Relationships Between the Wind Erodible Fraction and Freeze-thaw Cycles in Southern Alberta

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Problem

Soil structure can change significantly from fall to spring in southern Alberta. Better understanding of the climatic conditions under which soil clod breakdown occurs is important to predict wind erosion risk and provide insight on how to temper the climatic effects by management systems and preventative measures. A study was initiated at the Lethbridge Research Centre to find some relationships between climatic variables — such as freeze-thaw cycles, precipitation and snow cover — and soil clod breakdown over time.

Literature Review

Wind erosion is one of the main forms of soil degradation in the semi-arid region of the Canadian prairies[10]. Loss of organic matter and nutrient-rich topsoil is the main cause of this degradation, resulting in a decrease in soil productivity. As well as on-site impacts of wind erosion, there are also off-site impacts which affect air and water quality[9,4,11]. The majority of these impacts can be attributed to agricultural management systems and climatic effects.

The process of soil freezing and thawing contributes to increases of the soil erodible fraction. The erodible fraction is defined as the percent of soil aggregates less than 0.84 mm in diameter. In southern Alberta, overwinter changes in the erodible fraction for five fallow management systems on a clay loam soil were due to the climatic factors of cumulative snowfall, snow cover days and degree of freeze-thaw activity[7]. Increased snowfall and snow cover days reduced aggregate breakdown while freeze-thaw cycles increased it. In North Dakota, researchers found significant relationships between the dry soil aggregate size distribution and climatic factors including number of snow cover days, number of freeze-thaw cycle days with no snow cover, and fall precipitation[8]. From fall to spring, snow cover and fall precipitation decreased the erodible fraction while the number of freeze-thaw cycles increased the erodible fraction. For soils in Kansas and Texas, another researcher reported increases in erodibility from fall to spring for five soils ranging in texture from fine sandy loam to clay, with the greatest increases for the finer textured soils (i.e. clay)[3]. Erodibility increases were attributed to the freezing of moist soil during winter which caused the expansion of ice crystals within aggregates and subsequent shattering. Possible decreases of the erodible fraction for moist soils as reported by the North Dakota researchers may be related to weakened bonds between soil aggregates after freeze-thaw events which may lead to slaking upon thawing and wetting, and then crusting upon drying. Clods may be created when sampling a crusted soil surface for aggregate size distribution assessment.

These overwinter freeze-thaw and snow cover factors are prevalent in the chinook belt climatic region of southern Alberta. Air temperatures can change by 20°C or more within a few hours of the start or end of chinook conditions[6]. As many as 100 freeze-thaw cycles can occur during winter because of these temperature fluctuations. In addition, if temperatures are below 0°C, the strong winds associated with chinook conditions will either sublimate the snow or blow it into sheltered areas. If temperatures are above 0°C, the chinook winds can cause rapid melting and saturation of the soil surface. If the exposed moist soil is not dried by the wind, it can be very vulnerable to freeze-thaw cycles. Better understanding of the temporal changes in the erodible fraction as related to climatic factors would be helpful for predicting and quantifying wind erosion risk in southern Alberta.

Study Description

Three sites near Lethbridge, Alberta were chosen in 1992-93 (Fairfield site), 1993-94 (Wilson site) and 1994-95 (Lethbridge site) to monitor the erodible fraction and related overwinter climatic conditions. Before monitoring began in the fall, all sites were fallowed using conventional mechanical fallow practices during the summer. Soil aggregate size distribution was determined using a rotary sieve[2].

Rain, snowfall, snow depth and total precipitation were measured at the Lethbridge Research Centre weather station and air temperatures were measured at the study sites. From the air temperatures, the number of freeze-thaw cycles were determined for all days and for days without snow cover. Cutoffs of -2°C for freezing and +2°C for thawing were used to estimate the number of soil freeze-thaw cycles.

Major Findings

The total number of freeze-thaw cycles including all days was 54 for Fairfield, 65 for Wilson and 50 for Lethbridge. The number of cycles with no snow cover was 45 for Fairfield, 58 for Wilson, and 39 for Lethbridge.

The data were grouped into three periods based on the occurrence of rainfall (Table 1). The first period was called “fall rain” and began at study initiation and ended after the last rain event in the fall. The largest increase in the erodible fraction was at the Fairfield site at 7.44% and that increase was also accompanied by the most freeze-thaw cycles at seven. The Wilson site had the second largest increase in the erodible fraction at 4.12% and the second highest number of freeze-thaw cycles at five but had the least cumulative precipitation at only 7.0 mm. The Lethbridge site had the smallest erodible fraction increase, no freeze-thaw cycles, and the most precipitation.

