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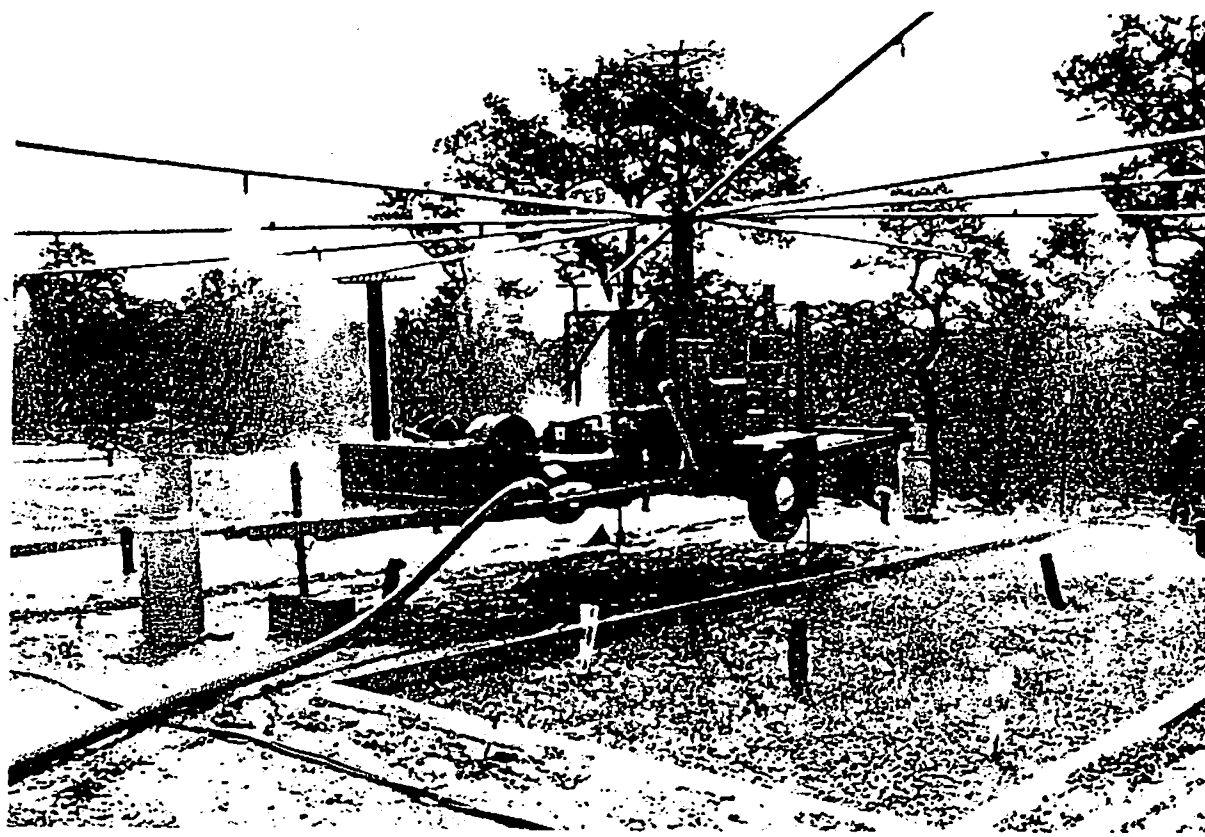
Erosion Control Technology: A User's Guide to the Use of the Universal Soil Loss Equation at Waste Burial Facilities



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On the cover: Determination of Universal Soil Loss Equation factors by using a rotating boom rain simulator to apply a simulated rainstorm to two erosion plots located on the simulated trench cap at the Los Alamos Engineered Test Facility.

