Management Induced Changes in Aggregate Stability in Three Different Soil Types

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1. Abstract

Poor aggregation reduces infiltration, increases runoff, and causes serious water erosion in many areas. These factors (especially reduced infiltration in the semi-arid prairie) influence soil/crop quality. Aggregate stability was assessed on cultivated and uncultivated fields in southern Saskatchewan. Three different landscape positions in three parent material types were evaluated. The relative importance of some of the mechanisms causing soil aggregate breakdown in the cultivated sites were also investigated. It was found that different mechanisms were important at different sites, however, landscape position had no influence. This paper will focus on the factors affecting soil aggregation at the three sites studied.

2. Introduction

Arshad and Mermut (1988) have found that in addition to inhibiting seedling emergence, surface crusts formed from the breakdown of soil aggregates reduce infiltration, increase runoff, and cause serious water erosion in many areas. These factors (especially reduced infiltration in the semi-arid prairie) influence soil/crop quality. Research has shown that factors which influence soil aggregate stability such as soil organic carbon (Tisdall and Oades, 1982) are often redistributed across a landscape (Pennock et al., 1994).

3. Objectives

This paper is centered around three objectives:

- to determine if cultivation affects aggregate stability;
- if so, to determine if the effects of cultivation on soil structural stability are different for different soil types;
- to determine if the effects of cultivation on soil structural stability differ across a landscape.

4. Methods

Soil samples were collected from a total of six fields. A cultivated and uncultivated field were sampled from each of till (Weyburn association), lacustrine (Sceptre association), and loess (Swinton association) parent materials.

The till fields were located just north of Lake Diefenbaker in southern Saskatchewan. The cultivated and uncultivated sites were adjacent to each other and shared the sarne legal land location (LLL) of SW 26-26-10 **W3rd**. The soil at this location was mapped as the Weybum association (Orthic Dark Brown Chemozem). The parent material was medium to moderately fine textured moderately calcareous,. unsorted glacial till. The area was strongly sloping (10 - 15% slope). The landscape in this area was described by Ellis et al. (1970) as being knob and kettle or knoll and depression with no external drainage.

The loess cultivated and uncultivated sites were both located at the Swift Current Research Station. The LLL for the sites were SE 16-15-13 W **3rd**, and SW 21-15-13 W **3rd**, respectively. Both sites were mapped by Ayres et al. (1985) as the Swinton association (Orthic Brown Chemozem). The parent material is medium textured, moderately calcareous, silty and very fine sandy loessial deposits overlying glacial till. Both sites are classified as gently sloping (2.0 - 5.0 % slope) dissected loessial plains (Ayres et al., 1985).

The lacustrine cultivated and uncultivated sites were located at the Matador Co-op farm (LLL NW 33-20-13 W 3rd) and Matador Research Station (LLL NW 10-20-30 W 3rd), respectively. The soil at both sites was mapped by Ayres et al. (1985) as the Sceptre association (Rego Brown Chemozem). The parent material was fine textured, weakly to moderately calcareous, uniform clayey glaciolacustrine deposits. The area was very gently sloping (0.5 - 2.0% slope). The landscape in both areas was described as dissected glaciolacustrine plains (Ayreset al., 1985).

At the till and lacustrine fields, sample sites were established along three transects which were treated as replicates. Within each transect, three landscape positions were sampled - the shoulder, midslope, and footslope. Due to the lack of slope at the loess site, no landscape positions were sampled, however three replicates of a level position were collected at that site.

Two types of samples were collected. First, a sample of the top 10 cm was removed using a shovel and hand trowel. A core sample was also collected using a hydraulic coring device. The core extended as deep as possible into the profile or was stopped at 20 cm into the C-horizon.

