Rainfall Simulator Studies of Earth Covers Used in Shallow Land Burial at Los Alamos, New Mexico

J.W. Nyhan and L.J. Lane

Key words: erosion, experimental plots, infiltration, waste management

Abstract

Ten 3.05 by 10.7 m experimental plots were established and subjected to simulated rainfall in a study of erosion of trench caps similar to those used for disposal of low-level radioactive wastes at Los Alamos, NM. Treatments included natural, tilled, bare soil, gravel mulch, vegetated, and vegetated plus gravel mulch plots. Measured soil loss data were used to estimate soil erodibility and cover-management factors for the Universal Soil Loss Equation (USLE).

Introduction

A conservative estimate (U.S. Department of Energy 1982) of the annual volume of low-level radioactive wastes produced in the United States is 16 million cubic meters by the year 2020. Disposal of this amount of waste material is a major concern, because new burial sites will be required. These new burial sites will be selected in many different locations with widely varying environmental conditions.

Currently, the most common method of disposing of low-level wastes is shallow land burial (SLB). Trenches are excavated, filled with wastes, and then closed. Management practices range from simple backfilling of the trench to cover the buried waste, to installation of multilayered trench caps and revegetation of the sites. When the burial site receives its final cover, it is subject to natural processes such as erosion, which can modify the configuration of the surface cover and threaten the integrity of the trench cap.

The purpose of our research was to study erosion rates and processes affecting the integrity of earth covers used in shallow land burial at Los Alamos, New Mexico. We used a rainfall simulator (see Swanson 1965 and Simanton and Renard 1982 for descriptions) to study runoff and erosion on simulated trench caps designed to closely match actual trench caps used for shallow land burial at Los Alamos (see Warren 1980 for descriptions).

Methods

Erosion plots (3.05 by 10.7 m) were subjected to simulated rainfall from a rotating boom simulator using materials and experimental design described by Simanton and Renard (1982) and Nyhan et al. (1984). Briefly, a simulated trench cap (15 by 63 m) was constructed with a profile consisting of 15 cm of topsoil (Hackroy sandy loam) over 90 cm of backfill (crushed Bandelier tuff). The downhill slope of both layers was installed at 7%, and 8 experimental plots were installed in paired-plots configuration. Three treatments imposed in 1982 were cultivated up and down slope and disked, bare soil, and vegetated. In addition, two natural and undisturbed plots were subjected to the same simulated rainfall sequences as the eight treated plots. In 1983, the treatments were changed to include the following plots: cultivated, bare soil, bare soil with a gravel (<13 mm diameter) mulch cover at an application rate 13 kg/m^2 and vegetated with the same gravel application rate. Rainfall simulator runs on all plots were in the following sequence. A dry run for 60 min, a wet run for 30 min 24 h later, and a very wet run for 30 min after a 30 min delay following the wet run. All application rates were constant and at a rate of about 60 mm/h. Rainfall rates were measured with a recording raingage, and rainfall amounts were measured with 8 nonrecording raingages on the plots. Runoff rates were measured with a small flume at the downstream end of the plots, and sediment concentration was determined by analyzing runoff/sediment samples collected from the flume outflow at several times during the duration of runoff.

Results

Primary methods of comparing runoff, sediment concentration, and soil loss or sediment yield used here include direct comparisons and comparison of parameters or factors used in mathematical models representing the processes. Because the experimental design was slightly modified from 1982 to 1983, the results will be described by experimental year.

The 1982 Studies

As expected, runoff and sediment yield from the two natural plots were quite different than runoff and sediment yield from the treated plots. Runoff during the dry run on the natural plots gradually increased from zero to about 30 mm/h, while sediment concentration remained relatively constant at 3.5 to 4.1 g/l. In the successive wet and very wet runs, runoff occurred much sooner after the initiation of rainfall than on the dry runs, and peak discharge rates of about 20 mm/h and about 40/mm/h were observed on the wet and very wet runs, respectively. This reflects decreased infiltration rates into increasingly wet soil profiles. The peak sediment concentrations of 4.0 to 5.4 g/l, during the very wet runs, also reflect the influence of antecedent moisture and increased runoff.

Equilibrium sediment concentrations from the cultivated plots generally ranged from under 50 to just over 100 g/l, which represent an increase of about 10 to 30 times the concentration from the natural plots. Instantaneous sediment concentration values exhibited even larger differences between the cultivated and natural plots.