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Erosion Control Technology: A User's Guide to the Use of the Universal Soil Loss Equation at Waste Burial Facilities

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EROSION CONTROL TECHNOLOGY:

A USER'S GUIDE TO THE USE OF THE UNIVERSAL SOIL LOSS EQUATION AT WASTE BURIAL FACILITIES

by

John W. Nyhan and Leonard J. Lane

ABSTRACT

The Universal Soil Loss Equation (USLE) enables the operators of shallow land burial sites to predict the average rate of soil erosion for each feasible alternative combination of plant cover and land management practices in association with a specified soil type, rainfall pattern, and topography. The equation groups the numerous parameters that influence erosion rate under six major factors, whose site-specific values can be expressed numerically. Over a half century of erosion research in the agricultural community has supplied information from which approximate USLE factor values can be obtained for shallow land burial sites throughout the United States. Tables and charts presented in this report make this information readily available for field use.

Extensions and limitations of the USLE to shallow land burial systems in the West are discussed, followed by a detailed description of the erosion plot research performed by the nuclear waste management community at Los Alamos, New Mexico. Example applications of the USLE at shallow land burial sites are described, and recommendations for applications of these erosion control technologies are discussed.

I. INTRODUCTION

The total volume of low-level radioactive wastes produced in the United States is conservatively projected to be about 16 million m^3 by the year 2020 (US Department of Energy 1982). This increasing production rate is of major concern because new and acceptable sites will be required for the disposal of these wastes. New burial sites need to be selected in a wide range of environments throughout the US, and actual or anticipated problems with closed shallow land burial sites must also be corrected.

The most popular current method for disposing of low-level radioactive wastes is shallow land burial (SLB). Burial trenches range in size from the 4.6-m deep, 3- by 15-m disposal pit at Oak Ridge National Laboratory to the 6.1-m deep, 30- by 300-m trench at Barnwell, South Carolina. After waste materials are placed in these trenches, current management practices range from simple backfilling of the trench to more elaborate installation of multilayered trench caps and revegetation programs.

Once the burial trench receives its final cover, several environmental processes begin to influence the configuration and integrity of the surface and subsurface of the trench cap (Fig. 1). The most serious problems encountered in shallow land burial are related to water management (Jacobs et al. 1980), as water comes into contact with the buried wastes either from infiltration of precipitation or from trench cap erosion, leading to the exposure of the buried wastes. Unfortunately, most management practices that reduce erosion of the trench cap will probably enhance infiltration; thus, burial site operators must ultimately arrive at techniques that will optimize control of infiltration and erosion.

Scientific planning for surface and subsurface water management at the SLB site requires a knowledge of the relationships between those factors that cause a loss of soil and water (Fig. 1). Controlled studies on field plots and small watersheds have supplied much valuable information regarding these complex factor interrelationships, mostly from the agricultural community. The greatest benefit from

