on Mollisols was carried out in cases of severe water repellency due to oil spills in the Canadian prairie (Roy et al., 2003).

Previous studies on the spatial pattern of water repellency at the field scale were conducted to predict the occurrence of severe water repellency and to suggest best management practices to minimize the problem (Harper and Gilkes, 1994). We were interested in evaluating aggregate wettability (subcritical water repellency) in an eroded field and grassed hillslope. Our hypothesis was that a field history of tillage and water erosion would alter the distribution of soil properties related to soil erodibility including aggregate wettability and stability. In addition we had as an objective the identification of the relationship of wettability with other soil properties including soil organic carbon.

Material and Methods

The experimental site was located near Cyrus MN (45.679184° N, -95.747298° W, WGS84) in the Northern Great Plains of North America. A cultivated field with a history of erosion was paired with a grassed hillslope that had never been tilled. The cultivated field had a history of corn, soybeans, and wheat using tillage practices that currently include a chisel plow and disk operation. In the past the tillage system was based on moldboard plow operations.

Soils along two transects for each land use were classified by Soil Series according to Soil Taxonomy (Soil Survey Staff, 1999) and by Soil Units according to the FAO-UNESCO Soil Map of the World (FAO, 1974). Each transect was 200 m long. Soil cores were taken by a hydraulic probe at 10-m intervals (0-1.40 m depth) and were used for the morphological description. Additional analyses were carried on topsoil samples taken by the spade along each transect (0-0.15 m depth) and air dried (p/p_0=0.28) at 25 ^oC.

A Leica survey grade DGPS system was used to collect data for a digital elevation model. Elevation data was collected on a 10-m grid. Erosion by tillage, water, and the combined effects of tillage and water was estimated at each node on the grid using the Water and Tillage Erosion Model (WATEM, van Oost et al., 2000) using a procedure described by Schumacher et al. (2005) and Papiernik et al., (2005).

The fine earth fraction (<2 mm diameter) of subsamples was separated and ground prior to textural and organic C analyses. Particle size distribution was determined by the pipette method after removal of organic matter without removing carbonates (Gee and Bauder, 1986). Soil organic C was determined by dry combustion (Nelson and Sommers, 1982) and subtraction of inorganic C (Wagner et al., 1998).

Wet aggregate stability was determined by the single-sieve mechanical procedure of Kemper and Rosenau (1986) shaking air-dried 1-2 mm aggregates for 5 minutes. Aggregates were directly immersed in deionized water without any prewetting treatment. Wet stable aggregation was expressed as mass (105° C oven-dry weight) of stable macroaggregates (g) on the initial sample mass (kg) after correcting for sand.

Bulk density was measured by the clod method (Grossman and Reinsch, 2002) on air-dry 10 ± 5 mm diameter aggregates. The total porosity of air-dry aggregates was calculated from bulk density, assuming a particle density of 2.65 Mg m^{-3}. Wettability was determined as wetting rate under tension by the sintered Büchner funnel method of Quirk and Panabokke (1962). Wettability measurements were performed on beds of 10-15 g of air-dry 10± 5 mm aggregates. Two beds of aggregates for each sample point were subjected to 300, 100, and 30 mm water tensions in three separate experiments. All data were analyzed using the SYSTAT 11 statistical program (SYSTAT, 2004). Relations between variables were tested by linear regression. Land use means were compared by t-tests. A power function of the form $y = \alpha x^{\beta}$ (linear form $\log y = \log \alpha + \beta \log x$), was fit to the water uptake data, where y = cumulative water uptake (g kg^{-1}); x = time (min); α = initial water uptake rate (g kg^{-1} min^{-1}) at x =1; β = a unitless curve fitting parameter that shows how the effect of time on water uptake changes as the water contents in soil aggregates tends to increase. A log-log transformation was applied to the water uptake data to remove heteroscedasticity (heterogeneity of variance), normalize the data for analysis, and linearize the time curve. Wettability results of measurements at different tensions were analyzed separately as these data pertained to separate measurements. Significance was considered at $P \leq 0.05$.

