DIVISION S-6—SOIL & WATER MANAGEMENT & CONSERVATION

Surface Residue Effects on Erosion of Thawing Soils

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ABSTRACT

Soils that experience freezing and thawing are most susceptible to erosion during the late winter and early spring. Greater than 50% of the total annual erosion may occur during this period in parts of the USA and Canada. In this period the upper layer of the soil profile thaws due to rising temperatures, while the subsurface layer stays frozen, greatly limiting water movement through the soil profile, weakening the surface soil. This experiment was conducted to evaluate the effects of four treatments—residue cover (0, 10, 30, and 80%), soil inclination (5, 9, and 13%), soil type (loess and glacial till), and a frozen vs. non-frozen subsurface layer—on two response parameters (soil eroded and soil splash) from small laboratory plots. An erosion box with a surface area of 0.13 m^2 received 0.0343 m of simulated rainfall in a 30-min period. Significantly higher erosion (0.212 vs. 0.152 kg) and soil splash (0.090 vs. 0.066 kg) was observed for the frozen than for the unfrozen subsurface soil layer treatments, respectively. The most erodible condition (13% inclination with frozen subsurface layer) was the most responsive to surface residue cover, 0.335 vs. 0.111 kg eroded soil for 0 vs. 80% residue cover, respectively. The least erodible condition (5% inclination without a frozen subsurface layer) was the least responsive to residue cover (0.161 vs. 0.076 kg eroded soil for 0 vs. 80% residue cover). Residue cover seems very important for reducing soil loss during the soil thawing period, particularly on steep slopes, and may be more important for subsurface frozen conditions than when subsurface frozen layers do not exist.

In the USA about 4.2 million km^2 of agricultural lands are affected by the freezing and thawing of soils (Formanek et al., 1990). Research has repeatedly shown that the freezing–thawing process changes soil physical condition and in particular, soil structure (Domby and Kohnke, 1954; Benoit, 1973; Bullock et al., 1988; Mostaghimi et al., 1988). In fact, disruption of soil aggregates by freezing can be more pronounced than a single pass of most tillage equipment (Bullock et al., 1988).

In addition to surface soil structure changes, hydraulic processes during soil thaw and rainfall may aggravate an already erosion-sensitive condition (Froese and Cruse, 1997). Impeded drainage caused by frozen layers beneath the thawed surface may cause surface soil matric potential to rise to zero as water ponds above the ice lenses. Because infiltration is impeded, a surface seal may fail to develop (Froese and Cruse, 1997). This results in a relatively low surface-layer bulk density. High matric potentials and low bulk density lead to low soil shear strength (Cruse and Larson, 1977) and high soil detachment rates (Towner, 1961; Cruse and Larson, 1977; Al-Durrah and Bradford, 1981; Cruse and Francis, 1984).

Soil erosion is composed of detachment and transport processes. The hydraulic conditions favoring detachment also favor increased runoff. Impeded drainage caused by frozen soil layers beneath the surface restricts infiltration, so water may either pond on the surface or run off (Kane, 1980). Most topographical conditions result in runoff. Elevated detachment rates and increased runoff suggest erosion potential will be very high for soil thawing conditions. Higher field erosion potentials exist during spring–thaw than at other times of the year (Coote et al., 1988; Kirby and Mehuys, 1987; Renard et al., 1997). The effect of management practices on soil erosion losses during the soil thawing period seems very important.

Surface residue cover reduces soil erosion losses. Residue, by intercepting raindrop-impact energy and reducing flow velocity of runoff water, minimizes soil erosion detachment and transport processes. This is quite well established for unfrozen conditions (Laflen et al., 1985). Logically, the effect should extend to soil thawing conditions. However, the magnitude of residue cover impacts on soil loss during the thaw period could differ due to the increased sensitivity of surface soil to soil detachment and increased runoff. Understanding this relationship is important because crop residue seems to be the most feasible management approach for reducing erosion losses during the thawing period on many cropped soils.

The objective of the experiment was to identify the effect of a frozen and non-frozen subsurface layer on soil splash and soil eroded from simulated rainfall on small laboratory plots when surface residue, soil inclination, and soil type were varied. Measured parameters included soil detachment and eroded soil.

