RADIONUCLIDE AND RARE EARTH ELEMENT TRACERS OF EROSIONAL PROCESSES ON THE PLOT SCALE

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INTRODUCTION

Soil erosion results in the loss of primary productivity for agriculture and silviculture and contributes to the degradation of aquatic ecosystems. The two dominant processes of erosion, sheetwash and rill erosion, can have very different impacts. Sheetwash can remove nutrients concentrated near the surface. Rilling can quickly excavate large volumes of soil and initiate unstable conditions. Typical management prescriptions differ as well. Rilling is best treated by contour planting, and by reducing concentrated flows with buffer strips and grassy swales. Sheetwash is better addressed by maintaining soil cover, and enhancing soil porosity. For example, the application of no-till agriculture has been shown to increase infiltration by maintaining macropores, organic matter and the size of soil-aggregates (Holland 2004).

The goal of this work is to develop tools to better understand sheetwash erosion processes and the development of rill networks. We seek to quantify the contributions of rill versus sheetwash erosion in agricultural settings. By developing a signal of rill erosion, we hope to be able to more completely understand the hydrological and geomorphological factors that lead to rill initiation. Better understanding of process is also important for the improvement of soil erosion models (Takken et al. 2005). The results will be directly relevant to land managers.

The first technique presented here is the use of the naturally-occurring radionuclide Be-7 as a tracer of soil movement. Created in the atmosphere by the spallation of nitrogen and oxygen, Be-7 is washed onto the landscape by wet and dry precipitation. Upon contact with the soil surface, it adsorbs onto soil particles with a very high partitioning coefficient (Kd ~10^4-10^5, Hawley et al. 1986). Because of its atmospheric source and short-half life ($t_{1/2}$=53 d) Be-7 tags only the top 1-5 mm of the soil surface. Once eroded, soil retains its diagnostic radionuclide activity. Thus high Be-7 content in sediment can be used as an indicator of sheetwash erosion and low Be-7 content can indicate rill erosion (Whiting et al. 2001, Matisoff et al. 2002).

A complementary technique in tracer studies is the use of soil labeled with rare earth elements (REE). While the radionuclides can serve as tracers of soil originating from specific depths, REEs can be used to tag soil from specific spatial regions. REE is co-precipitated onto soil taken from the study area in the laboratory, and then reapplied in the field setting (Matisoff et al. 2001). Measurements from the soil surface downslope of application sites or in suspended sediment (SS) from captured runoff samples can then indicate particle transport distances, travel times, and rates of deposition. Suites of different REEs can be applied to identify regions of the plot such as topslopes, side slopes, rills and depositional areas (Polyakov et al. 2004).

In this report we present findings from a study that used both REEs and fallout radionuclides to provide a more comprehensive view of spatial and temporal contributions to soil loss.

Figure 1 View of the erosion plot looking upslope.

METHODS

In June 2004, a 4 x 9 meter erosion plot was installed at the USDA Agricultural Research Service Deep Loess Research Station near Treynor, IA. The plot was located in a field with a slope of 8% (Figure 1). While planted to corn, the field was in rotation with soybeans, and no-till practices had been utilized for the previous two years. Borders prevented entry of runoff from regions above and to the side of the plot. A gutter pipe and cement sill were installed flush to the ground surface to collect runoff without causing erosion of the soil near the collection interface. Six cores were collected adjacent to the plot to establish inventories and depth-profiles for Be-7 prior to the study. Soil tagged with the REEs Tb, Ho, and Eu were applied in thin strips (0.25 x 4m) at 1, 4 and 7 meters, respectively, upslope from the bottom of the plot. We then waited for thunderstorm activity. All runoff was collected from the plot in 20-L sample containers. Precipitation was collected to determine Be-7 flux. After the event, 6 cores were taken from within the plot to determine change in radionuclide inventory. Sediment was extracted from runoff samples with settling and flow-through centrifugation. Samples were analyzed for suspended sediment yield, Be-7 activity and yield, and concentration and yield of REEs. Be-7 activity was determined with high efficiency germanium-drifted gamma spectrometry (Matisoff et al. 2002). REE concentration was measured by quadrupole, inductively coupled plasma mass spectrometry (Matisoff et al. 2001).