Results

Six soil series were included in the grass transects and four soil series in the crop transects (Table 1). Tillage and water erosion have significantly changed soil horizonation in the cultivated field as a result of downslope soil translocation and subsequent mixing of surface horizons (de Alba et. al., 2004). In particular, the Langhei soil found in the shoulder position and the Svea soil found in the footslope position are soils that are likely to have had sufficient soil loss and gain respectively from erosion processes to cause a change in soil classification from the original soil that was present prior to cultivation 80-100 years ago. In contrast erosion rates on the grass site were estimated to be very low at < 0.1 Mg/ha/y.

Table 1. Classification of soils considered in cropland and grassland of West central Minnesota (USA) according to Soil Taxonomy (Soil Survey Staff, 2004) and to the FAO-UNESCO Soil Map of the World (FAO, 1974).

Land use	Soil Series	Soil Taxonomy	FAO Soil Unit
Grass	Barnes	Fine-loamy, mixed, superactive , frigid Calcic Hapludolls	Haplic Chernozems
	Buse	Fine-loamy, mixed, superactive, frigid Typic Calciudolls	Calcic Chernozems
	Embden	Coarse-loamy, mixed, superactive, frigid Pachic Hapludolls	Haplic Chernozems
	Heimdal	Coarse-loamy, mixed, superactive, frigid Calcic Hapludolls	Haplic Chernozems
	No name	Coarse-loamy, mixed, superactive, frigid Typic Udifluvents	Eutric Fluvisols
	No name	Coarse-loamy, mixed, superactive, frigid Mollic Udifluvents	Eutric Fluvisols
Crop	Barnes	Fine-loamy, mixed, superactive , frigid Calcic Hapludolls	Haplic Chernozems
	Buse	Fine-loamy, mixed, superactive, frigid Typic Calciudolls	Calcic Chernozems
	Langhei	Fine-loamy, mixed, superactive, frigid Typic Eutrudepts	Calcic Cambisols
	Svea	Fine-loamy, mixed, superactive , frigid Pachic Hapludolls	Haplic Chernozems

Transect points from the severely eroding zone were significantly lower in SOC (Table 2). The grass hillslope had SOC three times greater than the severely eroding zone and double the SOC in the deposition zone of the cultivated field. Wet aggregate stability was five times greater in the grass hillslope than the severely eroding zone and approximately three times greater than the deposition zone in the cultivated field. The observed difference in SOC and WAS within the cultivated field was not observed for aggregate wetability. However the grass hillslope had significantly greater wettability at 100 mm tension than the cultivated field.

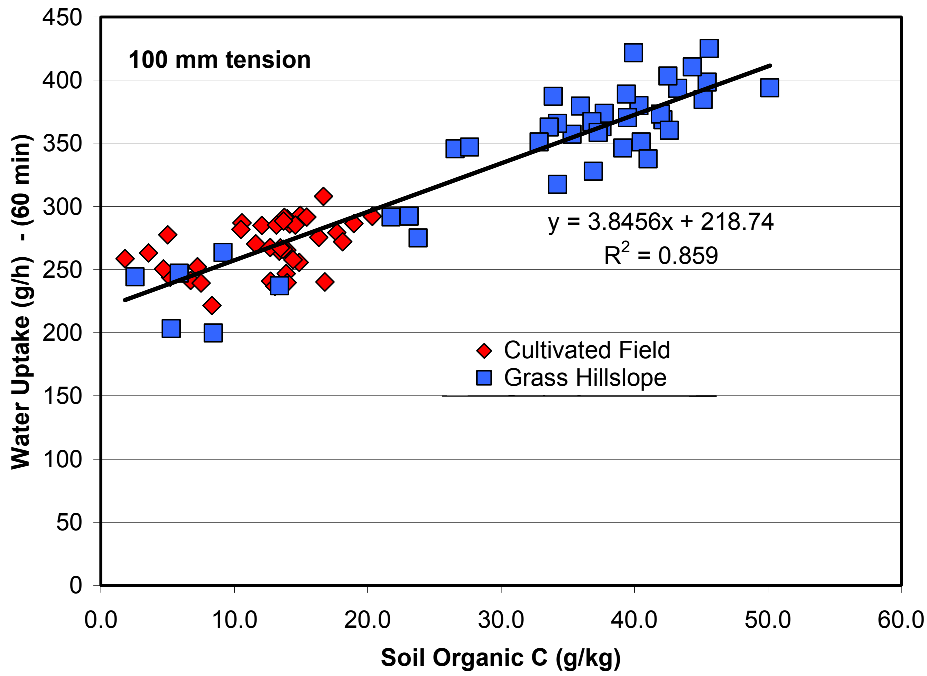
Table 2. Soil organic carbon (SOC), aggregate wettability at 100 mm tension (100w), and wet aggregate stability (WAS) for transect points that are: severely eroding (combined water and tillage erosion) in the cultivated field (>20 Mg/ha/y erosion), deposition in the cultivated field (> 0 Mg/ha/y deposition), and in grass.

