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RUNOFF AND EROSION RESPONSE OF SIMULATED WASTE BURIAL COVERS IN A SEMI-ARID ENVIRONMENT[1]

Gardner C. Bent, Bruce F. Goff, Kim G. Rightmire, and Roy C. Sidle[2]

ABSTRACT: Control of runoff (reducing infiltration) and erosion at shallow land burials is necessary in order to assure environmentally safe disposal of low-level radioactive-waste and other waste products. This study evaluated the runoff and erosion response of two perennial grass species on simulated waste burial covers at Idaho National Engineering and Environmental Laboratory (INEEL). Rainfall simulations were applied to three plots covered by crested wheatgrass [*Agropyron desertorum* (Fischer ex Link) Shultes], three plots covered by streambank wheatgrass [*Elymus lanceolatus* (Scribner and Smith) Gould spp. *lanceolatus*], and one bare plot. Average total runoff for rainfall simulations in 1987, 1989, and 1990 was 42 percent greater on streambank wheatgrass plots than on crested wheatgrass plots. Average total soil loss for rainfall simulations in 1987 and 1990 was 105 percent greater on streambank wheatgrass plots than on crested wheatgrass plots. Total runoff and soil loss from natural rainfall and snowmelt events during 1987 were 25 and 105 percent greater, respectively, on streambank wheatgrass plots than on crested wheatgrass plots. Thus, crested wheatgrass appears to be better suited in revegetation of waste burial covers at INEEL than streambank wheatgrass due to its much lower erosion rate and only slightly higher infiltration rate (lower runoff rate).

(KEY TERMS: erosion; runoff; hazardous waste management; waste burial covers; land rehabilitation; range management; wheatgrass; soil moisture; surficial macropores.)

INTRODUCTION

Idaho National Engineering and Environmental Laboratory (INEEL), other Department of Energy (DOE) sites, and commercially operated waste repositories require environmentally safe methods of disposal of low-level radioactive waste (LLRW) material. Shallow land burial (SLB) is the most common method of disposal of LLRW and many other waste products. Design life of SLB sites for LLRW is 300 to 500 yr (U.S. Nuclear Regulatory Commission, 1982; Bedinger, 1989; McConnell *et al.*, 1995), which allows adequate time for decay of two important radionuclides, strontium-90 (half life 28.1 yr) and cesium-137 (half life 30.2 yr), to one-thousandth to one-hundred thousandth of their initial radiation (Bedinger, 1989).

Since the most serious technical problems encountered in SLB are water-related, Bedinger (1989) and Reith and Thompson (1992) report that semi-arid and arid environments are the ideal waste burial locations to keep radionuclides from entering the biosphere. Arid regions are more suitable than humid regions for SLB sites because waste would be buried in the unsaturated zone, which is generally very thick (> 15 m), and ground-water flow paths and travel times from repositories to discharge points are long (Bedinger, 1989). Additionally, precipitation is low in arid regions so there is very little deep percolation, and potential evapotranspiration greatly exceeds precipitation.

At SLB sites, waste burial covers are designed to: (1) control erosion, thus preventing exposure of the waste material to the environment; and (2) minimize percolation of water through the waste burial cover and material zone, thereby preventing contamination of the ground water. Since most management practices that reduce erosion of the waste burial cover tend to increase infiltration, the goal of waste burial cover design is to optimize control of both erosion and infiltration.

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Vegetative and gravel covers effects on controlling runoff and erosion have been evaluated on simulated waste burial covers at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico (Nyhan *et. al.*, 1984; Nyhan and Lane, 1986a, 1986b). A gravel or gravel plus wheatgrass cover substantially reduced erosion while only slightly decreasing runoff (increasing infiltration) at LANL. Surface cavity collapses where found to greatly affect runoff and erosion rates on actual waste burial covers at a LLRW disposal site near Sheffield, Illinois (Gray, 1990, 1991). Hillslope erosion rates adjacent to waste burial covers were investigated at the Maxey Flats LLRW disposal site near Morehead, Kentucky (Carey et al., 1990).

Many studies in the last decade have focused on water balance at SLB sites to evaluate waste burial covers in minimizing percolation of water through the cover and material zone. Lower percolation rates occurred on LANL capillary barrier design waste burial covers than on conventional design waste burial covers at LANL (Nyhan *et al.*, 1990). Since then, lower percolation rates have been found on the modified USEPA recommended design (also referred to as the USEPA Resource Conservation and Recovery Act design) waste burial cover than on two LANL capillary barrier design waste burial covers at Hill Air Force Base in Layton, Utah, and at LANL (Hakonson *et al.*, 1994; Nyhan *et al.*, 1997). A gravel admixture in the upper most soil layer, to control erosion, was determined to not influence vegetation establishment or water balance on simulated waste burial at the Hanford Site in Hanford, Washington (Waugh *et al.*, 1994). Water balance was evaluated on actual waste burial covers at the LLRW disposal site near Sheffield, Illinois (Healy *et al.*, 1989).

A prototype decision support system (PDSS) was developed to assist waste disposal managers in selecting the appropriate waste burial cover design for their site (Paige *et al.*, 1996a). The PDSS uses the hydrologic evaluation of landfill performance (HELP) model (Schroeder *et al.*, 1984) and the erosion component of the chemicals, runoff, and erosion from agricultural management systems (CREAMS) model (Knisel, 1980) to simulate water balance and erosion of the waste burial cover, respectively. The PDSS produced reasonable results when evaluated by calibrating and testing the simulation models (HELP and CREAMS) to hydrologic data collected by Hakonson *et al.* (1994) (Paige *et al.*, 1996b).

At Idaho National Engineering and Environmental Laboratory (INEEL), studies of water related problems are limited. Anderson *et al.* (1987, 1993) studied the water use of sagebrush and perennial grasses on simulated waste burial covers at a site nearby this paperís study site. Shakofsky and Nimmo (1996) evaluated the hydraulic properties of the unsaturated zone of a simulated waste burial cover and an undisturbed soil profile at a site nearby this paper's study site. Goff *et al.* (1992, 1993, 1994), in companion studies to this paper, compared the hydraulic roughness characteristics of native soils and lakebed sediment at INEEL; described the erosion response of a disturbed sagebrush steppe vegetative cover on native soils at INEEL; and described the influence of rainfall on the interrill erodibility of native soils and lakebed sediment at INEEL, respectively.

In this study, we examined the runoff and erosion response of simulated waste burial covers planted with two perennial grass species: crested wheatgrass [*Agropyron desertorum* (Fischer ex Link) Shultes] and streambank wheatgrass [*Elymus lanceolatus* (Scribner and Smith) Gould spp. *lanceolatus*]. A rainfall simulator was used to induce runoff and erosion from the simulated waste burial covers during the early and late growing seasons ~~of~~ 1987, about one and a half years following revegetation, and during 1989 and 1990, several years after revegetation. The results were meant to aid INEEL to better manage existing and planned LLRW SLB sites.