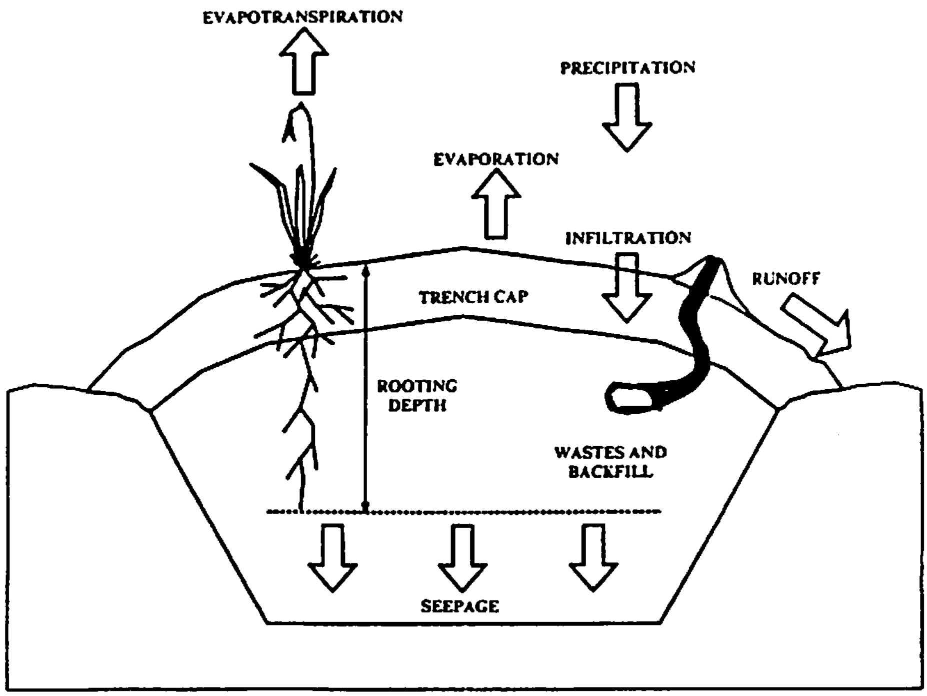


Fig. 1. Hydrology of shallow land burial of low-level radioactive wastes.

this research can be realized only when the findings from the agricultural and nuclear communities are converted to sound practice on the numerous waste disposal areas throughout the US. Specific guidelines are needed for selecting the control practices best suited to the particular needs of each SLB site.

The soil loss prediction procedure presented in this report provides such guidelines. The procedure methodically combines research information from many sources within the agricultural and nuclear waste management communities to develop burial site design data for each conservation plan. Field experience for more than two decades throughout the agricultural community has proved this procedure to be highly valuable as a planning guide.

More specifically, basic soil erosion processes are described, leading up to the burial site operator's need for a simple soil loss equation. The evolution of the Universal Soil Loss Equation (USLE) in the agricultural community is described, as well as techniques for determining USLE factors. Extension of the USLE to SLB systems in the West is discussed, followed by a detailed description of the erosion plot research performed by the nuclear waste management community at Los Alamos, New Mexico. Example applications of the USLE at SLB sites are described, and recommendations for applications of these erosion control technologies are discussed.

II. BASIC EROSION PROCESSES

Watershed erosion is described in terms of processes occurring on upland areas, in small stream channels, and over entire watersheds. A basic source document for these concepts is a book entitled *The Fluvial System* (Schumm 1977). An idealized fluvial system is described as consisting of Zone 1—the drainage basin as a sediment and runoff source, Zone 2—the main river channels as a transfer component, and Zone 3—the alluvial fans, deltas, etc., as zones of deposition. Further elaboration on these concepts is given by Schumm (1977) and in an American Society of Civil Engineers Task Committee Report (ASCE 1982). The emphasis here is on Schumm's Zone 1 as further divided into upland areas and small stream channels. Considered together, they form the watershed. Because of the engineered features of SLB systems, usual design and construction techniques place SLB facilities in upland areas, which are configured to minimize surface runoff flow concentration and the resulting channel erosion. Therefore, discussions herein are limited to upland areas that are subject to overland flow and interrill and rill erosion processes.

A. Detachment Processes

Soil particles are detached when the impact of raindrops or shear stresses caused by flowing water are in excess of the ability of the soil to resist the erosive forces. Factors that shield the soil from raindrop impacts (vegetation, which provides a canopy and ground cover or which produces dead material as mulch, or a gravel cover that protects the soil surface) are, therefore, directly involved in reducing soil detachment. Factors that bind the soil (roots, incorporated mulch, and cohesive mineral content) or protect it from shear stress (either by reducing the amount of soil exposed to flowing water or by reducing flow velocity and thus shear stress) are directly involved in reducing soil detachment by flowing water. As will be discussed later, erosion control methods have been developed to reduce detachment by raindrop impact and by flowing water.

B. Transport Processes

Detached sediment particles are transported by raindrop splash and by overland flow. Factors that limit raindrop detachment (e.g., vegetation or gravel mulch) limit the sediment supply available for transport by rain splash. In addition, vegetation canopies intercept splashed sediment particles and can further reduce transport by the splash mechanisms. Sediment transport by overland flow is affected by all the factors that control the available sediment supply (the detachment processes) and by flow characteristics such as depth and velocity. Slope length, steepness, and shape are important factors in determining sediment transport capacity.