MATERIALS AND METHODS

A randomized complete block design was used. There were three blocks (replications). The experimental unit was an erosion box with a specific treatment combination. Soil eroded and soil splash was measured. Treatments were soil inclination

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Abbreviations: F–NF, frozen–not frozen.

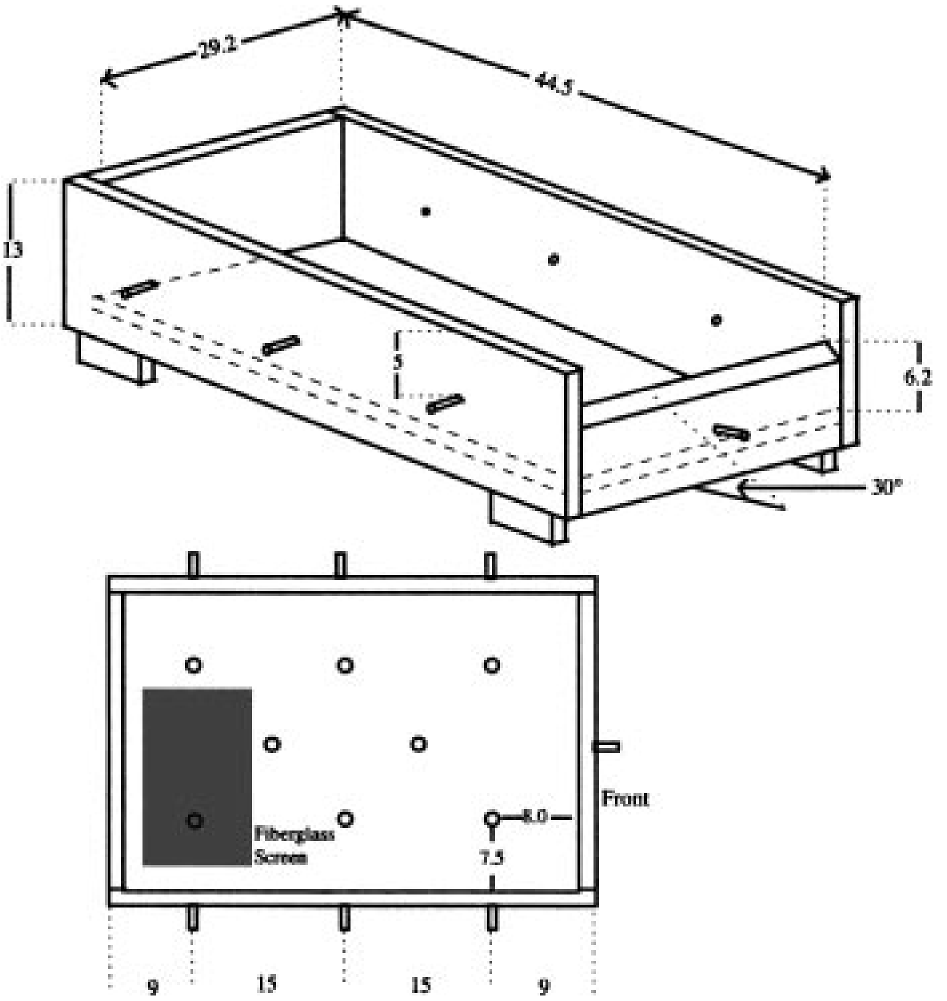

Fig. 1. Schematic of erosion box (three-dimensional and top views). All measurements are in 1 × 10^{-2} m.

(5, 9, and 13%), surface residue cover (0, 10, 30, and 80%), soil type (loess and till), and presence or absence of a frozen subsurface layer. Data were analyzed using analysis of variance.

Rainfall Simulation

A nail-board shuttle rainfall simulator was used to apply rainfall (Gasperi-Mago and Troeh, 1979). Water drop fall height was 6.2 m and water drop diameter was ≈0.0044 m, resulting in ≈93% of terminal velocity. Oscillating fans were operated in the raindrop tower to help insure random water drop impact patterns occurred on the soil. The rainfall simulator applied 0.0343 m of H_2O during a 30-min period.