STUDY AREA

The study site is located 5 km northeast of the Radioactive Waste Management Complex (RWMC) Subsurface Disposal Area (SDA) at INEEL and 80 km west of Idaho Falls, Idaho. The INEEL site encompasses 2312 km^2 in the upper Snake River Plain of southeastern Idaho. The elevation is 1524 m above mean sea level and the native soil texture is a sandy loam. The native sandy loam soil is a coarse-silty, mixed, frigid Xerollic Calciorthids (U.S. Department of Agriculture, Soil Conservation Service, Lincoln, Nebraska, written communication, 1987). The underlying bedrock consists of basalt flows and interbedded sedimentary deposits of the Snake River Group from Pliocene and Pleistocene time (Malde, 1965). The ground-water table is estimated to be approximately 170 m below land surface at the study site (Barraclough *et al.*, 1982; Davis and Pittman, 1990). Ground water underlying the INEEL site flows towards the southwest and discharges at springs along the Snake River near Hagerman, Idaho, approximately 150 km to the southwest (Barraclough *et al.*, 1982). Both the study site and the SDA are located within a cool desert ecosystem composed primarily of big sagebrush (*Artemisia tridentata* Nutt.), bluebunch wheatgrass [*Agropyron spicatum* (Pursh) Scribn. and Smith], and green rabbitbrush [*Chrysothamnus viscidiflorus* (Hook.) Nutt.] (McBride *et al.*, 1978).

National Oceanic and Atmospheric Administration weather data from INEEL (1950-1988) shows that the average annual precipitation is 221 mm with extremes of 114 mm and 366 mm (Clawson *et al.*, 1989). The months of May and June account for more than 25 percent of the yearly precipitation and December and January represent another slight peak in precipitation. The maximum one-day rainfall event during the 39-year period at INEEL was 41.7 mm. Average annual snowfall is 701 mm with extremes of 173 mm and 1516 mm. Snowfall generally occurs from October through April, and the maximum one-day snowfall during the 39-year period at INEEL was 218 mm. Precipitation events causing runoff at INEEL are spring snowmelt; rain on snow; and short duration, high intensity, convectional storms during the summer. The average annual temperature is 5.6°C with extremes of -44°C and 38°C. Potential evapotranspiration generally exceeds precipitation from June through September (Anderson *et al.*, 1993)

Since 1952, the SDA has been used for storage of low-level radioactive waste and transuranic wastes (Arthur and Markham, 1978). The waste in steel drums and wooden boxes is stacked in pits and trenches and covered with 1 m of lakebed sediment material. Up to 2 m of additional soil has been added to keep precipitation from ponding on the cover. Much of the 32 ha area has been drill seeded with a 50-50 mixture of crested wheatgrass (bunch grass) and streambank wheatgrass (sod-forming grass) (T. Cline, RWMC INEEL; and T. Reynolds, Environmental Science and Research Foundation, INEEL; oral communication, 1998).

The lakebed sediment material used to cover the waste is taken from the floodplain of the Big Lost River on the INEEL site. Soil texture analysis (Bouyoucos, 1962) of lakebed sediment material found it to be silt loam in the soil textural triangle with an average of 21 percent sand, 57 percent silt, and 22 percent clay (U.S. Department of Agriculture, Soil Conservation Service, National Soil Survey Laboratory, Lincoln, Nebraska, written communication, 1987). The average organic matter content was determined to be 0.8 percent using the Walkley and Black procedure (Walkley and Black, 1934). The average bulk density of soil cores taken in 1987 was 1.46 g cm^{-3}, with a standard deviation of 0.10 g cm^{-3}, using the method described by Blake and Hartge (1986). The clay-sized fraction consisted largely of montmorillonite, a 2:1 clay. Clay mineralogy was determined through X-ray diffraction (Whittig and Allardice, 1986).

METHODS

During the summer of 1985, seven test plots 3.05 m x 10.7 m were installed. The plots were first excavated to 1.5 m, and then backfilled with the same lakebed sediment material that is used at the SDA. Steel plates 20 cm in depth were placed along the two 10.7 m side borders and the upper 3.05 m edge of the plots to a depth of 10 cm. The down slope end of each plot was delineated by a 3.05 m long collection trough which was connected to a runoff collection tank. The plots were then leveled to a uniform 6 percent slope. By arranging the plots in pairs, 3.05 m apart, the rainfall simulator used could rain on the paired plots simultaneously.

In October 1985, crested wheatgrass was transplanted onto plots 2, 3, and 5 and streambank wheatgrass was sown on plots 1, 4, and 6. Vegetation treatments were assigned randomly with the constraint that each pair of plots contained both vegetation types. Plot 7 was left bare to serve as a control plot and to represent the worst case situation of seeding failure. Crested wheatgrass was taken from the surrounding area and transplanted in an offset diagonal pattern (Goff *et al.*, 1992) (plant centers 43 cm apart and rows 43 cm apart) to mimic the distances the plants are usually spaced naturally in the surrounding area. Planting density was an average of 4.85 plants m^{-2} for crested wheatgrass. Streambank wheatgrass was planted in rows 15 cm apart perpendicular to the slope of the plot.

These two grass species are commonly used in revegetation at the SDA. Crested wheatgrass is a bunchgrass and streambank wheatgrass is a rhizomatous grass; bunchgrasses and rhizomatous grasses exhibit distinctively different rooting characteristics. The streambank wheatgrass rhizomes grow radially and form a sod-like grass, whereas crested wheatgrass grows in clumps (caespitose).

To simulate rainfall, a trailer-mounted rotating-boom rainfall simulator similar to the design described by Swanson (1965) was used. The rotating-boom simulator produces rainfall at approximately 80 percent of the energy of natural rainfall (Simanton *et al.*, 1986). The rainfall simulations during June and September 1987 included three runs on each pair of plots at a rainfall intensity of 60 mm hr^{-1}. The initial run was for 60 min on a dry soil surface followed by a 30-min run 24 hours later on a wet soil surface and finally a 30-min run 30 minutes later on a very wet soil surface. Rainfall simulations during August 1989 and September 1990 consisted only of a 45-min run on a dry soil surface and a 45-min run on a dry soil surface followed by a 45-min run 48 hours later on a wet soil surface, respectively, at a rainfall intensity of 60 mm hr^{-1}.