Particles that are detached in the interrill areas move to the rills by splash mechanisms and as a result of suspension and saltation in overland flow. Thus, their detachment and movement is independent of processes in rill and stream channels (except for morphological features of rill and channel systems controlling length and slope of interrill areas). This situation is definitely not the case for erosion in rills and channels. The amount and rate of water and sediment delivered to the rills determines rill erosion rates, sediment transport capacity in the rills, and rate of sediment deposition. This illustrates the strong connection between erosion and sediment transport rates and the rate and amount of surface runoff. As will be shown later, many of the most effective erosion control techniques affect the control of soil loss by reducing rates and amounts of runoff.

C. Deposition Processes

As discussed above, a vegetation canopy can intercept splashed soil particles and induce a net soil deposition around the base of a plant. This hummock appearance is often noticed in arid and semiarid shrub areas of the West. With respect to overland flow, deposition of soil particles occurs when the weight of the particle exceeds the forces tending to move it. This condition is expressed as sediment load exceeding sediment transport capacity, with deposition as the result. Erosion control measures, which tend to slow the velocity of flowing water (i.e., gravel mulch, debris dams from surface litter, and increased hydraulic roughness) and induce temporary ponding, tend to reduce transport capacity and induce sediment deposition.

D. Detachment, Transport, Deposition, and Sediment Yield

Sediment yield from upland areas is simply the final and net result of detachment, transport, and deposition processes occurring from the watershed divide to the point of interest where sediment yield information is needed. Depending on the scale of investigation and definition of the problem, this point of interest can be a position on a hillslope, a property boundary at a SLB site, the edge of a farm field, delivery point to a stream channel, or some other location dependent on topography. In any event, sediment yield at the point of interest is determined by the physical processes of sediment detachment, transport, and deposition at all positions in the contributing area above the point of interest.

Therefore, erosion control technology, designed to reduce soil loss or sediment yield from a given area, must account for and manage the processes of detachment, transport, and deposition.

E. Need for a Simple Soil Loss Equation

The processes controlling soil loss are complex and interactive. Yet site operators, managers, and engineers need a rather simple means of screening and ranking erosion control alternatives. Moreover, once an erosion control method is selected, long-term average annual soil loss must be estimated for comparison with tolerable soil loss estimates to evaluate future SLB site performance.

III. THE UNIVERSAL SOIL LOSS EQUATION (USLE)

A. Evolution of the Universal Soil Loss Equation

The first scientific study of erosion effects is thought to have been accomplished by Wollny in the late nineteeth century (Hudson 1971). The first quantitative experiments in America were begun by the US Forest Service in 1915. In 1917, M. F. Miller began a plot study of the effect of crops and rotations on runoff and erosion. In the 1920s and early 1930s, the widespread concern about the dangers of soil erosion resulted in a large increase in scientific erosion research. Although results of this early work were, of necessity, qualitative in nature, a basic understanding of most of the factors affecting erosion was developed during this period (Ayres, 1936). During the 1940s, the importance of raindrop impact in the erosion process was finally more fully appreciated after the natural rainfall studies of Laws (1940) and the analysis of the mechanical action of raindrops by Ellison (1947).

Between 1940 and 1956, a field soil loss estimation procedure known as the slope-practice method, was developed in the Corn Belt. Initially, an equation was developed that related soil loss rate to length and percentage of slope (Zingg 1940). The following year, crop and conservation practice factors and the concept of a specific soil loss limit were added to develop a graphical method for determining conservation practices (Smith 1941, Smith and Whitt 1947). Finally, soil and management factors were included (Browning et al. 1947), and the slope-practice equation was used throughout the Midwest.

