Soil loss by splash and wash during rainfall from two loess soils

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Abstract

Physical processes occurring during surface seal formation through a rainstorm are well understood, but limited information is available regarding the quantity and particle size distribution of splash and runoff at certain time intervals. In this study, we evaluated the quantity and particle size distribution of suspensions of both splash and interrill runoff in two loess soils with different mineralogy and aggregate stability, and somewhat different particle size distribution, but similar organic matter content. The soils were subjected to simulated rainstorms of ~ 40 mm h⁻¹ and 100 mm h⁻¹ intensities. The amount of splash was about four times higher for the Saskatchewan soil (Typic Haploboroll) with high smectite than for the Grenada soil (Typic Fragiaudalf) which is rich in Fe-oxyhydroxides. The amount of splashed material and sediment load increased with increased rainfall intensity for both soils. Splash was decreased after wetting of the soil surface. The decrease in splash rate was more rapid with high rainfall intensity. The amount of clay size particles of the splash was similar to the original soil material. Micromorphological observations confirmed the fluctuations in clay content with time, at the very surface. Soil materials splashed were much higher (10 to 20 times) than the interrill runoff losses. The latter was controlled by the rainfall intensity. The soil material from Saskatchewan, produced more than 11 Mg ha⁻¹ of interrill runoff with low rainfall intensity. High rainfall intensity produced 10

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times more soil loss than low rainfall intensity. High amount of soil loss clearly shows that the Saskatchewan soil would benefit from erosion control measures. Both rainfall intensities removed preferentially more clay from the Saskatchewan B horizon material. This has important agronomic and environmental implications for this soil. Interrill soil losses from the Granada A horizon material were much less, with no clear evidence of preferential removal of clay size particles.

**Keywords:** interrill runoff; lateral clay movement; loess soil; rainfall intensity; simulated rain storm; soil erosion; soil splash

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### 1. Introduction

Development of surface seals in cultivated soils during rainstorms reduces infiltration rates, increases surface runoff and the erosion hazard, and consequently loss of organic matter and soil fertility. Several studies (Flanagan et al., 1988; Römkens et al., 1990; and Giménez et al., 1992) have shown the significance of rainfall intensity and storm patterns on seal characteristics. Other studies have recognized that with increases in raindrop impact energy, the extent of surface seal formation is enhanced, resulting in reduced infiltration rates and increased surface runoff (Agassi et al., 1985; Bradford et al., 1987; Keren, 1990; Bradford and Huang, 1991).

Several soil characteristics such as clay content, mineralogy, type and amounts of exchangeable cations, organic matter content, type and amounts of electrolyte concentration in the rain and soil solution influence crust formation. Other factors include rainstorm intensity, antecedent soil water content, soil hydraulic properties (Römkens et al., 1990), surface slope (Poesen, 1986), and likely management techniques (cultivation, crop types). Recent studies showed that rapid changes take place during rainfall, affecting infiltration and erosion processes (Arshad and Mermut, 1988; Remley and Bradford, 1989; Luk and Cai, 1990; Luk et al., 1990; Moss and Watson, 1991; Mermut et al., 1995).

An earlier study with four selected loess soils from different geographic locations (Römkens et al., 1995), the soil materials from the Saskatchewan B and Grenada A horizons were the most and the least susceptible to surface sealing, under specific experimental conditions in the laboratory. In an accompanying study, the influence of the clay mineralogy and rainstorm characteristics on the arrangement of the fundamental soil particles at the very surface in these two soils was investigated (Mermut et al., 1995).

Runoff from rainstorms may be predicted from rainfall data and infiltration, for a given soil. This is essential for soil erosion prediction and water conservation (Shainberg, 1991). Direct measurements of splash and soil transport by surface runoff at different rainstorm stages, especially the particle size distribution of solids in splash and runoff in crust prone soils, appears to be rare (Sutherland et al., 1996).

The objectives of this study were to: (1) determine total amounts and particle size distribution of splash and interrill runoff sediment, as influenced by rainfall intensity on disturbed soil material from the B horizon of the Saskatchewan and the A horizon of the
Grenada soils, at different time intervals, and (2) relate the observed differences to their properties.