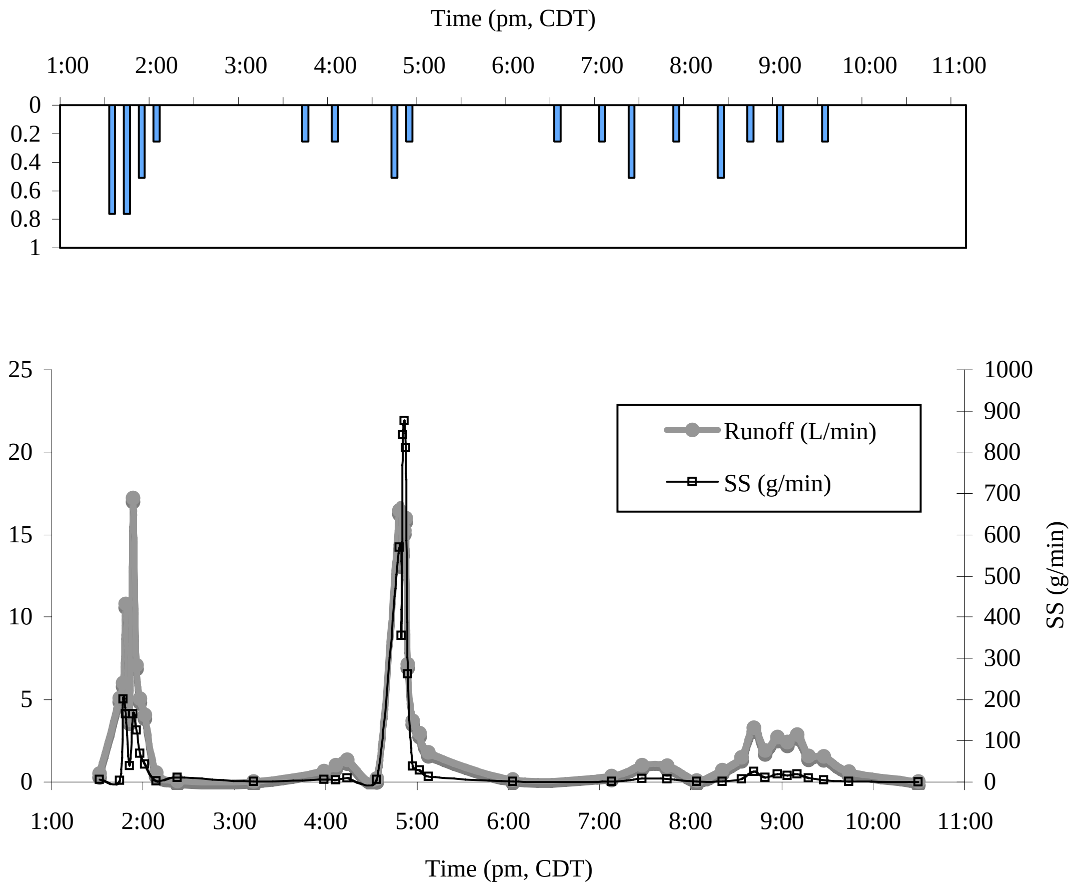
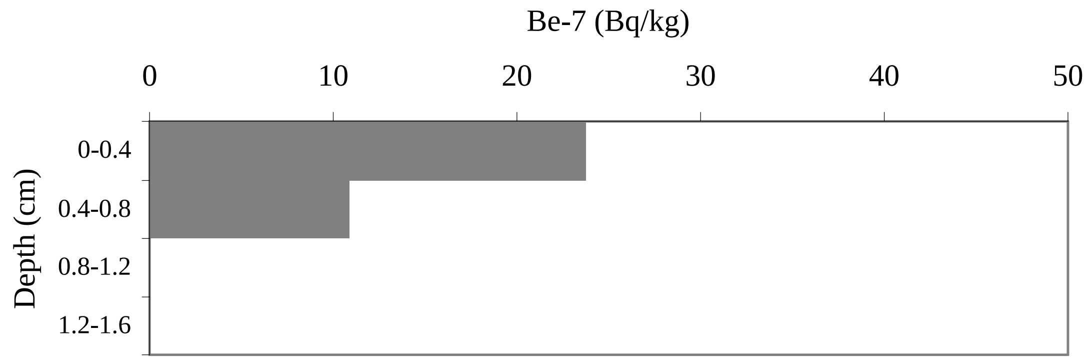


Figure 2 Rainfall, discharge and suspended sediment delivery over time.

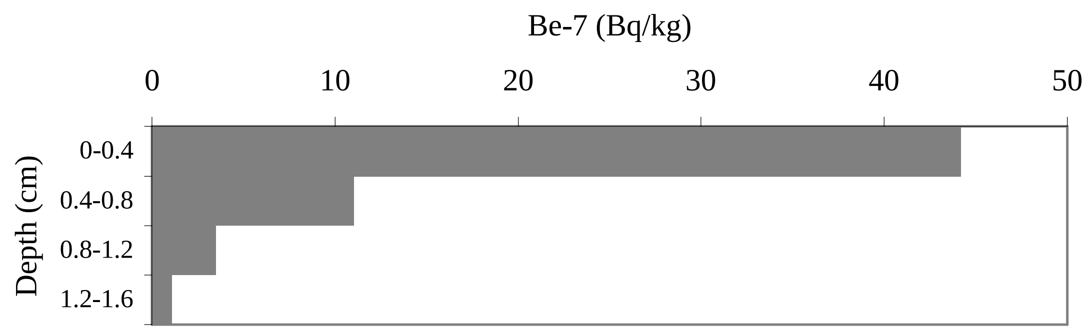
RESULTS

The thunderstorm yielded 10 cm of precipitation in three distinct pulses of gradually lessening intensity over twelve hours (Figure 2). The largest suspended sediment yield and concentrations occurred during the second pulse (Figure 2). The sustained, but less intense, rains of the third pulse produced large runoff volumes but less suspended sediment yield.