The samples were brought back to the laboratory where they were weighed and dried. The mean weight diameter, and percentage of aggregates in the erodible fraction (percent by weight with a diameter less than 1.3 mm) was determined on the grab samples. Aggregate stability of the 2.5 - 7.2 mm fraction (by wet sieving), organic carbon (by dry combustion), and texture were also determined on the grab samples. Soil redistribution was assessed using the core samples and Cs^{137} analysis (Pennock *et al.,* 1995). Air-dry bulk density was also determined using the core samples.

5. Results and Discussion

5.1 Till Site

The data in table 1 indicate there is a significant decline in aggregate stability associated with cultivation in the till site. Landscape position had no significant affect on aggregate stability in either the cultivated or uncultivated sites. A breakdown in soil structure associated with cultivation is also supported by the MWD data. The MWD is significantly lower in the cultivated site indicating that the average aggregate size at that site is reduced in comparison to the uncultivated site. The same trend is observed when the percentage of aggregates in the erodible fraction is calculated. A Larger portion of aggregates are in the erodible fraction in the cultivated site. The breakdown in soil structure in the cultivated site corresponds to a significant increase in bulk density at that site. The decline in aggregate stability and MWD, and the corresponding increase in % in the erodible fraction indicate an increased erosion hazard associated with cultivation in the till site.

Soil erosion was assessed at this site by measuring Cs^{137} concentration. A relatively high concentration of Cs^{137} indicates deposition, while a relatively low Cs^{137} concentration indicates erosion. The concentration of Cs^{137} was not significantly different between the cultivated and uncultivated fields at any landscape position. However, at the cultivated site, the concentration in the footslope was significantly greater than on the shoulder. This data suggests that erosion is occurring on the shoulder and that deposition of material is occurring at the footslope of the cultivated site (table 1).

Parameter	Slope Position	Cultivated	Uncultivated
Aggregate	Footslope	$33_{(a*)}$	$85_{(b)}$
Stability (%)	Midslope	$34_{(a)}$	$90_{(b)}$
	Shoulder	$40_{(a)}$	$87_{(b)}$
MWD	Footslope	$5.8_{(a)}$	$15.9_{(b)}$
(mm)	Midslope	$4.5_{(a)}$	$16.0_{(b)}$
	Shoulder	$5.1_{(a)}$	$15.0_{(b)}$
% Erodible	Footslope	$37.8_{(a)}$	$23.6_{(b)}$
Fraction	Midslope	$43.4_{(a)}$	$32.3_{(b)}$
	Shoulder	$41.1_{(a)}$	$32.0_{(b)}$
Bulk Density	Footslope	$1.25_{(a)}$	$0.93_{(b)}$
(g/cm^3)	Midslope	$1.35_{(a)}$	$0.95_{(b)}$
	Shoulder	$1.28_{(a)}$	$0.92_{(b)}$
Cs^{137}	Footslope	$2.09_{(a)}$	$2.57_{(ab)}$
(kBq/m^2)	Midslope	$1.16_{(ab)}$	$1.88_{(ab)}$
	Shoulder	$0.58_{(b)}$	$1.79_{(ab)}$
Organic C	Footslope	$2.42_{(a)}$	$5.27_{(ab)}$
(%)	Midslope	$1.93_{(ab)}$	$3.16_{(ab)}$
	Shoulder	$1.56_{(b)}$	$3.00_{(ab)}$
A-horizon	Footslope	$15.43_{(a)}$	$5.27_{(a)}$
Thickness	Midslope	$9.67_{(ab)}$	$3.16_{(ab)}$
(cm)	Shoulder	$9.13_{(b)}$	$3.00_{(b)}$
Clay Content	Footslope	$31.49_{(a)}$	$42.59_{(a)}$
(%)	Midslope	$35.43_{(a)}$	$37.16_{(a)}$
	Shoulder	$35.60_{(a)}$	$39.64_{(a)}$

Table 1: Indicators and determinants of structural stability in a till landscape.

(* lowercase letters are used to differentiate between numbers that are significantly different for a=0.05. Numbers which have a subscripted letter in common are not significantly different.)