2. Materials and methods

Two loess soils, one from southern Saskatchewan, identified as a Swinton soil (Typic Haploboroll), Canada and the other from Mississippi, USA, mapped as a Grenada soil (Typic Fragiudal), were used in this study. We chose the B horizon of the Saskatchewan soil for three reasons: (1) this horizon contains substantial amounts of smectite, to accentuate the impact of this silicate clay mineral on splash and runoff, (2) it is also exposed in eroded areas, (3) it contains similar amounts of organic matter (0.86%) in comparison with the Granada A horizon (0.83%), so that the influence of organic matter on our experiment will be eliminated.

The Saskatchewan B horizon is loam textured with a particle size distribution of 30% sand, 48% silt and 22% clay, and a pH of 6.2. Smectite, mica and vermiculite are the dominant silicate clays in the Saskatchewan B horizon. The Granada A horizon is a silt loam textured with 4% sand, 78% silt and 18% clay, and a pH of 6.1. Vermiculite, mica and kaolinite were the dominant clay minerals. More information about these two soils can be found in Römkens et al. (1995), and Mermut et al. (1995).

Samples were air dried and crushed to pass a < 2 mm sieve. Air dried samples were packed to the rim of 30 cm diameter by 30 cm deep cylindrical plexiglass containers (Römkens et al., 1995). The columns were then placed at a 9% surface slope on an electronic balance which provided a continuous record of the changing weight. Interrill runoff was collected in a 6 mm diameter tube, placed in a slightly recessed configuration relative to the soil surface. The tube exited through the plexiglass container about 5 cm from the soil surface and was connected to an aspirator in order to drain interrill runoff. Runoff was collected at time intervals of 20 rain or more, depending on the initiation and amount of suspension in the collection bottle. The results were expressed in cumulative mode to calculate the total quantity of soil material transported at a given time during the storm, following the initiation of surface runoff.

The columns were subjected to two rainfall intensities of about 40 and 100 mm h⁻¹ with a kinetic energy delivery rate of 27 J m⁻² per mm of rain, for two hours. A computer assisted system, described in Römkens et al. (1995), was used to measure the hydraulic conductance.

A transparent polyethylene curtain was used around the cylinder to collect all the splashed material during the experiment. The curtain was washed with distilled water and splashed material was collected at 10, 20, 30, 40, 50, 60, 80, 100, and 120 minutes for each experiment. The amount of suspension collected at each time interval was divided by the time elapsed to determine the average splash rate for each time interval. The average rates were taken to be the midpoint of each time interval. Each treatment was repeated three times and average values were used to evaluate the experimental results.

Particle-size analyses were carried out using the standard pipette method (McKeague, 1978). Size distribution of the aggregates was measured using the Kemper and Chepil (1965) method.
3. Results and discussion

3.1. Quantification of rainsplash material

The Saskatchewan soil: Fig. 1 (A and B), shows the amount of materials detached from the soil surface by splash (water drop impact), from the 707 cm² surface area.

At the lower rainfall intensity (40 mm h⁻¹), the Saskatchewan soil had an initial rate (average of first 10 min) of about 1.5 g min⁻¹. This increased to about 2 g min⁻¹ between 10 and 30 min, until the soil surface became wet. Following this, the amount of soil material in splash was reduced to near 1.2 g min⁻¹ and remained constant. The 10–30 min interval of the storm represented the time of surface seal development and decreasing infiltration rate.

The reduction in splashed materials can be explained by the development of a water film on the surface that reduces the impact of raindrop. Depletion of detached soil aggregates, due to their removal from the surface during the early stages of runoff, also add the reduction of splash materials. Results of the three replicates were very close (SD = 0.1 g).

The total amount of material splashed in two hours from the surface of the

![Graph A](attachment:image1.png)

**Fig. 1.** Splash rates for the Saskatchewan B horizon (A) and the Grenada A horizon (B) for the 40 mm h⁻¹ and 100 mm h⁻¹ rainfall intensities used in the study.
The experimental column was about 162 g which is the equivalent of about 23 Mg ha$^{-1}$ in two hours. This is in agreement with splash detachment rate for a loess soil studied by Poesen (1985), from the similar size of a surface area.