Erosion Boxes

Six boxes were made from 0.019-m-thick pressure treated pine plywood (Fig. 1). Drain holes were drilled on the sides and bottom, and 0.005-m-diam. copper tubing was inserted into the holes and extruded 0.0015 m from the plywood. A fiberglass screen was placed on the bottom of the boxes to minimize soil loss through the drain holes. The front of the box had a 0.525-rad bevel to fit the runoff collector (Fig. 2). The rear vertical piece of the collector was set inside the box and held in place by the pressure of the soil in the box. For boxes that were frozen, a piece of the material equal in thickness to that of the collector, was inserted prior to freezing and was replaced with the collector prior to each trial. The back of the collector was notched to allow drainage from the front of the box.

The raindrop splash was trapped with a splash guard made of 0.0008-m galvanized steel (Fig. 3). It fit tightly over the erosion boxes and was angled to account for slope. A hand level was used to vertically level the splashguard before every

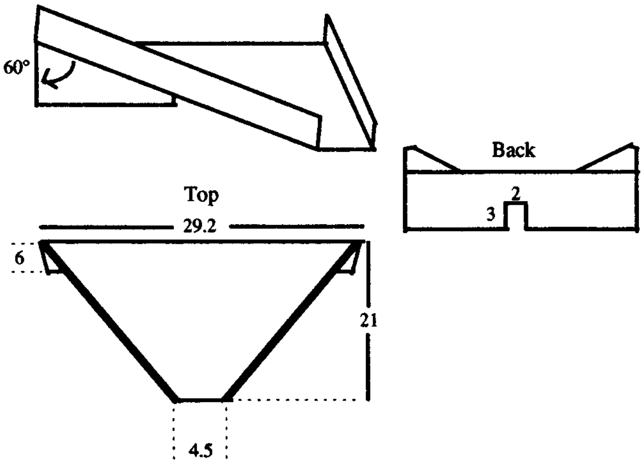

Fig. 2. Collector, angle, top, and back views. All measurements are in 1 × 10^{-2} m.

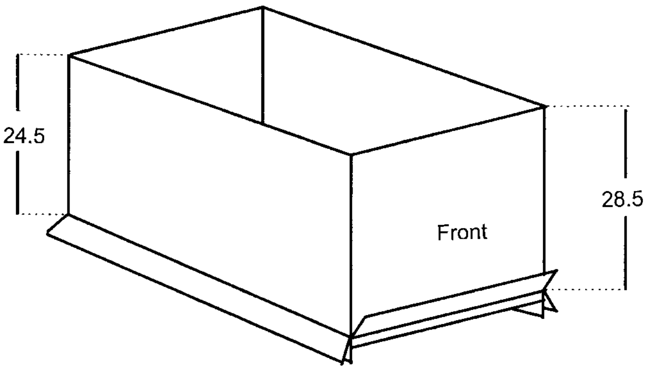

Fig. 3. Splash guard. All measurements are in 1 × 10^{-2} m.

run to minimize rainfall washing splashed material back into the erosion boxes. Small lifts placed at the back of the box were used to adjust inclination (5, 9, and 13%) using the rise-over-run method.

Soils

Glacial till, Nicollet loam (fine-loamy, mixed mesic Aquic Hapludoll) and loess, Galva, silty clay loam (fine-silty, mixed, mesic Typic Hupludoll) soils were used in this experiment (Table 1). Soil was hand cleaned of all undecomposed stems, leaves, and other large organic matter pieces and as many gravel particles as reasonably possible to minimize variability in the experiment. Prior to packing soil in the boxes, the soil was moistened to a predetermined water content, which enhanced ease and uniformity of packing.

The amount of moist soil needed to reach the target bulk density (Table 1) was added to each box. Target bulk densities for each soil were based on field average bulk densities for each soil obtained from county soil surveys. The initial gravimetric water content for the soil in each run was based on gravitational drainage after saturation. This was determined by packing the soils in 10-cm-deep soil rings and saturating from the bottom. Samples were then covered to prevent evaporation losses and allowed to gravitationally drain for a period of 48 h. Three tests for each soil were conducted to determine initial soil water content for the erosion trials.

Before each run all soil aggregates >5 mm were manually ground. This provided a more homogeneous structure of the soil being packed in the erosion box, which minimized preferential flow during the rainfall period.

Residue

Soybean [*Glycine max* (L.) Merr.] stem residue was collected in mid March from a field harvested the previous fall. The residue was sorted for uniformity by hand. Only solid soybean stems were used.