Equilibrium runoff rates from the bare soil, barley vegetated, and cultivated treatments were similar, but sediment concentrations were quite different. Maximum sediment concentrations from the smooth, bare soil plots were about 60 g/l, compared with 108 g/l from the cultivated plots. Maximum sediment concentrations from the vegetated plots (barley cover) were lower, and ranged from about 15 to 26 g/l. Hydrograph and sedigraph data from each simulator run were integrated over the time runoff occurred, and the resulting average runoff and soil loss amounts for each surface treatment are shown in Table 1. Average soil losses from the bare soil and barley plots were 64 to 67% and 29 to 38%,

---

Authors are staff member, Los Alamos National Laboratory, Los Alamos, NM 87545; and hydrologist, Aridland Watershed Management Research Unit, 2000 E. Allen Road, Tucson, Ariz. 85719.

Table 1. Average runoff and soil loss for rain simulator runs on dry, wet, and very wet soil surfaces on erosion plots as a function of surface treatment[1] (1982 data).

Treatment (No. of plots)	Average runoff (mm)			Average soil loss (kg)		
	Dry surface	Wet surface	Very wet surface	Dry surface	Wet surface	Very wet surface
Natural cover (2)	14.5	6.0	18.7	1.47	0.46	2.24
Cultivated (2)	44.1	25.0	27.2	104.93	65.37	66.09
Bare soil (2)	46.7	26.8	28.4	70.55	41.88	44.58
Barley cover (4)	37.9	26.5	27.6	30.56	23.43	24.84

[1] Represents an initial 60-min rainfall simulation (dry surface), a 30-min run 24 h later (wet surface), and another 30-min run after a 30-min delay (very wet surface), all performed at a nominal target rate of about 60 mm h^{-1}.

respectively, of losses from the cultivated plots. The influence of antecedent soil moisture erosion was significant for all plots. Overall, average soil loss rates increased by 19 to 53% between the dry and wet runs, and increased by 1 to 7% between the wet and very wet runs (Table 1).

We used the soil loss data to estimate values for the soil erodibility, K, and soil loss ratios for the cover-management, C, factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). Values for K were calculated from the measured soil losses from the cultivated plots and the energy and intensity of the simulated rainfall applied to these plots. Soil losses from the three rainfall simulator runs on the cultivated plots were summed and adjusted for soil loss from the standard unit plot (22.1 m length, 9% slope) according to USDA Agricultural Handbook 537 (Wischmeier and Smith 1978), using the recommended conversion to metric units (Foster et al. 1981). The simulated rainfall EI factor (storm erosivity factor) for the three simulated rainstorms was calculated (Meyer and McCune, 1958) as the product of the energy of the rainfall (MJ ha^{-1}) and the simulated rain intensity (mm h^{-1}). The average K factor, for all three simulator runs on both tilled plots, was then calculated by dividing the total unit-plot adjusted soil loss for the three simulator runs by the estimated total EI factor. This gave a K value of 0.085 Mg ha h ha^{-1} MJ^{-1} mm^{-1}, with a C.V. of 15% (n = 6). This K value agrees quite well with the estimate of 0.079 Mg ha ha ha^{-1} MJ^{-1} mm^{-1} that we determined from the soil erodibility nomograph (Wischmeier et al. 1971).

The cover management factor in the USLE is an average soil loss ratio, which in conjunction with the distribution of erosivity throughout the year is weighted according to the distribution of the soil loss ratio throughout the year. This factor reflects the ratio of the soil loss at a specific crop stage to the corresponding loss from the clean-tilled, unprotected soil of a unit plot. Thus, we calculated soil loss ratios for the barley cover and natural cover treatments by dividing the total soil loss from all three simulator runs for these treatments, adjusted for soil loss from the standard unit plot (Wischmeier and Smith 1978) by the corresponding soil loss from the tilled plots (Table 2). Soil loss ratios ranged from 0.27 to 0.3 for the barley plots, and from 0.013 to 0.023 for the plots with natural vegetative cover. These soil loss ratios agreed quite well with standard soil loss ratios for barley cover at crop stages 1 and 2 having soil loss ratio values of 0.31 to 0.60, and for the natural vegetation in local rangelands having soil loss ratio values of 0.01 to 0.08.