Organic carbon content (%) in the A-horizon follows the same trend as Cs^{137} (table 1). No significant differences existed between the cultivated and uncultivated sites at all landscape positions. However, a significant increase in organic carbon occurred at the footslope position as compared to the shoulder position in the cultivated site (table 1) indicating an increase in organic carbon in the downslope position at that site.

No significant differences in A-horizon thickness occurred between sites, however the A-horizon thickness at the footslope was significantly greater than the shoulder position for both cultivated and uncultivated sites. The Cs^{137}, organic carbon, and A-horizon thickness data indicate there is movement of material downslope in the cultivated site. This movement of material may be partially responsible for the decline in soil structure observed at the cultivated till site.

Neither landscape position nor management had any affect on A-horizon clay content.

5.2 Lacustrine Site

In the lacustrine sites, landscape position had no effect on aggregate stability in either the cultivated or uncultivated fields. However, aggregate stability was significantly reduced in the cultivated site as compared to the uncultivated site at all landscape positions (table 2).

Parameter	Slope Position	Cultivated	Uncultivated
Aggregate Stability (%)	Footslope	$42_{(a)}$	$79_{(b)}$
	Midslope	$48_{(a)}$	$74_{(b)}$
	Shoulder	$36_{(a)}$	$75_{(b)}$
MWD (mm)	Footslope	$11.4_{(a)}$	$14.2_{(a)}$
	Midslope	$5.6_{(b)}$	$13.1_{(a)}$
	Shoulder	$7.1_{(b)}$	$14.0_{(a)}$
% Erodible Fraction	Footslope	$20.3_{(ab)}$	$15.6_{(a)}$
	Midslope	$38.5_{(ab)}$	$18.0_{(ab)}$
	Shoulder	$34.5_{(ab)}$	$18.7_{(b)}$
Bulk Density (g/cm^3)	Footslope	$0.92_{(a)}$	$1.06_{(abcd)}$
	Midslope	$1.12_{(b)}$	$0.98_{(abcde)}$
	Shoulder	$1.33_{(c)}$	$0.96_{(abce)}$
Cs^{137} (kBq/m^2)	Footslope	$0.92_{(a)}$	$1.59_{(b)}$
	Midslope	$1.01_{(a)}$	$1.68_{(b)}$
	Shoulder	$0.92_{(a)}$	$1.77_{(b)}$
Organic C (%)	Footslope	$1.85_{(ab)}$	$2.90_{(a)}$
	Midslope	$1.97_{(ab)}$	$2.00_{(b)}$
	Shoulder	$1.35_{(ab)}$	$2.12_{(b)}$
A-horizon Thickness (cm)	Footslope	$8.53_{(a)}$	$8.23_{(a)}$
	Midslope	$8.43_{(a)}$	$6.57_{(a)}$
	Shoulder	10.901.,	$6.17_{(a)}$
Clay Content (%)	Footslope	$45.60_{(a)}$	$60.97_{(b)}$
	Midslope	$49.08_{(a)}$	$80.99_{(c)}$
	Shoulder	$44.26_{(a)}$	$79.93_{(c)}$

Table 2: Indicators and determinants of structural stability in the lacustrine site.

A similar trend was observed in the MWD. The MWD was significantly reduced at the cultivated site at the midslope and shoulder. The percentage of aggregates in the erodible fraction appears to follow the expected trend (i.e. to increase in the cultivated site), however this increase is not significant at the 95% confidence interval.

Given the observed decrease in aggregate stability and MWD at the cultivated lacustrine site, a corresponding increase in bulk density was also expected. However, this was not observed. Bulk density was affected by landscape position in both the cultivated and uncultivated sites. At the cultivated site, bulk density was significantly different at all three landscape positions and was greatest at the shoulder. The opposite trend was observed in the uncultivated field. In the uncultivated field, the bulk density was greatest at the footslope position and lowest at the shoulder.