As expected, splash rates at the 100 mm h$^{-1}$ rainfall intensity were between 2.5 and 4 (on average 3.5) times higher than those at the lower rainfall intensity. Fluctuations between the three replicates were proportional to the amount of splashed materials ($\pm 0.5$ g). While the initial rate was 5.5 g min$^{-1}$, it was reduced to 4.2 g min$^{-1}$ at the end of the experiment. The reduction in splash started at about 50 min. This corresponds fairly well with surface runoff initiation at about 45 min. As the surface is covered by a thin seal or sedimentational layer of about 25 $\mu$m, the infiltration decreased and a water film at the surface contributed to the reduction in splash.

The total amount of splash material measured for the high rainfall intensity, in two hours of experiment was 575 g, or about 81 Mg ha$^{-1}$, which is 3.5 times more than that of the low rainfall intensity. Considering a measured splash rate of 225 Mg ha$^{-1}$ from a very heavy rain (Brady, 1990), it seems that a rainfall intensity measurement of 100 mm h$^{-1}$ does not cause very much splash loss from the Saskatchewan soil.

The Grenada soil: Splash rates were lower for the Grenada soil (Fig. 1B) than the Saskatchewan soil. At the 40 mm h$^{-1}$ rainfall intensity, the decrease from the initial splash rate was rather gradual. While the infiltration rate remained the same for the first hour, the surface roughness was gradually decreased and became nearly flat, at about 30 min. Surface roughness, which was observed visually, in this soil was greater than the Saskatchewan soil (Mermut et al., 1995).

The total amount of splash measured in 2 hours for the 40 mm h$^{-1}$ rainfall intensity was the equivalent of 7.3 Mg ha$^{-1}$. This is about 0.3 times that of the Saskatchewan soil. The substantial reduction in splash rate was attributed to the presence of Fe-oxyhydroxides that increased aggregate stability (Table 1) compared to the Saskatchewan soil. The reduction in splash rate with time was gradual, as the surface gradually become wet. This agrees well with the high infiltration rate in this soil.

With the high rainfall intensity (100 mm h$^{-1}$) initial splash rate was, on average, 2.8 and 3 times higher than with the low rainfall intensity (40 mm h$^{-1}$), but the ratio was lower than the Saskatchewan soil and closer to the proportion of the two rainfall intensities (2.5 times) used in this study. The reduction in splash rate with time was rapid. This was attributed to the rapid breakdown of the first layer of stable aggregates and consequently the early formation of the flat surface and reduction in infiltration.

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Swinton loam (B horizon)</th>
<th>Grenada silt loam (A horizon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1.0</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>0.5-1.0</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>1.0-0.25</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>&lt; 0.25</td>
<td>78</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
slight increase in splash was noted between 45 min and 120 min. This was likely due to the increased amount of detached soil materials accumulated in the microdepressions that could not be transported by the force of runoff but could be lifted up by splash.

The total amount of splash loss at the end of the experiment was 20.7 Mg ha\(^{-1}\) which is 0.26 of the Saskatchewan soil loss. This suggests that mineralogy of the soil which influences aggregation (Table 1) plays an important role in splash, seal formation, and surface runoff. While both soils have a similar organic matter content, however, the aggregate size distribution clearly shows that the Granada soil has much larger stable aggregates than the Saskatchewan soil. A high degree of aggregation in the Granada soil is also apparent from the rigidity of aggregates under pressure.

3.2. Distribution of clay size particles of splash material

Fig. 2 (A, B), depicts the average clay contents of the splashed material for the two soils with two rainfall intensities. The splash material collected during the experiment

![Figure 2](image-url)
with 40 mm h\(^{-1}\) rainfall for the Saskatchewan soil, showed similar amounts of clay throughout the experiment. The fluctuations were within the accuracy of the particle size analyses. For the 100 mm h\(^{-1}\) rainfall intensity, the clay content in the splashed material fluctuated more than the low rainfall intensity.

Micromorphological studies of these soils have shown that the particle size distribution of the soil surface continuously changes with the formation and deformation of the washed layers or lamellar seals with low and high clay contents (Mermut et al., 1995). Here a washed layer means a zone of about 500 \(\mu\)m that has lost the most of its clays by runoff and perhaps by vertical displacement. This may explain why there is a rapid textural change in splash, during this experiment.