Canopy and soil surface covers of each plot were measured before rainfall simulations using a 3.05 m pin-point meter (Simanton and Renard, 1982) with holes spaced 6 cm apart. The pin-point meter was placed perpendicular to the plot slope at five locations at 2 m increments along the plot borders. At each of the five locations, measurements of surface and canopy cover were made by dropping a pin through each of the 48 holes. Before the 1987 rainfall simulations (June and September), vegetative crown cover (canopy cover) on each plot was measured as a first hit. Bare soil, litter, and vegetative basal cover under the vegetative crown cover (canopy cover) was measured as soil surface cover (second hit) on each plot. Canopy and soil surface cover data are not additive, but bare soil, litter, and vegetative basal cover added together equal 100 percent for the soil surface cover of each plot. Vegetative data from August 1989 and June 1990 were collected using the same pin-point meter. However, the canopy and soil surface data are additive and equal 100 percent, which means that only the first hit (whether it was leaf, stem, basal, litter, or bare soil) was recorded, not both canopy and soil surface cover separately as in 1987.

In September 1987 (after rainfall simulations), above ground biomass on all plots was estimated by selective clipping. Samples from five randomly selected plants on the crested wheatgrass plots and four randomly selected 30 cm x 60 cm areas on the streambank wheatgrass plots were clipped, oven dried at 65°C for 24 hours, and weighed. The number of samples collected differed for the two grass species due to their dissimilar growth forms. Also, the number of samples clipped was kept low to keep destructive sampling to a minimum.

Before each rainfall simulation (dry, wet, and very wet soil moisture conditions) in June and September 1987, three soil samples were taken to a depth between 0 to 50 and 0 to 200 mm, depending on depth the soil core could penetrate, from each plot using a 25 mm diameter soil core for determination of gravimetric soil moisture using the method described by Gardner (1986). Before rainfall simulations in August 1989 and 1990, six soil samples were taken from a depth of 10 to 50 mm just outside the plots.

Average rainfall amounts for each simulation were measured using wedge shaped rain gauges. Water runoff measurements and sediment concentration sampling started on the first full minute after runoff began and continued at one minute intervals until the runoff rate reached equilibrium, then at two minute intervals until rainfall stopped. Then runoff rate measuring frequency and sampling frequency returned to one minute intervals until runoff stopped. One liter plastic bottles were used to sample the runoff water for sediment concentration. Runoff rate measurements were calculated by determining the volume of water in the one liter plastic bottles and dividing it by the time it took runoff to fill the bottle. When the runoff rate exceeded 1 L per five seconds a 6 L graduated cylinder was used to determine the runoff rate, while the one liter plastic bottles were used to sample the runoff water for sediment concentrations. The one liter runoff samples were allowed to settle, then the supernatant was suctioned off and the samples were filtered to catch all the sediment. The sediment and filter paper were oven dried at 105°C for 24 hours, and then weighed. After each run (dry, wet, and very wet), the lip of the collection trough and the trough were cleaned of all sediment. This sediment was then oven dried at 105°C for 24 hours and added to the total sediment loss of that rainfall simulation.

Gross runoff and soil loss data were collected from natural precipitation events during monthly site visits between January and August of 1987. Bulk measurements of runoff were made by measuring the depth of runoff in plot collection tanks and converting it to a volume. Cumulative soil loss measurements were made by collecting sediment from the runoff collection tank, lip of the collection trough, and trough. The sediment was oven dried at 105°C for 24 hours and weighed.

RESULTS

Vegetation

Plot vegetation cover data collected prior to rainfall simulations in June and September 1987, August 1989, and June 1990 are presented in Table 1. Comparisons between plot vegetative data collected in June and September 1987 versus data collected in August 1989 and June 1990 are complicated by the different sampling techniques (see METHODS section). Average canopy cover data were fairly similar between the two grass species in and between June and September 1987. Average plant basal cover data were fairly similar for the two grasses in 1987, but decreased 3 percent for crested wheatgrass and increased 2 percent for streambank wheatgrass (which is within the range of sampling error). The greatest change between June and September 1987 was the 9 and 20 percent decrease in bare soil for crested wheatgrass and streambank wheatgrass plots, respectively. Differences in bare soil between crested wheatgrass and streambank wheatgrass in June and September 1987 also changed, as crested wheatgrass plots were 10 and 2 percent lower than streambank wheatgrass plots, respectively. The changes in bare soil percent are most likely due to the 17 and 10 percent increase in surface litter cover for streambank wheatgrass and crested wheatgrass, respectively, between June and September 1987. In September 1987, after rainfall simulations, measurements of above ground biomass (phytomass) found an average of 136 and 183 g m^{-2} for streambank wheatgrass and crested wheatgrass plots, respectively.

General comparisons were made between data collected late in two different growing seasons (September 1987 and August 1989). Using the assumption that canopy cover was equal to the total of leaf, stem, and plant basal; average canopy covers would be crested wheatgrass 48 and 45 percent, and

TABLE 1. Plot Canopy and Surface Cover Data for June and September 1987, August 1989, and June 1990 (% = percent; g m^{-2} = grams per meter squared; CWG = crested wheatgrass; SWG = streambank wheatgrass; nm = not measured).

CANOPY AND SURFACE COVER DATA[1]

Treatment	June 1987 Canopy Cover (%)	June 1987 Surface Plant Basal Cover (%)	June 1987 Surface Litter Cover (%)	June 1987 Bare Soil Cover (%)	September 1987 Canopy Cover (%)	September 1987 Surface Plant Basal Cover (%)	September 1987 Surface Litter Cover (%)	September 1987 Bare Soil Cover (%)	September 1987 Above Ground Biomass (g m^{-2})
CWG (Plot 2)	52.9	11.3	31.1	57.6	45.4	7.9	42.9	49.2	204.1
CWG (Plot 3)	38.1	11.3	33.9	54.8	51.3	9.2	40.8	50.0	117.7
CWG (Plot 5)	49.4	13.0	32.6	54.4	46.3	10.8	44.2	45.0	227.5
Mean	46.8	11.9	32.5	55.6	47.7	9.3	42.6	48.1	183.1
Standard Error	3.6	.5	.7	.8	1.5	.7	.8	1.3	27.3
SWG (Plot 1)	49.6	7.5	31.3	61.2	46.3	6.3	46.2	47.5	124.4
SWG (Plot 4)	49.0	6.7	33.1	60.2	50.0	10.0	44.6	45.4	155.5
SWG (Plot 6)	30.6	2.1	22.3	75.6	42.1	6.2	47.1	46.7	126.0
Mean	43.1	5.4	28.9	65.7	46.1	7.5	46.0	46.5	135.3
Standard Error	5.1	1.4	2.7	4.1	1.9	1.0	.6	.5	8.3
Bare (Plot 7)	2.1	.8	.0	99.2	22.9	.4	9.6	90.0	nm

SURFACE COVER DATA[2]