Soil loss ratios are obviously more than just a function of vegetative cover, as evidenced by the large difference between soil loss ratios for the barley on the trench cap and the cover on the natural plots (Table 2). Plant cover on the barley plots increased from 62 to 84% as soil loss decreased from 44.9 to 28.4 Mg ha^{-1}. The plant cover on the natural plots, which included some additional protection due to litter, etc. also ranged from 63 to 78% cover, yet much smaller soil losses were observed on these plots than on the barley plots.

Table 2. Soil loss, cover management factor (C), and plant cover estimates for the trench cap plots with barley cover, and for the natural plots (1982 data).

Plot number	Total soil loss[1] (Mg ha^{-1})	C factor[2]	Plant cover (%)
----Trench cap plots with barley cover----			
2	45	0.43	62
4	28	0.27	84
5	28	0.27	78
7	39	0.37	62
----Natural plots----			
N1	2.4	0.023	63
N2	1.3	0.013	78

[1] Sum of soil losses from plot during dry, wet, and very wet soil surface rain simulator runs, adjusted for losses from a standard USLE unit plot.

[2] Total soil loss from the vegetated plot/average total soil loss from the cultivated erosion plots.

Table 3. Average runoff and soil loss for rain simulator runs on dry, wet, and very wet soil surfaces on erosion plots as a function of surface treatment[1] (1983 data).

Treatment (No. of plots)	Average runoff (mm)			Average soil loss (kg)		
	Dry surface	Wet surface	Very wet surface	Dry surface	Wet surface	Very wet surface
Cultivated (2)	60.4	28.0	30.7	96.17	53.22	59.70
Bare soil (2)	51.1	23.6	27.2	60.23	26.69	33.27
Gravel (2)	46.2	23.3	28.3	5.08	1.92	2.37
Gravel plus wheatgrass (2)	47.2	25.8	29.0	3.91	1.55	1.21

[1] Represents an initial 60-min rainfall simulation (dry surface), a 30-min run 24 h later (wet surface), and another 30-min run after a 30-min delay (very wet surface), all performed at a nominal target rainfall rate of about 60 mm h^{-1}.

Several subfactors of the cover-management factor (C factor) should be considered in making a comparison of the soil loss ratios in the plots with natural cover and the barley plots on the trench cap. The C factor is directly influenced by variations in subfactors involving not only plant and canopy cover, but also residual mulch, incorporated plant residues, plant roots, and changes in soil structure, density, biological activity, and many other properties (Wischmeier and Smith, 1978). Shallow land burial site preparation, such as those that occurred on our trench cap plots, removes vegetation, the root zone of the soil, residual effects of prior vegetation, and partial covers of mulch and vegetation, all of which substantially increase soil erosion. Another observed difference was the large amount of dark green lichens and algae (cryptogams) growing in erosion-resistant pedestals throughout the natural plots. An additional contributing factor was the difference in the texture of the surface soils in the two plots: the fine-textured subsoil in the natural soil series was mixed into the soil surface layer of the trench cap plots compared with the undisturbed and sandier topsoil found on the natural plots. These factors influenced the infiltration/runoff relationships on these two types of soils and surfaces (Table 1).

In time, plant succession and soil formation processes will make the erosional and hydrologic properties of the disturbed soil surfaces at the SLB site more similar to those of the undisturbed natural plots. Thus, the time required for the revegetated trench cap surfaces to reduce soil erosion as effectively as the natural systems has major implications in waste management decisions at these sites. Clearly, more research is needed to investigate how the cover-management and the soil erodibility factors change with time on the trench cap to ensure successful, long-term management of infiltration and soil erosion processes in a wide range of trench cap environments.

The 1983 Studies

Four treatments were imposed on the eight erosion plots by the end of July, 1983. As in 1982, two plots received a new up- and downslope disking (cultivated treatment). Both standard tilled plots were thus again comparable to the standard USLE plot used to determine the erodibility factor. A second year's data were collected on the two plots that were not tilled and had no vegetative cover (bare soil treatment). To determine the influence of partial gravel cover on soil erosion, two plots were prepared as the bare soil treatment, and they then received a gravel (<13 mm diameter) mulch cover at an application rate of 13 kg/m^2 (gravel cover treatment). The influence of partial gravel cover plus vegetation on soil erosion was determined on two plots that were first seeded with Western Wheatgrass (*Agropyron smithii* Rydb.) at a seeding rate of 13 g/m^2 and received a simultaneous surface application of 18-24-6 (N-P-K) fertilizer at a rate of 13.5 g/m^2. Both plots then received the same gravel application rate as the gravel cover treatment (gravel and plant cover treatment).