Following the breakdown of the first layer of aggregates and the removal of the material by splash and runoff, new layers of aggregates in the plastic column are exposed to the same processes. Formation and deformation of the washed and lamellar layers are an integral part of the general crust formation (Mermut et al., 1995) and textural changes are, therefore, expected at the very surface of all soils that develop surface seal.

Despite the somewhat lower amount of clay, the Grenada soil (Fig. 2B) had similar degree of clay fluctuations. Considering the deviations between the three runs (with different rainstorm intensities) (± 2.0%) and also the accuracy of the method used to determine particle size distribution, fluctuations do not seem to be significantly different than the original soil texture. Consequently, we can say that the splash by itself does not cause a significant change in clay size distribution in the Grenada soil.

### 3.3. Amounts of eroded materials by surface runoff

**The Saskatchewan B horizon:** Fig. 3 shows the amount of eroded materials in runoff in the two soils studied. With the 40 mm h\(^{-1}\) rainfall intensity, the sediment transported was low and three replicates were almost identical. The first runoff sample was collected after 20 minutes, following the formation of an incipient surface seal and reduction in infiltration. The total amount of sediment during the 2 h experiment was 15 g (average of the triplicate). This corresponds to 2.1 Mg ha\(^{-1}\) soil loss, which is much above the annual amount of natural erosion (between 0.2 and 0.5 Mg ha\(^{-1}\), Brady, 1990). It appears that even this rainfall intensity, repeated 5 to 6 times a year, which is normally expected, would provide a total of 11 Mg ha\(^{-1}\) sediment, which is considered to be a critical value for the decline of soil production capacity (Brady, 1990).

As indicated earlier, high rainfall intensity caused a reduction in infiltration and between 10 and 20 minutes the runoff produced. Fig. 3 indicates that the cumulative amount of sediment in runoff increased approximately linearly with time which proves the importance of rainstorm duration on erosion. The high rainfall intensity substantially destroyed the surface aggregates and generated high splash (81 Mg ha\(^{-1}\)); on average, about 151 g sediment was produced by runoff in 2 h which is one order of magnitude higher than the low rainfall intensity. This amount would be equal to 21.4 Mg ha\(^{-1}\), and is almost the double the amount that is considered as tolerable water erosion in a year. As reported by Mermut et al. (1995), the reduction in infiltration rate between 1 and 2 h
was 10 times less than the initial 5 minute average. This was attributed to the swelling of the smectite silicate clays in the Saskatchewan soil.

The above discussions show that the Saskatchewan soil has very high erosion potential and erosion control measures are needed to maintain the productivity level of this soil.

The Grenada A horizon: The Grenada soil with low rainfall intensity yielded much less sediment (6.4 g in a single total 2 h run), than the Saskatchewan soil. Because of the low sediment yield, replicated runs for low rainfall intensity was omitted. Sediment could be collected only after 1 h, following the formation of the surface seal. At the field scale, this would translate into an erosion loss of about 0.91 Mg ha\(^{-1}\). It appears that the low intensity rainfalls would not produce appreciable soil losses as the rain infiltrates the soil.

Erosion loss with high rainfall intensity was 3.8 times higher than the lower rainfall intensity. A sudden change in infiltration rate, just before 30 minutes (Mermut et al., 1995), was due to early breakdown of aggregates and surface seal formation that resulted in an increased runoff, and thus, more earlier and higher water erosion. The average of the three separate experiments resulted in a total of about 37 g sediment. Using this value, the calculated erosion loss was 5.2 Mg ha\(^{-1}\). Thus, even the Grenada
soil, if it is exposed to a high rainfall intensity, may produce soil erosion that exceeds the tolerable level. Linearity of the relationships in Fig. 3 is consistent with the measured gradual decrease in infiltration (Mermut et al., 1995).