Treatment	August 1989 Leaf Cover (%)	August 1989 Stem Cover (%)	August 1989 Plant Basal Cover (%)	August 1989 Litter Cover (%)	August 1989 Bare Soil Cover (%)	June 1990 Leaf Cover (%)	June 1990 Stem Cover (%)	June 1990 Plant Basal Cover (%)	June 1990 Litter Cover (%)	June 1990 Bare Soil Cover (%)
CWG (Plot 2)	25.4	7.5	10.4	15.4	41.3	5.4	1.6	2.5	54.5	36.0
CWG (Plot 3)	23.8	6.3	10.4	12.9	46.6	8.8	2.9	3.8	56.3	28.2
CWG (Plot 5)	30.4	9.2	11.3	15.4	33.7	5.4	5.0	5.0	52.1	30.5
Mean	26.5	7.7	10.7	14.6	40.5	6.5	3.2	3.8	54.3	31.6
Standard Error	1.6	.7	.2	.7	3.1	.9	.8	.6	1.0	1.9
SWG (Plot 1)	25.0	1.4	13.8	13.8	46.0	5.0	1.6	3.3	55.0	35.1
SWG (Plot 4)	20.8	1.7	10.0	20.0	41.3	18.3	.0	5.8	45.4	28.2
SWG (Plot 6)	17.0	.8	11.7	19.6	50.9	8.3	.0	4.2	51.3	31.7
Mean	20.9	1.3	11.8	17.8	46.1	10.5	.5	4.4	50.6	31.7
Standard Error	1.9	.2	.9	1.6	2.3	3.3	.4	.6	2.3	1.6
Bare (Plot 7)	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm

[1] June and September 1987 canopy and surface cover data are not additive (are greater than 100 percent), but the surface cover data (plant basal, litter, and bare soil cover) is additive (equal to 100 percent).

[2] 1989 and 1990 surface cover data is additive (equal to 100 percent), but note CWG (Plot 3) June 1990 total was 98.0 percent; SWG (Plot 4) August 1989 was 93.8 percent and June 1990 was 97.7 percent, and SWG (Plot 6) June 1990 was 95.5 percent.

streambank wheatgrass 46 and 34 percent for September 1987 and August 1989, respectively. Plant basal cover was crested wheatgrass 9 and 11 percent, and streambank wheatgrass 8 and 12 percent for September 1987 and August 1989, respectively. Using the assumption that there was surface litter under the leaf and stem cover data, surface litter cover would be crested wheatgrass 43 and 49 percent, and streambank wheatgrass 46 and 40 percent for September 1987 and August 1989, respectively. Bare soil was crested wheatgrass 48 and 40 percent, and streambank wheatgrass 46 and 46 percent for September 1987 and August 1989, respectively. These approximated comparisons between the two growing seasons produced fairly similar vegetative characteristics between the two grass species over the two-year period given the differences in sampling techniques.

June 1990 vegetative data had much lower leaf and plant basal cover percents than in August 1989, but litter cover data increased substantially. Bare soil cover actual decreased 9 and 14 percent for crested wheatgrass and streambank wheatgrass, respectively, between 1989 and 1990 data. Bare soil cover was only 6 and 0 percent lower on crested wheatgrass plots than streambank wheatgrass plots in 1989 and 1990, respectively.

Soil Characteristics

Soil Moisture. Gravimetric soil moisture contents prior to the dry, wet, and very wet rainfall simulations values (Table 2) were slightly higher in June 1987 than September 1987. Average soil moisture contents by species for the three antecedent soil moisture conditions in 1987 were within 1 to 2 percent, with the crested wheatgrass plots always slightly greater than the streambank wheatgrass plots.

Average gravimetric soil moisture contents were within 1 percent for crested wheatgrass and streambank wheatgrass in August 1989 and September 1990. Soil moisture contents for dry runs in August 1989 were greater than in September 1990.

Soil Cracking. The volume and number of cracks (macropores) on each crested wheatgrass and streambank wheatgrass plot were recorded in September 1986 and June 1987. The crack volumes were estimated using length, width, and depth measurements. In 1986 the streambank wheatgrass plots had an average of 11 cracks per plot with an average volume of 261 cm^3 per crack and crested wheatgrass plots had an average of 26 cracks per plot with an average volume of 677 cm^3 per crack. One possible explanation for these differences in crack numbers and volume was the application of about 125 mm of water on the streambank wheatgrass plots during the summer of 1986 to help plant survival, prior to macropore assessment. This additional water could have sealed some of the cracks. In June 1987 streambank wheatgrass plots had only an average of one crack per plot. Crested wheatgrass plots had an average of 15 cracks and an average volume of 564 cm^3 per crack. During the winter of 1986-1987 some natural healing of the

TABLE 2. Gravimetric Soil Moisture Prior to Rainfall Simulations During June and September 1987, August 1989, and September 1990 (% = percent; CWG = crested wheatgrass; SWG = streambank wheatgrass; nm = not measured).

	GRAVIMETRIC SOIL MOISTURE (%)								
	June 1987[1]			September 1987[1]			August 1989[2]	September 1990[2]	
Treatment	Dry	Wet	Very Wet	Dry	Wet	Very Wet	Dry	Dry	Wet[3]
CWG (Plot 2)	7.7	21.4	27.0	6.5	20.1	25.5	3.7	5.3	16.0
CWG (Plot 3)	10.4	24.1	30.0	8.3	16.1	27.6	6.4	4.3	12.0
CWG (Plot 5)	8.1	19.6	31.7	6.8	19.0	26.2	6.8	3.6	11.0
Mean	8.7	21.7	29.6	7.2	18.4	26.4	5.6	4.4	13.0
Standard Error	.7	1.1	1.1	.5	1.0	.5	.8	.4	1.2
SWG (Plot 1)	7.6	17.7	25.7	5.9	19.9	22.8	7.4	5.0	13.7
SWG (Plot 4)	8.1	18.6	28.2	6.9	13.2	28.2	4.3	4.6	12.0
SWG (Plot 6)	7.4	17.2	29.2	6.6	17.5	24.8	6.1	3.2	11.0
Mean	7.7	17.8	27.7	6.5	16.9	25.3	5.9	4.3	12.2
Standard Error	.2	.3	.8	.2	1.6	1.3	.7	.4	.6
Bare (Plot 7)	14.4	20.7	25.6	9.5	20.1	25.5	nm	nm	nm

[1] 1987 data collected between 0-50 mm and 0-200 mm depth depending on penetration of soil probe.

[2] 1989 and 1990 data collected from 10-50 mm depth.

[3] September 1990 wet rainfall simulations were done 48 hours after the dry run, not 24 hours after dry run as was done for 1987 data.

surficial macropores occurred. In June 1987, before rainfall simulations, all visible macropores were filled with lakebed sediment to insure that comparable data would be collected. In August 1989 and 1990 prior to rainfall simulations, a greater percentage of surface cracks on crested wheatgrass than streambank wheatgrass plots were observed. Also, greater surface crack widths were observed on crested wheatgrass plots in September 1989.

Soil Crusting. Average crust strengths were determined to be 1.41 and 0.69 kg mm^{-2} for dry soils and 1.05 and 0.69 kg mm^{-2} for wet soils on streambank wheatgrass and crested wheatgrass plots, respectively, using a soil penetrometer during September 1990.