A mesh frame the size of the erosion box was used to determine the percentage residue cover by the point intercept method (USDA Soil Conservation Service, 1994). Several trials were conducted to establish air-dried residue weights required for the three surface residue cover treatments (10, 30, and 80%). This air-dry weight of residue was randomly placed on the surface of each soil prior to conducting the erosion trial.

Soil Packing

Because we were simulating a frozen layer below a thawed layer, the packing process consisted of two steps. For frozen runs, the first step packed 84% of the soil (0.052 m) into the erosion box; this was to be the frozen layer. To avoid packing the top portion of this frozen layer more than the underlying soil, the unit was divided horizontally into thirds and each packed separately; thus differences in bulk density were minimized. Soil water content was then increased to the drained soil water content (Table 1) using a watering can over a double layer of fiberglass screening, which minimized disturbance to the soil surface. The soil and erosion boxes were placed into a freezer set at −12°C for a minimum of 24 h. The second step consisted of packing the remaining 16% of the (unfrozen) soil over the frozen soil. The water content of the top 0.01 m of the (unfrozen) soil was then increased using the method described above.

For nonfrozen runs a similar process was used. However, the soil and erosion boxes were not frozen, and the water content of the units was increased as a whole instead of as individual layers. The packing sequence still followed the 84% first and the 16% second steps.

Erosion Runs and Data Collection

The wooden box provided suitable insulation for the frozen subsurface layer. Thawing was not detected before the run occurred. The average time required to remove the box from the freezer and initiate the run was about 15 min.

Soil splash was collected from the splash guard by first washing the soil off the sides of the guard into a large pan. The solution was then transferred to a jar of known weight where it remained at rest until all, or most, of the soil particles had settled to the bottom (no less than 24 h). A siphon was used to carefully remove as much excess water as possible without disturbing the soil. Then the jar was placed into the drying oven at 105°C for 24 h or until a constant weight was reached. This weight, minus the jar weight, was recorded as the splash weight.

Soil eroded from the box into the collection container and any soil on the collector after rainfall simulation was the basis for soil erosion values. Soil on the collector was washed with runoff solution into the container. This solution was transferred to a preweighed aluminum roasting pan. This solution was treated like the splash solution. The oven dry weight minus the container weight was the soil erosion value.

RESULTS AND DISCUSSION

Treatment Effects on Soil Eroded

Data analysis for amount of soil eroded (Table 2) revealed that, in general, (i) as percentage residue cover

Table 1. Soil characteristics.

Soil name	Parent material	Particle-size distribution Sand	 Silt	 Clay	Bulk density	K† factor	Organic matter	Initial H_2O
			%		g cm^{-3}		g kg^{-1}	g g^{-1}
Galva	**loess**	**3**	**61**	**36**	**1.27**	**0.32**	**5.6**	**0.47**
Nicollet	**Glacial till**	**37**	**39**	**24**	**1.20**	**0.24**	**4.2**	**0.36**

† K factor in Universal Soil Loss Equation (Iowa Cooperative Soil Survey, 1997).

Table 2. Analysis of variance table for soil eroded showing main effects, interactions, and selected linear effects.

Source	df	Mean square	$P > F$
Block	2	5 385	<0.001
Residue	3	129 191	<0.001
Linear	(1)	(382 833)	<0.001
Slope	2	30 500	<0.001
Linear	(1)	60 950	<0.001
Residue × slope	6	3 107	<0.001
Soil	1	8 791	<0.001
Residue × soil	3	2 429	0.005
Slope × soil	2	113	0.809
Residue × slope × soil	6	736	0.229
F–NF†	1	127 053	<0.001
Residue × F–NF	3	3 231	<0.001
Linear × F–NF	(1)	(9 540)	<0.001
Slope × F–NF	2	114	0.808
Residue × slope × F–NF	6	1 488	0.015
Soil × F–NF	1	1 796	0.069
Residue × soil × F–NF	3	1 585	0.035
Slope × soil × F–NF	2	908	0.187
Residue × slope × soil × F–NF	6	175	0.920
Error	94	532	

† F–NF is frozen–nonfrozen.

increased, soil eroded decreased in a linear manner ($P < 0.001$); (ii) as soil inclination increased, eroded soil increased in a linear manner ($P < 0.001$); and (iii) a frozen layer increased soil eroded ($P < 0.001$). Despite the main effect trends, there were many interactions ($P < 0.001$), which complicates the general trends in some situations.