Runoff rates and maximum sediment concentrations (63.6 to 75.5 g/l) from the cultivated plots were similar to the data collected on the same plots in 1982. Maximum sediment concentrations of 30 to 50 g/l from the bare plots were also similar to the corresponding values from the 1982 experiments. However, the plots with gravel cover exhibited maximum sediment concentrations and sediment loss rates some 13 to 24 times smaller than those from the cultivated plots (Table 3).

Runoff hydrographs and sedigraphs were integrated throughout the duration of runoff for each run. The average runoff and soil loss for each treatment are shown in Table 3. The influence of the gravel was to reduce the amount of soil loss and increase the amount of infiltration with respect to the bare soil plots.

Values of the soil erodibility factor, K, in the USLE, were calculated from the measured soil losses from the cultivated plots, and the energy and intensity of the simulated rainstorms applied to these plots, as previously described for the 1982 simulator runs. The average K factor for all three simulator runs on both tilled plots in 1983 was 0.069 Mg ha h ha^{-1} MJ^{-1} mm^{-1}, with a C.V. of 11% (n = 6). There is no significant difference between this K value and the 1982 estimate, both of which agree with the K estimate from the soil erodibility nomograph (Wischmeier et al. 1971).

We calculated estimates of the USLE cover management factor which reflect the soil loss ratio from a plot with a certain amounts of gravel and/or plant cover to the corresponding loss from the clean-tilled, unprotected soil of a unit plot (as shown in Table 4).

Table 4. Soil loss, cover management factor (C), and gravel cover estimates for the trench cap plots with gravel and gravel plus wheatgrass covers (1983 data).

Plot number	Total soil loss[1] (Mg ha^{-1})	C factor[2]	Gravel cover (%)	Plant cover (%)
---Trench cap plots with gravel cover---				
2	3.71	0.040	75	0.0
7	4.66	0.050	71	0.0
---Trench cap plots with gravel plus wheatgrass cover---				
4	4.55	0.048	70	[3]29(20)
5	1.47	0.016	70	32(23)

[1] Sum of soil losses from plot during dry, wet, and very wet soil surface rain simulator runs, adjusted for losses from a standard USLE plot.

[2] Total soil loss from the vegetated plot/average total soil loss from the cultivated erosion plots.

[3] Numbers in parenthesis represent percentages of cover where gravel and wheatgrass were both present in the field, i.e., for plot 4, 29% of the 385 field locations had wheatgrass present, but 20% of the 385 field locations also had gravel present.

Soil loss ratios ranged from 0.040 to 0.050 for the trench cap plots with gravel cover, and from 0.016 to 0.048 for the plots with a cover if gravel plus wheatgrass.

The gravel and plant cover estimates responsible for these reductions in soil loss are also presented in Table 4. Gravel cover estimates ranged from 70 to 75%, with the young, small wheatgrass plants contributing very little additional cover in the two plots with gravel plus wheatgrass cover.

These soil loss ratio values are generally slightly lower than standard soil loss ratios observed in other field studies for gravel and mulch covers with this amount of ground cover. Data from Wischmeier and Smith (1978) indicate that soil loss ratios equal to about 0.10 to 0.15 would be expected for the amount of ground cover we observed (Table 4). A similar study of stone mulches on construction sites in Indiana also resulted in high soil loss ratio values relative to this amount of plant cover (Meyer et al. 1972). However, the explanation for our small soil loss ratio values lies in the fact that, even with the low landslope (7%) on our erosion plots relative to much larger landscape values on erosion plots in other field studies, our unprotected, highly erosive trench cap soil had larger soil loss rates than unprotected soil surfaces in other studies. Thus, any amount of plant or gravel cover would reduce the amount of soil loss from our trench cap plots even more than from less erodible soils in other field studies.

Discussion

After the determination of the K and C factors with the use of the rainfall simulator, the major purpose of the resulting soil loss prediction procedure is to supply specific and reliable guides for selecting adequate erosion control practices for the SLB site. This process is also used to estimate the upland erosion phase of sediment yield to predict stream loading rates.

The USLE is most successfully used to predict long-term average soil losses from upland shallow land burial sites, but not for specific rainstorms. The average soil losses are predicted for a sufficient number of similar events or time intervals to cancel out the effects of short-time fluctuations in uncontrolled variables. The USLE-estimated soil losses will be the most accurate for medium-textured soils, slope lengths of less than 400 ft, gradients of 3 to 18%, and cover-management systems that have been used in erosion plot studies. As these limits are exceeded, the probability of extrapolation error will be increased.