3.4. Clay content of eroded materials

The Saskatchewan B horizon: Clay content of the surface transported materials from the Saskatchewan, as seen in Fig. 4 for both rainfall intensities, showed preferential removal of the clay size particles in the surface runoff. This confirms the earlier suggestion by Mermut et al. (1995) that fine particles (coarse and fine clays) were preferentially suspended by raindrops in a thin water film and transported from the surface. While the original soil had a clay content of 22%, there was an absolute increase of 7 to 12% clay in the eroded materials (> 30% relative increase) with that of high rainfall intensity.

There was no preferential sorting between the fine and coarse clay size fractions in
the eroded materials. The preferential removal of soil clays by surface runoff has important agronomic and environmental implications, as much of the nitrogen, phosphorus, and potassium together with fertilizers pesticides and herbicides which are attached to inorganic and organic clays (Mermut et al., 1983) will preferentially be lost by erosion. In true pedological sense, in addition to vertical translocation, the preferential removal of clay size particles by surface erosion observed in the Saskatchewan soil provides an opportunity to reconsider all the concepts related to the physical translocation of clay size particles, in the soils dominated by smectite clays. The coarser texture of the surface soil in the heavy swelling clay soil can be explained in terms of lateral movement rather than the vertical clay translocation process.

The Grenada A horizon: The quantity of eroded materials collected for the low rainfall intensity was not enough to run a reliable regular texture analyses. The results of the analyses (Fig. 5) from the high rainfall intensity show that this soil has provided sediments which have a similar texture of the original soil. Fluctuations reflect some textural changes at the soil surface which were observed in thin sections (Mermut et al., 1995).

The presence of smectite (swelling clay), as the dominant clay mineral, lower amount of free Fe oxides, and more sand and less silt in the Saskatchewan soil play significant role in low aggregate stability and consequently more splash and erosion, in comparison to the Granada soil. Both soils have normal electrical conductivity and exchangeable Na percentage is < 1.

4. Conclusions

Amounts of splash and interrill runoff erosion, regardless of rainfall intensity, were much higher for the Saskatchewan loam soils than the Grenada silt loam soil. This is attributed to the presence of smectite (swelling clays) as the dominant silicate clay minerals, and low aggregate stability. As expected, the amounts of splash were initially higher and after surface wetting and formation of a water film, it was reduced in both
rainfall intensity storms. The amount of splash appears to be proportional to the rainfall intensity and it was 23 Mg ha\(^{-1}\) and 81 Mg ha\(^{-1}\) for the low (40 mm h\(^{-1}\)) and high rainfall intensity (100 mm h\(^{-1}\)) regimes. The Grenada soil with more stable aggregates (high Fe-oxyhydroxides) had considerably less splash in comparison with the Saskatchewan soil. With high intensity the decrease in splash rate was more rapid. This was attributed to the rapid breakdown of the surface aggregates.

The amount of clay size particles in the splash material appeared to be similar to the original soil material, the fluctuation likely related to continuous textural change at the very surface, as it was proved by micromorphological studies. Fluctuations of clay content were lower for low rainfall intensity, especially for the Saskatchewan soil.

Soil material splashed appears to be much higher than the losses by wash. It should be noted that, under the field conditions, the splash and runoff would influence each other and the pattern would be somewhat different than the reported values in this work.

Materials lost by erosion is a function of rainfall intensity. The quantification of soil losses showed clearly that the Saskatchewan soil, even with low rainfall intensity (2.1 Mg ha\(^{-1}\)), repeated 5 to 6 times a year would produce of a 11 Mg ha\(^{-1}\) sediment which is considered a threshold value for the decline of the soil production capacity. The high rainfall intensity has produced 10 times more sediment than the lower rainfall intensity (21.4 Mg ha\(^{-1}\)) and losses increased with time which signifies the importance of rainstorm duration on erosion. This high amount of soil loss suggests that erosion control measures are needed. Erosion losses were much lower for the Grenada soil. However, even this soil, if it is exposed to high rainfall intensity, is capable of producing erosion which may be above the threshold level.

Clay content of the eroded materials clearly showed that both rainfall intensities have preferentially removed more clays from the Saskatchewan soil. Increase in clay content in the eroded materials was slightly higher with low rainfall intensity. The removal of clay particles has important agronomical and environmental implications for this soil. The Grenada soil provided sediments which have a similar texture of the original soil. As with splash, the fluctuations likely reflect some textural changes at the soil surface.

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