The measured trend in bulk density can be explained by considering changes in MWD and texture. The MWD in the cultivated site was greatest at the footslope position, but remained constant across the landscape in the uncultivated site. The MWD, therefore had no affect on bulk density in the uncultivated site, however the observed increase in the cultivated site may be responsible for the reduction in bulk density which occurred at that position.

At the uncultivated site, the highest bulk density occurred at the footslope. The clay content in the uncultivated footslope is significantly lower than at any other position and may account for the measured increase in bulk density.

No significant differences in Cs^{137} concentration were detected at the various landscape positions at both the cultivated and uncultivated sites. However, the Cs^{137} concentration was significantly lower at all positions in the cultivated site. The reduced Cs^{137} concentration in the cultivated site suggests that material is being exported from this system.

The texture data supports this conclusion. Clay content was lower at the cultivated site than the uncultivated site at all landscape positions. Tillage enhanced wind erosion may be capable of selectively removing the clay fraction from the cultivated field. The reduction in clay content may be responsible for the decrease in aggregate stability observed at the cultivated site.

Organic carbon (%) was significantly lower on the shoulder and midslope than the footslope in the uncultivated site. No other comparisons either within or between fields were significantly different.

5.3 Loess Site

A dramatic decrease in aggregate stability occurred in all landscape positions at the cultivated site (table 3). No significant difference in MWD or % erodible fraction between sites was detected (table 3). Management also had an affect on bulk density. Bulk density at the cultivated site was significantly higher than bulk density at the uncultivated site (table 3).

Parameter	Cultivated	Uncultivated
Aggregate Stability (%)	$15_{(a)}$	$92_{(b)}$
MWD (mm)	$11.2_{(a)}$	$7.8_{(a)}$
Bulk Density (g/cm^3)	$1.32_{(a)}$	0.92,
% Erodible Fraction	$25.2_{(a)}$	$18.4_{(a)}$
Cs^{137} (kBq/m^2)	$1.60_{(a)}$	$1.62_{(a)}$
Organic C %	$1.74_{(a)}$	$4.64_{(b)}$
A-horizon Thickness (cm)	$15.90_{(a)}$	$8.27_{(b)}$
Clay Content (%)	$26.86_{(a)}$	$22.53_{(a)}$

Table 3: Indicators of structural stability in the loess landscape.

Erosion was assessed in the loess landscape by measuring Cs^{137} concentration throughout the horizon at each sampling location. No significant differences in Cs^{137}

concentration were detected either within or between sites (table 3). The lack of erosion of material within this landscape is not surprising given the low slope of the land.

Organic carbon in the cultivated site was significantly decreased within the cultivated site. The thickness of the A-horizon followed the same trend.

Prior to cultivation, the cultivated site likely had the same thin rich A-horizon that the uncultivated site presently has. Once this site was broken this thin A-horizon was mixed with the B-horizon below. The result was a relatively thick, but less productive A-horizon in the cultivated site. This reduction in organic carbon in the A-horizon may be sufficient to cause the observed reduction in aggregate stability and corresponding increase in bulk density in that site.

The lack of a significant difference in MWD and % erodible fraction between sites is surprising given the dramatic decrease in aggregate stability in the cultivated field. However, the MWD and % erodible fraction are greater in the cultivated field (the expected trend), however, this increase is not significant. The lack of a significant increase may be due in part to the small sample size.

6. Summary and Conclusions

In all three soils, cultivation had a negative impact on soil structural stability. However, landscape position had no significant control on soil structure,

At the till site, the decline in soil structure was attributed to an enhanced erosion hazard, and movement of material downslope in the cultivated site. A decrease in clay content at the cultivated lacustrine site was responsible for structural breakdown there. At the loess site, the breakdown in soil structure at the cultivated site was due to a dilution of A-horizon organic carbon by mixing with the B-horizon.

7. References

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