Runoff

Total runoff (mm) data are presented in Table 3 for the three cover types, three antecedent soil moisture conditions (where applicable), and June 1987, September 1987, August 1989, and September 1990.

TABLE 3. Total Runoff and Soil Loss for Rainfall Simulations During June and September 1987, August 1989, and September 1990 (mm = millimeters; Mg ha^{-1} = megagrams per hectare; CWG = crested wheatgrass; SWG = streambank wheatgrass; nm = not measured).

Treatment	June 1987				September 1987				August 1989	September 1990			Total of All Rainfall Simulations
	Dry	Wet	Very Wet	Total	Dry	Wet	Very Wet	Total	Dry	Dry	Wet[1]	Total	
TOTAL RUNOFF (mm)													
CWG (Plot 2)	12.0	12.1	16.0		21.2	17.5	19.2		9.5	18.5	23.6		
CWG (Plot 3)	19.7	13.9	16.3		11.3	13.6	17.1		6.8	3.7	17.1		
CWG (Plot 5)	11.7	10.3	14.3		23.8	15.5	17.6		11.4	12.2	18.7		
Mean	14.5	12.1	15.5	14.0	18.8	15.5	17.9	17.4	9.2	11.5	19.8	15.6	15.0
Standard Error	2.1	.8	.5	.9	3.1	.9	.5	1.2	1.1	3.5	1.6	2.6	.9
SWG (Plot 1)	28.0	18.7	21.9		33.3	22.1	22.5		18.4	22.4	27.2		
SWG (Plot 4)	30.5	17.2	19.8		13.9	16.3	19.5		13.9	9.3	25.8		
SWG (Plot 6)	28.4	17.6	21.6		37.0	19.2	21.4		14.9	19.3	29.4		
Mean	28.9	17.8	21.1	22.6	28.1	19.2	21.1	22.8	15.7	17.0	27.5	22.2	21.8
Standard Error	.6	.4	.5	1.6	5.8	1.4	.7	2.4	1.1	3.2	.9	2.7	1.2
Bare (Plot 7)	35.5	22.2	22.9		27.5	18.6	22.5		nm	nm	nm		
Mean				26.9				22.9					24.9
Standard Error				3.5				2.1					2.2
TOTAL SOIL LOSS (Mg ha^{-1})													
CWG (Plot 2)	0.81	0.67	1.05		1.56	1.66	1.91		nm	0.64	1.14		
CWG (Plot 3)	.63	.47	.87		.59	.66	.64		nm	.10	.38		
CWG (Plot 5)	.28	.32	.43		.69	.42	.52		nm	.29	.41		
Mean	.57	.49	.78	0.61	.95	.91	1.02	0.96		.34	.64	0.49	0.71
Standard Error	.13	.08	.15	.08	.25	.31	.36	.18		.13	.20	.13	.09
SWG (Plot 1)	3.69	2.57	3.17		2.67	1.92	1.93		nm	.66	.78		
SWG (Plot 4)	1.90	1.50	1.97		1.29	1.39	1.57		nm	.42	.94		
SWG (Plot 6)	1.05	.83	1.02		1.20	.69	.83		nm	.48	.60		
Mean	2.21	1.63	2.05	1.97	1.72	1.33	1.44	1.50		.52	.77	.65	1.46
Standard Error	.64	.41	.51	.31	.39	.29	.26	.19		.06	.08	.07	.17
Bare (Plot 7)	7.15	6.94	6.88		4.19	3.74	3.88		nm	nm	nm		
Mean				6.99				3.94					5.46
Standard Error				.07				.11					.63

[1] September 1990 wet rainfall simulations were done 48 hours after the dry run, not 24 hours after dry run as was done for 1987 data.

TABLE 4. Total Runoff and Soil Loss Per Hour for Rainfall Simulations During June and September 1987, August 1989, and September 1990 ($mm\ hr^{-1}$ = millimeters per hour; $(Mg\ ha^{-1})\ hr^{-1}$ = megagrams per hectare per hour; CWG = crested wheatgrass; SWG = streambank wheatgrass; nm = not measured).

Treatment	June 1987				September 1987				August 1989	September 1990			Total of All Rainfall Simulations
	Dry	Wet	Very Wet	Total	Dry	Wet	Very Wet	Total	Dry	Dry	Wet[1]	Total	
TOTAL RUNOFF ($mm\ hr^{-1}$)													
CWG (Plot 2)	16.2	24.2	32.0		21.2	35.0	38.4		12.7	24.7	31.5		
CWG (Plot 3)	19.7	27.9	32.6		21.9	27.2	34.2		9.1	7.7	22.8		
CWG (Plot 5)	11.7	20.6	28.6		23.8	31.0	35.2		15.2	16.3	24.9		
Mean	15.9	24.2	31.1	23.7	22.3	31.1	35.9	29.8	12.3	16.2	26.4	21.9	23.9
Standard Error	1.9	1.7	1.0	2.3	.6	1.8	1.0	2.0	1.5	4.0	2.1	3.1	1.6
SWG (Plot 1)	37.8	37.4	43.8		33.3	44.2	45.0		24.5	29.9	32.3		
SWG (Plot 4)	30.5	34.4	39.6		26.9	32.6	39.0		18.5	20.7	34.4		
SWG (Plot 6)	28.4	35.2	43.2		37.0	38.4	42.8		19.9	25.7	39.2		
Mean	32.2	35.7	42.2	36.7	32.4	38.4	42.3	37.7	21.0	25.4	36.6	31.0	34.0
Standard Error	2.3	.7	1.1	1.6	2.4	2.7	1.4	1.9	1.5	2.2	1.1	2.6	1.4
Bare (Plot 7)	35.5	44.4	45.9		27.5	37.2	45.0		nm	nm	nm		
Mean				41.9				36.6					39.2
Standard Error				2.6				5.1					2.7
TOTAL SOIL LOSS ($(Mg\ ha^{-1})\ hr^{-1}$)													
CWG (Plot 2)	1.09	1.34	2.10		1.56	3.32	3.82		nm	0.85	1.52		
CWG (Plot 3)	.63	.94	1.74		1.14	1.32	1.28		nm	.21	.51		
CWG (Plot 5)	.28	.64	.86		.69	.84	1.04		nm	.39	.55		
Mean	.67	.97	1.57	1.07	1.13	1.83	2.05	1.67		.48	.86	0.67	1.19
Standard Error	.19	.17	.30	.18	.21	.62	.73	.35		.16	.27	.17	.17
SWG (Plot 1)	4.98	5.14	6.34		2.67	3.84	3.86		nm	.88	1.04		
SWG (Plot 4)	1.90	3.00	3.94		2.50	2.78	3.14		nm	.93	1.25		
SWG (Plot 6)	1.05	1.66	2.04		1.20	1.38	1.66		nm	.64	.80		
Mean	2.64	3.27	4.11	3.34	2.12	2.67	2.89	2.56		.82	1.03	.92	2.44
Standard Error	.97	.83	1.02	.58	.38	.58	.53	.31		.07	.11	.08	.31
Bare (Plot 7)	7.15	13.88	13.76		4.19	7.48	7.76		nm	nm	nm		
Mean				11.6				6.48					9.04
Standard Error				1.82				.94					1.46

[1] September 1990 wet rainfall simulations were done 48 hours after the dry run, not 24 hours after dry run as was done for 1987 data.