Be-7 profiles from before and after the event show concentrations of Be-7 and the increment of the radionuclide added during the thunderstorm (Figure 3). The highest concentration is found at the surface. Levels decay exponentially with depth. The increment added by the thunderstorm is found entirely in the top sample (0-0.4 cm). In Figure 4, Be-7 activity of the suspended sediment and cumulative suspended sediment yield are plotted against time. During periods of highest sediment yield, Be-7 activities drop. In pulse two, starting at 4:00, Be-7 activity drops from 0.5 to 0.1 Bq/g. In pulse three, starting at 7:20, activity drops from 0.62 to 0.2 Bq/g. After each rainfall pulse subsides, Be-7 activity, per gram of runoff sediment, rises.



a.



b.

Figure 3 Be-7 activity with depth. a. Before rainstorm; b. after rainstorm.

In Figure 5, REE concentrations in runoff are plotted against time. Above background concentrations from all three REEs are detected during the first pulse, with the magnitude of the concentration inversely related to the distance to the outlet. During the second pulse, all three REEs are detected; however Tb remains high, while Ho concentration drops. During the third pulse, at 5:06, Tb drops relative to earlier concentrations, Ho attains the concentration of the first pulse and Eu reaches its highest concentration.

DISCUSSION

The results presented above present a consistent picture of the sequence of erosional processes. At the onset of precipitation, rain infiltrates into the soil. As the rainstorm continues, the soil becomes locally saturated, resulting in local overland flow and sheetwash erosion. During the first pulse of rainfall, relatively intense rains produce a modest amount of sediment (as compared to later pulses of rain and runoff). The sediment collected during runoff from this first event has a relatively low activity of Be-7 (0.15-0.25 Bq/g) (Fig 3). An exception is at the end of the runoff from the first pulse when the activity of Be-7 in sediment increases to near 0.4 Bq/g. As observed in our earlier work at this site (Whiting et al. 2001), such an increase in activity is associated with sediment produced by more shallow erosion of the soil column – sheetwash erosion. After the onset of the second pulse of precipitation (at ~4:50), sediment yield increases.

Initially the activity of Be-7 associated with runoff during this second event is high, indicating sheetwash erosion. During the peak of runoff, the activity of Be-7 in sediment drops to less than 0.1 Bq/g. This low value indicates a shift to more of the sediment being produced by deeper rill erosion. As sediment yield wanes after the second event, the activity of Be-7 climbs again to above 0.3 Bq/g, indicating a sheetwash source. The third pulse of rainfall is distributed over a longer time period than the first two pulses and the runoff volumes and sediment yields are lower. High Be-7 activity in runoff sediment suggests that sheetwash is the initial source of much of this sediment. During the period 8:30-9:40, Be-7 activity again decreases to 0.1-0.2 Bq/g. This time period corresponds to an interval of substantial production of sediment which we infer to be primarily by rilling.