	Soil Properties		
Transect Points	OC	100W	WAS
	(g/kg)	(g/h)	g/g x 100
Severely Eroding	10.3a	268a	17.8a
Deposition	15.7b	266a	25.5b
Grass	32.9c	344b	80.2c

Values followed by the same letter are not significantly different at the 0.05 level of probability.

A linear relationship was observed between SOC and aggregate wettabiity at 100 mm tension (Figure 1). Low organic carbon values in the grass hillslope sampling points were associated with coarse textured soils from the toeslope and footslope of one of the grass transects. Comparable coarse textured soils were not present in the cultivated field transects. Both the coarse textured and cultivated soils had low SOC and correspondingly low aggregate wettability and low WAS (data not shown).

Figure 1. Relationship of aggregate wettability at 100 mm tension to soil organic carbon for transects from the cultivated field and the grass hillslope. The slope of the line is significantly different than zero.



Discussion

Although significant differences were observed between SOC and WAS within the cultivated field this did not translate into differences in aggregate wettability. There was a strong linear relationship between aggregate SOC and wettability as well as WAS. The relationship of wettability with SOC within the cultivated field was in part obscured because of the overall low organic matter levels observed at all topographic positions in the cultivated field and may have also reflected a difference in the relationship of SOC placement and aggregate structure compared to grass aggregates.

Other studies have demonstrated an effect of SOC placement within the aggregate on wettability relationships of grasslands and cultivated soils (Eynard et. al., 2006). SOC placement along macropores could strengthen pores enabling them to resist forces that occur during the wetting process. This process would be more likely to occur in relatively undisturbed environments with abundant root biomass such as those found in long-term grasslands.

High aggregate wettabilities are beneficial when associated with aggregates that have SOC distributions that stabilize larger pores within aggregates resulting in stable aggregate structure during the wetting process (Eynard et. al., 2006). When relatively high aggregate wettabilities are associated with low SOC, aggregates are susceptible to the formation of micro-cracks during tension wetting. That is likely to be the case of low SOC (<10 g/kg) containing aggregates in the severely eroded parts of the field which would result in a greater uptake of water by the aggregates than expected.

Conclusions

The redistribution by the combined action of water and tillage erosion of SOC has a significant impact on soil properties within undulating landscapes. Wet aggregate stabilities were found to differ depending on SOC distribution within an eroded field. However aggregate wettabilities were not found to depend on SOC distribution within the eroded fields to the same extent as WAS. Aggregate wettabilities tended to be higher at the lowest SOC contents in the most eroded parts of the field than would be expected based on the linear relationship between aggregate wettability and SOC developed from combined grass and cultivated transect points. This may be related to an increased tendency of aggregates with low SOC (<10 g/kg) to form microcracks during the wetting process. Additional measurements are needed to verify the effect of low SOC on aggregate wettability and test this hypothesis.

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