Total runoff (mm) data were divided by the time length of the rainfall simulation (hr) (Table 4) as a standardizing procedure to more accurately compare runoff differences among treatments.

Streambank wheatgrass had greater average total runoff ($mm\ hr^{-1}$) than crested wheatgrass on dry, wet, and very wet soil in June 1987 (2.03, 1.48, and 1.36 times greater), but both grass species had more similar average total runoff in September 1987 (streambank wheatgrass was only 1.45, 1.23, and 1.18 times greater). Total runoff from streambank wheatgrass was 1.71, 1.57, and 1.39 times greater than crested wheatgrass in August 1989 (dry soil) and in August 1990 (dry and wet soil), respectively. Streambank wheatgrass had greater average total runoff (1.55, 1.27, 1.70, and 1.42 times greater) than crested wheatgrass during June and September 1987, August 1989, and September 1990, respectively. The bare soil plot had greater total runoff in June 1987 than the other vegetated plots, but in September 1987 it had similar total runoff to the two grasses. Average total runoff for all simulations and years was 1.42 times greater on streambank wheatgrass plots than on crested wheatgrass plots.

Soil Loss

Total soil loss (Mg ha^{-1}) data are presented in Table 3 for the three cover types, three antecedent soil moisture conditions (where applicable), and June 1987, September 1987, and September 1990. Soil loss data were collected during September 1990, but not during August 1989. Soil loss data (Mg ha^{-1}) were divided by the time length of the rainfall simulation (hr) (Table 4) as a standardizing procedure to more accurately compare soil loss differences among treatments.

Average total soil loss [(Mg ha^{-1}) hr^{-1}] in June 1987 for streambank wheatgrass was 3.94, 3.37, and 2.62 times greater than crested wheatgrass for the dry, wet, and very wet antecedent soil moisture conditions, respectively. In September 1987, average total soil loss for streambank wheatgrass was 1.88, 1.46, and 1.41 times greater than crested wheatgrass for the three antecedent soil moisture conditions (dry, wet, very wet), respectively.

Total soil loss in September 1990 was similar to September 1987 results, as average total soil loss on streambank wheatgrass plots was 1.71 and 1.20 times greater than on crested wheatgrass plots for dry and wet antecedent soil moisture conditions, respectively. Average total soil loss was 3.12, 1.53, and 1.37 times greater on streambank wheatgrass plots than on crested wheatgrass plots during June 1987, September 1987, and September 1990, respectively. Average total soil loss for all simulations and years was 2.05 times greater on streambank wheatgrass plots than crested wheatgrass plots. The bare soil plot had total soil loss about 2 to 4 and 9 to 14 times greater than streambank wheatgrass and crested wheatgrass, respectively, for the three soil moisture conditions in June 1987. In September 1987 though, total soil loss on the bare soil plot was about 2 to 3 and 3 to 4 times greater than streambank wheatgrass and crested wheatgrass, respectively, for the three soil moisture conditions.

Runoff and Soil Loss from Natural Events

Total runoff and soil loss responses were highly variable for individual plots from natural precipitation events between January 17, 1987 and August 20, 1987 (Table 5). Average total runoff and total soil loss was 1.25 and 2.05 times greater, respectively, on streambank wheatgrass plots as crested wheatgrass plots during this time period. The bare soil plot produced much greater soil loss, but not runoff, as compared to the two grass species.

TABLE 5. Total Runoff and Soil Loss from Natural Precipitation Events Between January 17 and August 20, 1987 (total precipitation for the period was 162.0 mm) (mm = millimeters; Mg ha^{-1} = megagrams per hectare; CWG = crested wheatgrass; SWG = streambank wheatgrass).

Treatment	Total Runoff (mm)	Total Soil Loss (Mg ha^{-1})
CWG (Plot 2)	16.3	1.22
CWG (Plot 3)	52.1	2.71
CWG (Plot 5)	9.5	.55
Mean	26.0	1.49
Standard Error	7.6	.37
SWG (Plot 1)	44.6	4.45
SWG (Plot 4)	22.4	2.48
SWG (Plot 6)	20.9	2.21
Mean	32.6	3.05
Standard Error	3.7	.41
Bare (Plot 7)	24.8	7.87

DISCUSSION

Vegetation and Soil Characteristics Relation to Runoff and Soil Loss

The greater total runoff and soil loss from streambank wheatgrass plots in June 1987 than during the other simulations could be because streambank wheatgrass plots, which were seeded in October 1985, may not have reached their mature state by the June 1987 rainfall simulations. Streambank wheatgrass may not have reached maturity by June 1987 because we observed an increase in canopy and surface cover data (Table 1) between June and September 1987 (mid to late growing season). Anderson *et al.* (1987) reported that it was not until the end of the second growing season that streambank wheatgrass plots reached maturity and where able to withdraw water from an entire 2.2 m soil profile. Thus, total runoff and soil loss results from streambank wheatgrass plots after June 1987 might be a better indication of the plots response to runoff and erosion.

Differences between ratios of total runoff from crested wheatgrass and streambank wheatgrass were varied, but fairly similar over the four rainfall simulation series, with streambank wheatgrass always greater. Differences between ratios of total soil loss from crested wheatgrass and streambank wheatgrass plots were similar during September 1987 and September 1990, with streambank wheatgrass always greater. The greater ratio of total soil loss between the two grasses in June 1987, than in September 1987 and 1990, could be the result of the greater percentage of bare soil on the streambank wheatgrass plots, which could be the result of the streambank wheatgrass not having reached its maturity.

A major reason for the decrease in soil loss and runoff on the streambank wheatgrass plots between June and September 1987 was the decrease in bare soil cover (Table 1). Vegetative cover greatly reduces interrill erosion during rainfall simulations in a semiarid environment (Wilcox and Wood, 1989). The small increases in the canopy and plant basal cover data on the streambank wheatgrass plots were probably not as important as the large increase in surface litter cover between June and September 1987, which accounted for most of the reduction in bare soil. The reasons for the increased surface litter on the streambank wheatgrass plots is because, as the streambank wheatgrass planted in rows perpendicular to the slope of the plots matured, the rows could act as a barrier to wind blown plant litter, capturing it and creating more plot surface roughness. The streambank wheatgrass rows could form a barrier and retard the movement of sediment by overland runoff. This theory could only be supported by the changes in plot canopy and surface cover data between June and September 1987. Reasons for the decrease in runoff and erosion from the bare soil plot between June and September 1987 may be due to the decrease in the percentage of bare soil from 99 to 90 percent (Table 1).