Table 1. Comparison of climatic variables and erodible fraction changes during three overwinter periods at three sites near Lethbridge

Period	Site	Start-end	Days	Rainfall Daily maximum (mm)	Snowfall (cm)	Total precipitation (mm)	Snow cover (days)	Mean snow depth (cm)	Freeze-thaw cycles, all days	Freeze-thaw cycles, no snow cover	Erodible fraction change (%)
Fall Rain	Fairfield 1992-93	Sept. 18-Nov. 13	56	39.6 10.0	21.2	60.4	9	2.5	7	7	+7.44
	Wilson 1993-94	Oct. 26-Nov. 11	16	3.6 2.4	2.8	7	2	0.8	5	5	+4.12
	Lethbridge 1994-95	Aug. 30-Oct. 28	59	47.6 13.2	21.6	83	3	2.7	0	0	+1.11
No Rain	Fairfield 1992-93	Nov. 13-Feb. 8	87	0	43.2	41	67	3.8	24	18	+11.18
	Wilson 1993-94	Nov. 11-Mar. 29	138	0	82.4	64.4	60	4.4	46	40	+25.14
	Lethbridge 1994-95	Oct. 28-Jan. 26	90	0	42.1	35.9	60	3.1	26	18	+16.96
Spring Rain	Fairfield 1992-93	Feb. 8-May. 12	93	44.6 12.6	36.1	84.2	31	4.6	23	20	+5.69
	Wilson 1993-94	Mar. 29-Apr. 29	31	7.3 5.0	8	14.1	2	6.3	14	13	+1.25
	Lethbridge 1994-95	Jan. 26-May 24	118	121.1 24.4	45.7	155.7	30	2.7	24	21	-9.16

The next period was the "no rain" period (snow only). For all three sites, this period had the largest increases in the erodible fraction (Table 1). Of the three sites, the Wilson site had the most snowfall but the most freeze-thaw cycles without snow cover, and the largest erodible fraction increase. The Fairfield and Lethbridge sites had similar snowfall and freeze-thaw cycles, but the Lethbridge site had a 6.0% larger increase in the erodible fraction compared to Fairfield. The Fairfield site did have slightly more snow cover days and the average depth of snow was slightly greater than for Lethbridge which may have provided better insulation from the climatic elements.

The last period was the "spring rain" period which began at the first rain event in the spring and included precipitation as rain and snow until the end of the study. Only the Fairfield and Wilson sites had erodible fraction increases and these increases were the smallest for all three periods. The Lethbridge site actually had a decrease in erodible fraction which seemed to be correlated with the largest amount of total precipitation and daily maximum rainfall recorded for any period and site. Most of that precipitation was in the form of rain near the end of the study period.

Applied Questions

What are the effects of rainfall, snowfall and freeze-thaw cycles on soil aggregate breakdown?

The results from this study (Table 1) suggest that rainfall, snowfall and freeze-thaw cycles all influence soil aggregate breakdown, but the nature and degree of their influence varies depending on the timing and magnitude of these events.

If fall rain is accompanied by freeze-thaw cycles, the risk of soil aggregate breakdown increases, as indicated by the Fairfield site data for the "fall rain" period. Ice expansion between aggregates would cause aggregate breakdown, and as air and soil temperatures go below freezing as the "no rain" period approaches, the reversal of aggregate breakdown would not be possible.

On the other hand in the "spring rain" period, rain after the majority of spring freeze-thaw cycles are over would result in saturation of the surface with slaking of aggregates. As these saturated surfaces dry, aggregates would be drawn together by water tension, and soil crusting would be likely, especially for soils with a higher clay content. The decreasing number of freeze-thaw cycles as summer approaches would decrease the risk of soil aggregate breakdown. These factors may explain the generally smaller increases in the erodible fraction for the "spring rain" period compared to the "fall rain" period. The Lethbridge site exhibited a dramatic decrease in the erodible fraction during the "spring rain" period likely due to higher rainfall. Although it had almost the same number of freeze-thaw cycles without snow as the Fairfield site, the Lethbridge site had about three times the total rainfall and twice the daily maximum rainfall.

During the "no rain" period, the Wilson site had the largest erodible fraction increase. It had twice the number of freeze-thaw cycles without snow compared to the other sites, increasing the risk of soil aggregate breakdown. It also had twice the snowfall, increasing the opportunity of wetting the soil surface during the many thaw periods, which would further increase the risk of soil aggregate breakdown upon freezing. The Lethbridge site had a greater increase in the erodible fraction than the Fairfield site even though they had similar precipitation and freeze-thaw cycles. One reason may be that the Fairfield site had a higher initial erodible fraction (46%) than the Lethbridge site (32%) and further soil structure breakdown may have been difficult. But it may also be that other processes besides freeze-thaw of the soil are involved. These may include freeze-drying of the soil surface or soil abrasion by blowing snow[1,5].

Would chemical fallow systems reduce the effects of climatic factors that might increase wind erosion risk?

From the results of this study, frequent freeze-thaw cycles without snow cover in the "fall rain" and "no rain" periods are quite detrimental to soil structure, particularly if rainfall or snow melt add moisture to the soil. Under conventional fallow (little to no surface residue), as in this study, the majority of freeze-thaw cycles occur with no snow cover (Table 1). Under chemical fallow (i.e. zero tillage fallow), the crop residue cover traps snow, insulating the soil surface from freeze-thaw effects. As well, surface residue and especially standing stubble can slow wind speeds at the soil surface thereby decreasing erosion risk. Thus chemical fallow offers some advantages over mechanical fallow for reducing the effects of climatic factors that may increase wind erosion risk.

Chemical fallow also improves moisture conservation through snow trapping, if the subsoil is not frozen when thawing temperatures occur. Moisture conservation practices are essential in the semi-arid region of southern Alberta because moisture is the most limiting input for maximum crop yields in this region.

However, researchers at the Lethbridge Research Centre have found that the erodible fractions are actually higher under zero tillage fallow systems than mechanical fallow systems[7]. This may be the result of soil moisture retention under zero tillage, because wet soil surfaces are prone to soil aggregate breakdown from freeze-thaw cycles. If the residue cover is lost due to fire or drought, then these fields may be at high erosion risk.

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