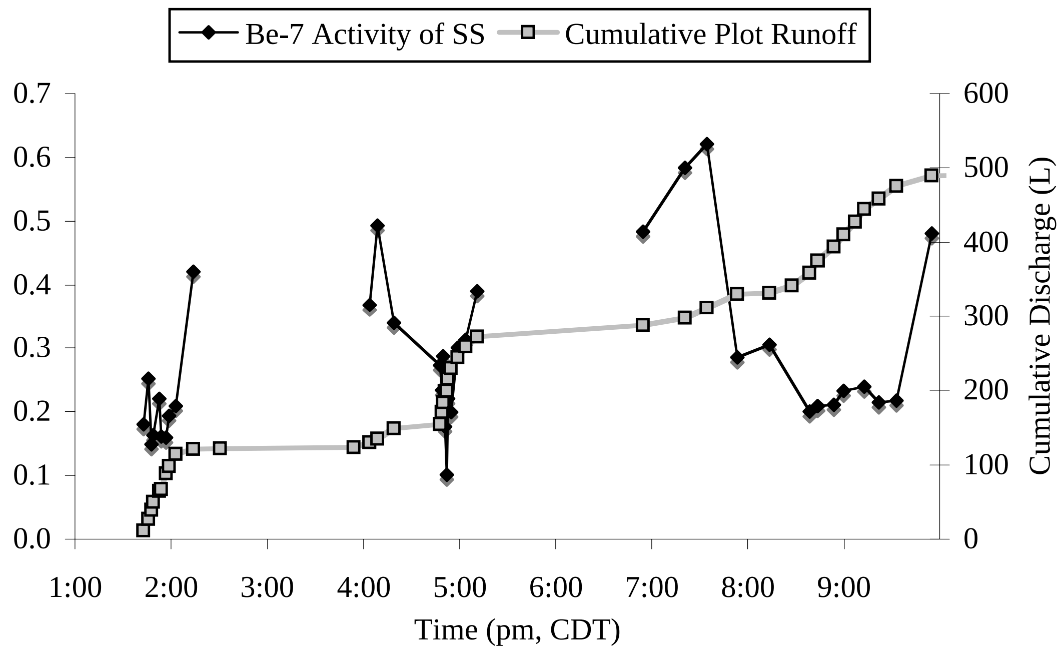


Figure 4 Be-7 activity in sediment and cumulative runoff with time.

Evidence of the gradual expansion of flow networks over the course of the event is provided by REE data (Figure 5). During the first rain pulse (~1:40) REE signal is detected for all three bands. However the concentration of REE in the runoff suspended sediment is related to the distance from the outlet; with Tb, 1 m from the outlet reaching 80 ug/g; Ho at 4 m reaching 40 ug/g; and Eu, 7 m from the outlet, peaking at 20 ug/g. As the second event begins (4:00) the same relative concentration pattern is observed. Then the rainfall intensifies and the sediment yield increases (~4:50, Figure 5). Concentrations of all REEs drop. This reflects dilution by sediments derived from rill erosion as identified by the Be-7 concentrations. Since the REEs were applied to the soil surface, decreasing concentrations in the suspended sediment imply deeper erosion. As the rainfall abates and sediment yield drops (~5:00), there is an increase in the Eu concentration to an event maximum of 44 ug/g. The farthest upslope band now contributes substantially to the sediment load. This indicates that the entire plot is hydrologically linked. REE concentrations were diluted during the period of maximum rill cutting and this may have masked high inputs of Eu occurring at this time. The third pulse of rainfall (~7:00) has consistently low REE levels. This may reflect reduced sediment transport as a result of lower intensity rainfall, or depletion of available stores of REE-labeled sediment.

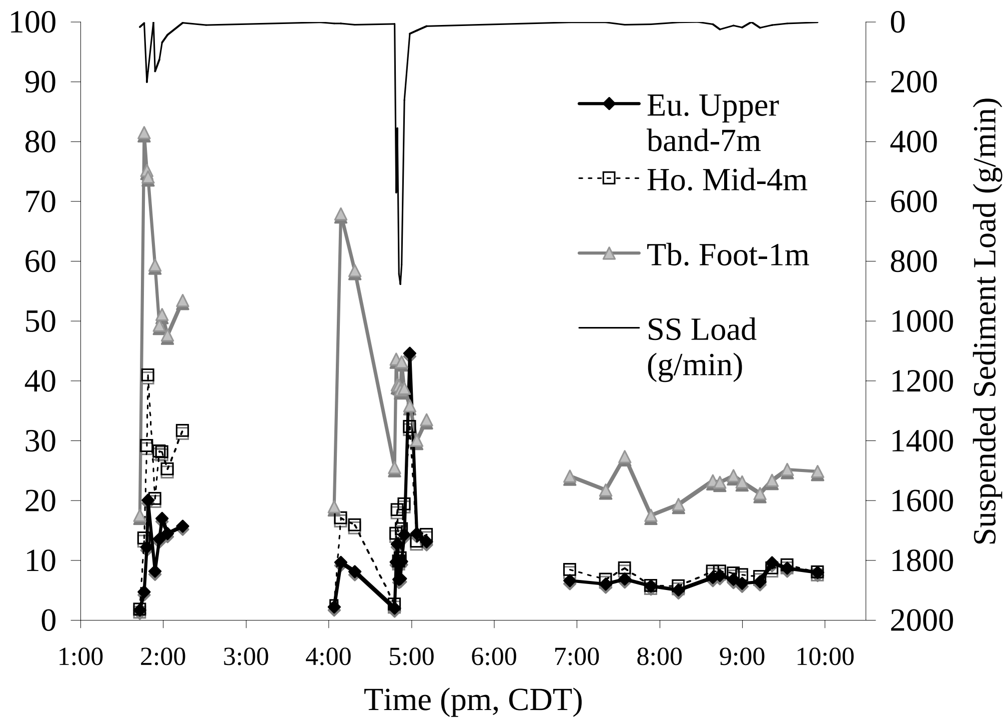


Figure 5 REE concentrations in sediment versus time. Second axis is suspended sediment loading versus time.

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