Differences in runoff rates between the two grasses were also due to phytomass and root biomass characteristics of the two grasses. Crested wheatgrass (bunchgrass) plots had a greater phytomass (above ground biomass) than streambank wheatgrass (sod-forming grass) plots (Table 1). Reynolds (1990) reported that crested wheatgrass has a greater root biomass than streambank wheatgrass. Wood (1988) and Blackburn et al. (1980) also found bunchgrasses to have more phytomass and root mass than sod-forming grass. Wilcox *et al.* (1988) reported that phytomass (above ground biomass) was positively correlated to infiltration on vegetated semiarid rangelands. A supporting fact may be that soil moisture is always slightly greater on crested wheatgrass plots suggesting more infiltration. The greater phytomass and root biomass of crested wheatgrass would result in more canopy interception of precipitation, stem flow, and percolation of precipitation into the root zone on the crested wheatgrass plots. This would result in the crested wheatgrass plots having lower runoff rates (greater infiltration), which is consistent with our findings.

The greater runoff and soil loss encountered with the increasing antecedent soil moisture (Tables 3 and 4) is directly related to declines in infiltration rates and increases in runoff as the soil profile becomes more saturated (Table 2). This same pattern has been shown in other studies (Nyhan *et al.*, 1984; Nyhan and Lane, 1986a, 1986b; Simanton *et al.*, 1986; Goff *et al.*, 1993). Comparison of dry run soil moisture contents from September found 1987 to be 2 to 3 percent greater than 1990. Wet run soil moisture contents in September 1990 are lower than other wet runs (1987), because plots only received 45 minutes, not 60 minutes, of rainfall during dry runs and plots were allowed to dry for 48 hours not 24 hours between the dry and wet runs.

Very wet runs in June and September 1987 most likely are good approximations of natural rain on snow or snow melt runoff events. This is because when the gravimetric soil moisture prior to the very wet runs is converted to volumetric soil moisture (multiply gravimetric soil moisture times soil bulk density) it is very close to the estimate of pore volume for the lakebed sediment plots. For example, in 1987 the pore volume of the lakebed sediment plots was 44.9 percent (100 minus bulk density divided by particle density times 100) and the average volumetric soil moisture from 0 to 0.2 m depth prior to very wet runs were 43.2 and 40.4 percent during June and 38.3 and 36.9 percent during September for crested wheatgrass and streambank wheatgrass, respectively. In late spring (right after the spring thaw) volumetric soil moisture of lakebed sediment plots were between 25 and 35 percent (near saturation) from a depth of 0 to 0.5 m at INEEL (Anderson *et al.*, 1987, 1993).

A possible explanation for the increased total runoff and soil loss on the crested wheatgrass plots between June and September 1987 could have been the development of surficial macropores on the soil surface of the plots during 1986 and 1987. The surficial macropores on the crested wheatgrass plots were caused by cracking (which occurs during wetting and drying cycles of the montmorillonite clay) and subsidence of the lakebed sediment material. Surficial macropore (surface cavity collapse) development acting as a preferential flow path was described in another study of landfill covers in Sheffield, Illinois (Gray, 1990, 1991). Although all cracks observed in June 1987 were filled prior to the rainfall simulations, the newly filled cracks may still have been able to act as preferential flow pathways. This could have been due to a lower bulk density of the filled lakebed sediment in the cracks, discontinuities along crack walls, and isolated voids in portions of the cracks. The comparatively higher runoff and erosion experienced in the streambank wheatgrass plots (compared to crested wheatgrass plots) during the June 1987 simulations may have reflected the larger number of preexisting macropores in the crested wheatgrass plots. Prior to the September 1987 rainfall simulations, no new cracks were visible on the plots as the June 1987 simulations and summer rainstorms probably sealed all the macropores.

Another possible reason for the increased total runoff and soil loss from crested wheatgrass plots is that increases in runoff and erosion from spring to fall, due to climatic effects on the soil surface, in the western United States have been documented in previous studies Schumm and Lusby (1963), Simanton and Renard (1982), and Simanton *et al.* (1986). They partially attributed lower runoff and erosion rates in the spring to winter freeze-thaw processes in the soil which loosen the surface and consequently allow more infiltration. During the summer, however, the soil surface is compacted and sealed again from summer thunderstorms, which cause higher fall runoff and erosion rates.

Soil crust measurements using a penetrometer in 1990 found streambank wheatgrass plots to have a stronger soil crust, which would result in greater runoff on the streambank wheatgrass plots than the crested wheatgrass. Reasons for the lower crust strength on crested wheatgrass plots may be related to the greater root biomass for the crested wheatgrass plants (Reynolds, 1990) which loosens (breaks) up the soil.

Crested wheatgrass plots had a greater hydraulic roughness than the streambank wheatgrass plots (Goff *et al.*, 1992), which would lead to greater infiltration on the crested wheatgrass plots. The difference in hydraulic roughness between the grasses was suggested to be a combination of vegetative characteristics as well as the initial disturbance during planting (one grass transplanted one grass seeded) (Goff *et al.*, 1992).

Although ratios for total runoff and soil loss remained fairly similar during the three years, the individual values appear lower for both grasses in 1989 and 1990 than in 1987 (Table 4). Even though

and other vegetative covers had a decrease in bulk density from 1.4 to 1.28 g cm^{-3} during a four-year period (Anderson *et al.*, 1993).

Runoff and soil loss from natural rainfall and snowmelt events from January to August 1987 for both grass species were similar to results (streambank wheatgrass greater runoff and soil loss than crested wheatgrass) of the 1987 rainfall simulations. Lower total runoff on the bare soil plot could be the result of unmeasured runoff from overflow of the runoff collection tank between visits and/or evaporation of runoff in the collection tank. This could have occurred on the grassed plots, but one might expect greater runoff from the bare plot which could lead to more potential runoff losses between visits. The variability in total runoff between plot results could be to due to some evaporation of runoff in collection tanks between measurements and possible runoff overflow from collection tanks during events. The ratios of total runoff and soil loss between grasses for natural precipitation events corresponds well to ratios of average runoff and soil loss between grasses for the two 1987 rainfall simulations combined.

Comparison with Native Soils at INEEL

During 1987, rainfall simulations were done on nine native soil (sandy loam) plots (Goff *et al.*, 1993) during the same time periods as the seven simulated waste burial covers (lakebed sediment-silt loam) plots at INEEL. Three plots were covered by a natural sagebrush steppe vegetation, three plots were clipped of all standing vegetation, and three plots were clipped and all litter was removed to simulate bare plots. Note that the native soil plots had additional rainfall and supplemental overland flow applied during the very wet runs (Goff *et al.*, 1993) so compara-

TABLE 6. Average Total Runoff and Soil Loss and Cover Data from Rainfall Simulations on Simulated Waste Burial Covers (lakebed sediment) at INEEL in 1987, on Native Soil Plots at INEEL in 1987, and Simulated Trench Covers at LANL in 1982 and 1983 (mm = millimeters; Mg ha^{-1} = megagrams per hectare; CWG = crested wheatgrass; SWG = streambank wheatgrass; % = percent).