Soil erosion decreased as residue cover increased for each of the six combinations of soil inclination and frozen–not frozen (F–NF) treatments (Fig. 4). The slopes of the simple linear regression of soil eroded on residue for four of the six combinations are quite similar. But the slope for the frozen 13% inclination treatment is much steeper than the others, and the slope for the not-frozen, 5% inclination treatment is considerably less. Note that these two treatment combinations comprised the most and least erodible conditions, respectively. The differences in regression slopes show that the relationship between soil eroded and residue cover is dependent on the combination of soil inclination and F–NF conditions ($P < 0.001$). The more erodible condition (steepest inclination with thawing soil) seemed most responsive to surface residue cover.

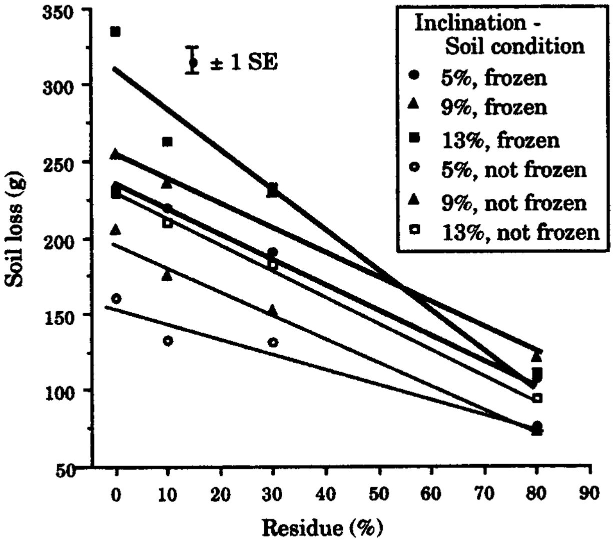

Fig. 4. Average soil eroded vs. percentage residue cover for the six combinations of inclination and frozen–nonfrozen treatments.

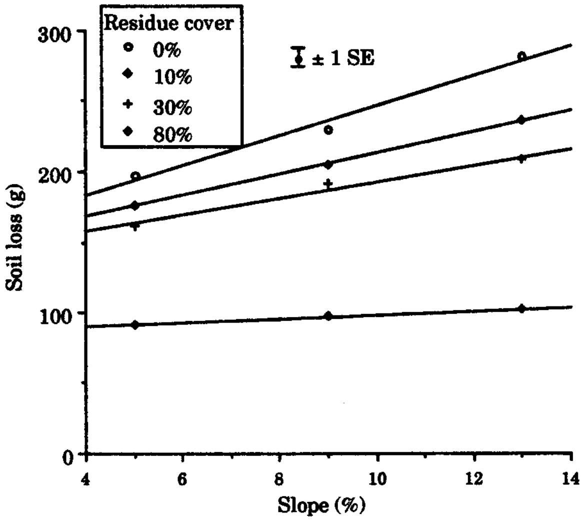

Fig. 5. Average soil eroded vs. inclination for four levels of residue cover. Lines represent simple linear regression of soil eroded on inclination for the four residue levels.

The relationship between soil eroded and soil inclination was linear for each level of residue cover ($P < 0.001$), but as shown by the slopes of the lines in Fig. 5, the inclination effect was strongly influenced by the amount of residue present ($P < 0.001$). Surface residue cover reduced the effect of soil inclination on soil erosion.

Soil eroded without residue cover was essentially the same for both soils (Table 3), suggesting that the particle-size distribution differences had little influence on soil erosion. This conclusion is not supported, however, by results obtained with surface residues. With surface residue loess soil eroded faster than till ($P < 0.001$). It is unknown why the loess and till soils had similar erosion losses in the absence of residue, but differed when resi-

Table 3. Soil type and residue cover effect on average soil eroded and average soil splash, and soil freezing treatment and residue cover effect on soil splash averaged across soil materials (loess and glacial till).