If this degree of accuracy of the USLE is inadequate, and if estimates of soil loss from specific storms, sediment yield from complex areas within the SLB site, and characteristics of eroded and transported sediment are required, more detailed models such as CREAMS (Knisel 1980) must be used. CREAMS, a field scale model for Chemical, Runoff, and Erosion from Agricultural Management Systems, was first applied to SLB of low-level radioactive wastes at Los Alamos (Lane and Nyhan 1981, Nyhan and Lane 1982, Hakonson et al. 1984). Although several USLE factors are used in CREAMS, the water balance component of CREAMS, unlike the USLE, addresses the influence of antecedent soil water content on sediment, nutrient, and pesticide losses on a storm-by-storm basis.

However, researchers and users should not see either the USLE or the CREAMS model as a final representation of erosion prediction technology. Both of these models are but continuing steps in our efforts to develop improved models to estimate erosion and sediment yield for applications such as improved shallow land burial design criteria.

Literature Cited

Foster, G.R., D.K. McCool, K.G. Renard, and W.C Moldenhauer. 1981. Conversion of the Universal Soil Loss Equation to SI metric units. J. Soil Water Cons. 36:355-359.

Hakonson, T.E., G.R. Foster, L.J. Lane, and J.W. Nyhan. 1984. The application of an agricultural water balance and erosion model in environmental science - a user perspective. *In:* Symposium on prediction of agricultural non-point source pollution: model selection and application, Venice, Italy.

Knisel, W.G. 1980. CREAMS: a field-scale model for chemicals, runoff, and erosion from agricultural management systems. USDA Cons. Res. Rep. 26, U.S. Government Printing Office, Washington, D.C.

Lane, L.J., and J.W. Nyhan. 1981. Cover integrity in shallow land burial of low-level wastes: hydrology and erosion. Oak Ridge Nat. Lab. Rep. ORNL/NFW-81/34:419-430.

Meyer, L.D., and D.L. McCune. 1958. Rainfall simulator for runoff plots. Trans. Amer. Soc. Agri. Engrs. 39:644-648.

Meyer, L.D., C.B. Johnson, and G.R. Foster. 1972. Stone and woodchip mulches for erosion control on construction sites. J. Soil Water Cons. 27:264-269.

Nyhan, J.W., and L.J. Lane. 1982. Use of a state-of-the-art model in generic designs of shallow land repositories for low-level wastes. *In:* R.G. Post and M.E. Wacks (eds.) Waste management '82. University of Arizona, Tucson.

Nyhan, J.W., G.L. DePoorter, B.J. Drennon, J.R. Simanton, and G.R. Foster. 1984. Erosion of earth covers used in shallow land burial at Los Alamos, New Mexico. J. Environ. Qual. 13:361-366.

Simanton, J.R., and K.G. Renard. 1982. Seasonal changes in infiltration and erosion from USLE plots in southeastern Arizona. Hydrology and Water Resources in Arizona and the Southwest, Office of Aridland Studies, Univ. Arizona, Tucson 12:37-46.

Swanson, N.P. 1965. Rotating-boom rainfall simulator. Trans. ASAE 8:71-72. U.S. Department of Energy, Office of Nuclear Energy. 1982. Spent fuel and radioactive waste inventories, projections, and characteristics. U.S. Dept. Energy Rep. No. DOE/NE-0017-1.

Warren, J.L. 1980. Shallow land burial: experience and developments at Los Alamos. *In:* Underground disposal of radioactive wastes. International Atomic Energy Agency, Vienna, Austria.

Wischmeier, W.H., C.B. Johnson, and B.V. Cross. 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil Water Cons. 26:189-192.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses—a guide to conservation planning. USDA Handb. No. 537, U.S. Government Printing Office, Washington, D.C.

EROSION ON RANGELANDS: EMERGING TECHNOLOGY AND DATA BASE

Proceedings of the Rainfall Simulator Workshop

January 14–15, 1985
Tucson, Arizona

Edited by
Leonard J. Lane
Hydrologist
U.S. Department of Agriculture
Agricultural Research Service
2000 East Allen Road
Tucson, Arizona 85719

Published by
SOCIETY FOR RANGE MANAGEMENT
2760 West Fifth Avenue, Denver, CO 80204