Treatment (number of replications)	Cover Data				Average Total Runoff (mm)			Average Total Soil Loss (Mg ha^{-1})		
					Dry	Wet	Very Wet	Dry	Wet	Very Wet
SIMULATED WASTE BURIAL COVERS (LAKEBED SEDIMENT-SILT LOAM) AT INEEL 1987										
CWG (n=6)	See Table 1				16.6	13.8	16.8	0.76	0.70	0.90
SWG (n=6)					28.5	18.5	21.1	1.98	1.49	1.14
Bare (n=2)					31.5	20.4	22.7	5.70	5.37	5.41
NATIVE SOIL (SANDY LOAM) PLOTS AT INEEL 1987 (Goff *et al.*, 1993)[1]										
Natural (n=6)	46% canopy	91% litter	9% crusted soil	9% total bare soil	0.3	0.4	6.6	0.02	0.02	0.04
Clipped (n=6)	2% canopy	80% litter	20% crusted soil	20% total bare soil	.7	1.0	9.9	.05	.05	.26
Bare (n=6)	<1% canopy	12% litter	66% crusted soil	88% total bare soil	12.5	9.6	30.1	1.88	1.68	7.68
SIMULATED WASTE BURIAL COVERS (SANDY LOAM) AT LANL 1982 (Nyhan and Lane, 1986a, 1986b)[2]										
Barley (n=4)	72% plant	28% bare soil			37.9	26.5	27.6	9.47	7.26	7.70
Bare (n=2)	100% bare soil				46.7	26.8	28.4	21.86	12.98	13.82
SIMULATED WASTE BURIAL COVERS (SANDY LOAM) AT LANL 1983 (Nyhan and Lane, 1986a, 1986b)[2]										
Gravel (n=2)	0% plant cover	73% gravel	27% bare soil		46.2	23.3	28.3	1.57	0.59	0.73
Gravel + western wheatgrass (n=2)	30% plant cover	22% gravel under plant cover	70% gravel		47.2	25.8	29.0	1.21	.48	.48
Bare (n=2)	100% bare soil				51.1	23.6	27.2	18.67	8.27	10.31

[1] Very wet runs on the native soil and cover at INEEL had an additional supplemental overland flow component and period of rainfall intensity at 120 mm hr^{-1}, which is described in Goff *et al.* (1993).

[2] LANL total soil loss data from 1982 and 1983 (Nyhan and Lane, 1986a, 1986b) was converted to Mg ha^{-1} using the average plot size of 0.0032 ha.

waste at INEEL), the bare native soil was undisturbed, had some litter cover (Table 6), and had dead plant roots to slow runoff and erosion. Goff *et al.* (1994) reported greater interrill erosion on bare disturbed native soil (sandy loam) plots than bare disturbed lakebed sediment (silt loam) plots during laboratory rainfall simulations.

Comparison with a Similar Study

Simulated waste burial cover total runoff and soil loss data collected at INEEL during 1987 were compared to similar data at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico (also in a semi-arid environment) during 1982-83 (Nyhan and Lane, 1986a, 1986b) (Table 6). Average total runoff data from four plot treatments on a sandy loam soil at LANL were greater than the three plot treatments on lakebed sediment (silt loam) at INEEL. Average total soil loss from the barley and bare soil (sandy loam) plots at LANL were greater than the three plot treatments on lakebed sediment at INEEL. Average total soil loss data from the gravel and gravel plus wheatgrass treatment at LANL was greater during the dry run and then similar during the wet and very wet runs to crested wheatgrass. Soil loss from streambank wheatgrass plots was always greater than the gravel and gravel plus wheatgrass plots. At LANL the effect of gravel was the most interesting as it decreased erosion substantially while only slightly increasing infiltration (Table 6). Simanton *et al.* (1986) reported that rock and gravel cover (erosion pavement) (particles >5 mm) have a greater effect on reducing erosion rates on rangeland than vegetative canopy.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

Total runoff and soil loss was lower on crested wheatgrass plots than streambank wheatgrass plots from rainfall simulations in 1987, 1989, and 1990 and natural precipitation events in 1987. The lower total runoff on crested wheatgrass plots, which resulted in more infiltration of precipitation, could be view as a draw back in revegetation of waste burial covers. But, water use (evapotranspiration) by crested wheatgrass and streambank wheatgrass can and most likely can, respectively, exceed the maximum annual precipitation (366 mm) at INEEL and both grasses can remove water to a depth of at least 2.2 m (Anderson *et al.*, 1993). Crested wheatgrass has several characteristics which may make it a better choice for landfill covers than streambank wheatgrass: (1) it establishes itself well on disturbed sites, (2) once established it is very resistant to invasion of other species, (3) it is very tolerant to drought, and (4) can tolerate mowing (Anderson *et al.*, 1993). Bare disturbed lakebed sediment (silt loam) has a lower interrill erosion rate than disturbed native soil (sandy loam) at INEEL (Goff *et al.*, 1994), and a 1.8 to 2.0 m lakebed sediment waste burial cover could store the maximum precipitation (277) when evapotransporation does not exceed precipitation at INEEL (Laundre, 1990; Anderson *et al.*, 1993). Thus, crested wheatgrass and a lakebed sediment appear to be the better choice as a vegetative cover and soil cover (at least 2 m thick) for SLB waste burial covers at INEEL than streambank wheatgrass and native soil. If there are further concerns for reducing erosion, the addition of a rock and gravel cover (Nyhan and Lane, 1986a, 1986b) between crested wheatgrass plants or a gravel admixture in the upper most soil layer (Waugh *et al.*, 1994) may be desirable. Some elements of this suggested waste burial cover at INEEL could potentially be used in waste burial covers at other SLBs (landfills) located in semiarid environments through out the western United States.

Additional runoff and erosion data from natural events would be helpful, but not essential because rainfall simulations in 1987 on very wet antecedent soil moisture conditions most likely produced extreme events that would equal or exceed any rainfall, snowmelt, or rain on snow events on lakebed sediment when they are saturated at INEEL. More emphasis, however, is needed on surficial macropore (cracking) development on lakebed sediment covers since they could provide water a direct path to the waste zone and lead to leaching of radioactive pollutants into groundwater. In actual low-level radioactive waste sites, soil may subside over time because of voids around containers of wastes and create preferential flow paths (Gray, 1990, 1991). Additional caution should be taken to ensure that overland flow does not concentrate during runoff events at the SLB at INEEL, thus leading to rill and (or) gully erosion which might lead to exposure of waste material.

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