Soil treatment	Surface residue cover (%) 0	10	30	80
	Soil eroded			
	kg			
Loess	0.233†	0.217	0.202	0.104
Till	0.240	0.194	0.171	0.090
	Soil splash			
	kg			
Loess	0.132‡	0.112	0.090	0.019
Till	0.095	0.089	0.074	0.025
	Soil splash			
	kg			
No frozen layer	0.092§	0.082	0.068	0.023
Frozen layer	0.134	0.118	0.086	0.022

† Standard error = 0.0053 kg.
‡ Standard error = 0.0035 kg.
§ Standard error = 0.0035 kg.

Table 4. Analysis of variance table for soil splash showing main effects, interactions, and selected linear effects.

Source	df	Mean square	$P > F$
Block	2	1 837	<0.001
Residue	3	58 534	<0.001
Linear	(1)	(175 484)	<0.001
Slope	2	8 280	<0.001
Linear	(1)	(16 425)	<0.001
Residue × slope	6	1 329	<0.001
Linear × linear	(1)	(2 483)	0.001
Soil	1	7 993	<0.001
Residue × soil	3	3 213	<0.001
Linear × soil	(1)	(8 064)	<0.001
Slope × soil	2	391	0.170
Residue × slope × soil	6	235	0.376
F–NF†	1	20 238	<0.001
Residue × F–NF	3	3 381	<0.001
Linear × F–NF	(1)	(9 722)	<0.001
Slope × F–NF	2	31	0.868
Residue × slope × F–NF	6	229	0.394
Soil × F–NF	1	74	0.560
Residue × soil × F–NF	3	293	0.261
Slope × soil × F–NF	2	257	0.309
Residue × slope × soil × F–NF	6	343	0.160
Error	94	216	

† F–NF is frozen–nonfrozen.

due was added. When considered in light of the soil splash data (discussed later), common soil loss with bare surface conditions became even more challenging to explain.

Because of the numerous interactions, one cannot simply describe the effect of residue by itself. The four treatments had seven degrees of freedom for main effects, and three of the degrees of freedom were for residue. Residue accounted for 60% of sum of squares for main effects, and 99% of that was for the one degree of freedom linear effect. Residue was involved in 93% of the sum of squares for all interactions. There was an obvious negative linear relationship between soil loss and residue cover. Higher percentages of residue cover effectively decreased the impacting force of the raindrop, limiting soil detachment and surface seal development. Residues also decreased the rate of overland flow by interrupting the flow path, thus favoring infiltration and reduced runoff.

The linear response of soil loss to residue cover differs from that observed in field plot studies (Meyer et al., 1970). Differences in methods probably account for much of this. Larger plots more completely integrate detachment, surface transport, and deposition processes than do the erosion boxes used in this study. A significant portion of the splashed sediment in this study was intercepted by the splashguard. This material was unavailable for transport and erosion loss. It is anticipated that this effect is greatest when residue cover is lowest. If this material were available for erosion loss measurement, elevated measures would be likely to occur, particularly with little residue cover. This could increase the nonlinearity of the residue cover vs. soil erosion observed in this study, and more closely align this relationship with that common in the field.

A frozen subsurface layer 0.01 m below a thawed surface limited water movement below 0.01 m. This was visually evident for the frozen layer treatment even though water failed to drain from the drainage tubes for any treatment. Reduced water infiltration increased the susceptibility of erosion, but as shown in Fig. 4, the impact of the frozen layer varied, depending on the inclination and the amount of surface residue ($P <$ 0.001). Based on observations of Towner and Childs (1972), Cruse and Larson (1977), Cruse and Francis (1984), and Froese and Cruse (1997), a frozen subsurface layer should significantly reduce shear strength of the surface layer, decreasing soil resistance to erosion.

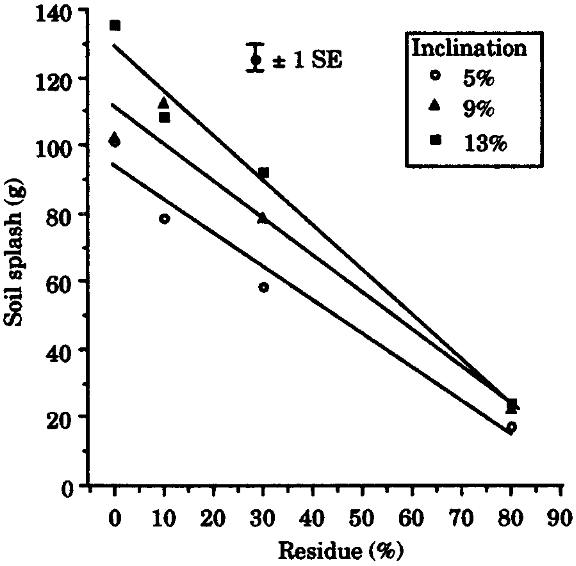

Fig. 6. Average soil splash vs. percentage residue cover for three inclinations. Lines represent simple linear regression of soil splash on residue cover for the three inclinations.

Because there were four levels of residue and three levels of inclination, a variety of regression equations could be developed. Fig. 4 and 5 show the lines for selected relationships. Of particular interest are the high R^2 values of these equations. For the six lines in Fig. 4, the R^2 values ranged from 0.94 to 1.00, and for the four lines in Fig. 5, R^2 ranged from 0.98 to 1.00. These values indicated how linear the relationships were between soil eroded and inclination and percentage residue cover. The slope of the lines depended on the particular combination of treatments being evaluated, but all relationships were linear.

Treatment Effects on Soil Splash

Analysis of soil splash data (Table 4) revealed three substantial two-way interactions ($P < 0.001$) and that the four treatments produced different amounts of splash ($P < 0.001$). The three significant interactions, residue × inclination, residue × soil, and residue × F–NF, demonstrate the importance of residue cover on soil splash.

The residue × soil type interaction seems to be caused by the greater soil splash from the loess with 0 and 10% residue than from the till, but there were similar amounts of splash for both soils with 30 and 80% residue cover (Table 3). Straight lines fit the data for both soils well ($P < 0.001$), but the slopes are quite different ($P <$ 0.001). It is anticipated that soil or soil treatment effects on splash would diminish with increased residue cover; that is, with complete residue cover soil splash should be minimal for any soil. This is supported by results of this experiment.

The residue by F–NF interaction (Table 3) seems to be similar to the residue by soil type interaction. With 0% residue cover soil splash is ≈50% greater with a frozen layer, but with 80% residue cover, there are essentially no differences between the two. Apparently 80% cover is adequate protection to compensate for the frozen layer. Soil splash has a strong linear relationship to residue cover for frozen and nonfrozen soils ($P < 0.001$), and the slope is steeper for the frozen soil ($P < 0.001$).

Although increasing residue cover linearly decreased splash for each inclination (Fig. 6), there were obvious differences in the slope of regressions of splash on residue for each inclination level ($P < 0.001$). Increasing splash with greater inclination can also be observed, but at 80% residue, there is little difference among the three inclinations. Foster and Martin (1969) and Bryan (1979) found splash transport to increase with greater inclination.

The effects of inclination, residue, and soil type were expected and are clearly identified in the literature (Wischmeier and Mannering, 1969; Foster, 1982; Renard et al., 1997). The linear effect of residue cover on soil loss was unexpected. The small measurement area, combined with the raindrop splash interception, probably contributed to this observation. While the linear response was probably an artifact of experimental methods, the methods allowed clear detection of treatment effects on soil detachment and soil loss. Higher splash levels for soil with the frozen subsurface layer indicates soil is more vulnerable to detachment. This is probably due to elevated matric potentials in the surface layer (Froese et al., 1999). Froese and Cruse (1997) found soils to be more susceptible to detachment under thawing conditions than soil that had not been frozen or thawed. Freezing of the subsurface layer and increasing the matric potential of the top 0.01-m layer decreases the soil strength resistance to detachment from raindrop impact.

Caution is advised in extending results from this laboratory study to directly predict field results. However, principles governing erosion losses for these small plots should also operate in the field. With this in mind, it seems expedient to field evaluate the effect of residue cover on soil erosion losses for spring thawing conditions. Past research has evaluated residue cover effects on soil erosion for unfrozen soils. This research indicates that surface residue cover plays a significantly greater role in soil conservation during the thawing period, particularly on steeper inclinations, than may be anticipated from research on unfrozen soils. Surface residue management is a proven effective soil conservation tool for unfrozen soils. This research suggests surface residue management may be even more important in controlling erosion on thawing soils.

CONCLUSIONS

Residue cover and soil slope had linear relationships with both soil detachment and erosion on these small laboratory erosion plots. As expected, residue cover decreased soil loss, and increasing soil inclination resulted in greater soil loss. Soils, loess vs. till, were also significantly different with regard to detachment and soil erosion—loess being more erosive. A subsurface frozen layer significantly increased detachment and erosion losses. With small erosion plots and simulated rainfall, residue had a greater effect on soil loss for highly erosive conditions (i.e., steep slopes with a subsurface frozen layer) than for conditions which were less erosive (i.e., gentler slopes with no subsurface frozen layer).

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Subcritical Water Repellency of Aggregates from a Range of Soil Management Practices

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ABSTRACT

Subcritical water repellency is a poorly acknowledged physical property of soil. It refers to soil where water uptake appears to occur readily, yet is impeded to some extent by the presence of hydrophobic surface films. It was only after the recent development of a sensitive testing technique that subcritical water repellency was shown to be a common feature of many soils. It is a fundamental physical property of soil and has implications for the resistance of soil structure against disruption by wetting, bypass flow, and surface runoff. Using a technique adapted by Hallett and Young (1999), we assessed a water repellency index, *R*, of individual soil aggregates from a range of cultivation practices with different fertilizer inputs and depths. The parameter *R* is extremely powerful since it is directly proportional to the decrease in water sorptivity caused by repellency. The hypotheses tested are (i) that soil disturbance reduces *R* and (ii) that high levels of plant nutrients (fertilizer) will enhance *R*. Cultivation was found to cause a twofold decrease in *R* for all soils tested except one pasture treatment. Pasture soil from another site had an *R* value that was three times higher to a depth of 60 cm than an adjacent plowed soil. Soil aggregates were more repellent from no-till than plowed treatments. Higher levels of N added to field soil did not affect *R*.

Living matter in soil, such as plant roots and microbes, produce extracellular polysaccharides that may enhance nutrient uptake and defend against desiccation stress (Chenu and Roberson, 1996; Hart et al., 1999). Some of these exudates form hydrophobic surface films on soil particles, particularly after physical alteration by drying or heating. Soil may also contain hydrophobic organic matter and waxes from plant leaves (Wallis and Horne, 1992). In some soils, the coverage of particles by hydrophobic surface films is so abundant that water infiltration is completely repelled (Carrillo et al., 1999). Soil exhibiting this extreme condition is not widespread, however, leading to an assumption by soil physicists that non-water repellent behavior is the norm (Wallis and Horne, 1992).

The assumption that soil is generally nonrepellent was challenged by Tillman et al. (1989). They suggested a widespread condition in soils is subcritical water repellency that occurs when hydrophobic surface coverage is less abundant. These soils are difficult to detect with conventional water repellency tests because they appear to uptake water readily. Tillman et al. (1989) overcame this problem by developing a sensitive and physically meaningful measurement of water repellency based on sorptivity. By comparing the sorptivity of water against a liquid not affected by repellency, they were able to define a repellency index that was directly proportional to the reduced infiltration rate. Further research by Wallis et al. (1991) and Hallett and Young (1999) using the technique of Tillman et al. (1989) revealed that most soils exhibit subcritical water repellency. However, given the limited amount of work conducted in this area, the implications of this finding have not been appreciated by soil scientists.

Subcritical water repellency in soil has both detrimental and beneficial impacts on the environment and agriculture. It is paramount to the hydraulic transport properties of soil and may contribute to the heterogeneity of soil structure. One direct consequence of retarded rapid wetting is enhanced structural stability of soil as the energy release rate and buildup of air pressure in pores (i.e., slaking) caused by the intrusion of water is lowered (Piccolo and Mbagwu, 1999; Caron et al., 1998), but the reduction in wetting rate also enhances surface runoff and pollutant transport through higher levels of macropore and interaggregate flow.

Soil stability and interaggregate flow properties are important to assess following tillage when the structural form of soil is predominantly discrete aggregates, particularly at or near the surface. Leeds-Harrison and Youngs (1997) devised a method for evaluating the hydraulic characteristics of individual soil aggregates using a miniature infiltration device. When they assessed the technique, some of the soils tested appeared to be hydrophobic. Hallett and Young (1999) combined their approach with the repellency technique developed by Tillman et al. (1989) in order to assess the extent of subcritical water repellency of soil aggregates amended in the laboratory with specific nutrients. It showed direct

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Abbreviations: DRIFT, diffuse reflectance infrared fourier transform spectroscopy.