In 1946, a national committee reappraised the Corn Belt factor values, added a rainfall factor, and applied the resulting Musgrave equation to croplands in other regions (Musgrave 1947). In 1952, a graphical solution of this equation was published and used by the Soil Conservation Service (SCS) in the northeastern states (Lloyd and Eley 1952).

In 1954, the USLE was developed at the National Runoff and Soil Loss Data Center established by the Agricultural Research Service in cooperation with Purdue University. In contrast with previous regionally-based soil loss equations, more than 10 000 plot-years of basic runoff and soil loss data were contributed to this center from federal/state cooperative research projects at 49 locations (Table I). Immediately after 1960, rainfall simulators (Meyer and McCune 1958) operating from Indiana, Georgia, Minnesota, and Nebraska were used in field plots in 16 states to supply additional information to evaluate USLE factors.

Developments since 1965 have expanded the use of the USLE by providing techniques for estimating site values of USLE factors for additional land uses, climatic conditions, and management practices. Some of these have included a soil erodibility nomograph for farmland and construction areas (Wischmeier et al. 1971), topographic factors for irregular slopes (Foster and Wischmeier 1974, Wischmeier 1974), cover factors for range and woodland (Wischmeier 1975), erosion prediction on construction areas (Meyer and Ports 1976, Meyer and Romkens 1976, Wischmeier and Meyer 1973), and estimated erosion index values for the western states (McCool et al. 1976, Wischmeier 1974).

B. Description of the Equation

The most widely accepted and successful model used to predict soil loss from upland areas is the USLE, best described by Wischmeier and Smith (1978) in a publication entitled "Predicting Rainfall Erosion Losses. A Guide to Conservation Planning." With appropriate selection of its factor values, the USLE will compute the average soil loss for a given site as the product of six major factors whose most likely values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but effects of the random fluctuations tend to average out over extended periods. Because of the unpredictable short-time fluctuations in the levels of influential variables, however, the USLE is substantially less accurate for prediction of specific events than for prediction of long-time averages.

The USLE was originally derived and presented in English units with subsequent conversion to SI (Foster et al. 1981; see Appendix A). The soil loss equation is:

TABLE I

LOCATIONS WHERE RUNOFF AND SOIL LOSS DATA WERE COLLECTED BY FEDERAL/STATE COOPERATIVE RESEARCH PROJECTS (Wischmeier and Smith 1978)

Arkansas	Batesville	New York	Ithaca Geneva Marcellus
Georgia	Tifton Watkinsville	North Carolina	Statesville Raleigh
Illinois	Dixon Springs Joliet Urbana	Ohio	Coshocton Zanesville
Indiana	Lafayette	Oklahoma	Cherokee Guthrie
Iowa	Clarinda Castana Beaconsfield Independence Seymour	Pennsylvania	State College
		South Carolina	Clemson Spartanburg
Kansas	Hays	South Dakota	Madison
Louisiana	Baton Rouge	Tennessee	Knoxville Greeneville
Maine	Presque Isle		
Michigan	Benton Harbor East Lansing	Texas	Temple Tyler
Minnesota	Morris	Virginia	Blacksburg
Mississippi	Holly Springs State College	Washington	Pullman
		Wisconsin	La Crosse Madison Owen
Missouri	Bethany McCredie		
Nebraska	Hastings	Puerto Rico	Mayaguez
New Jersey	Beemerville Marlboro New Brunswick		

$$A = RLSKCP \quad (1)$$

where

A is the computed loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year, but other units can be selected (Appendix A).

R, the rainfall factor, is the number of rainfall erosion index units plus a factor for runoff from snowmelt or applied water where such runoff is significant.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft length of uniform 9% slope continuously in clean-tilled fallow.

C, the cover management factor, the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.

In the following subsections, the significance of each USLE factor will first be described, and then the user will be presented with charts and tables that can be used to select factor values.

C. The Rainfall and Runoff Factor (R)

Casual observations of sediment deposits and gulley erosion after a large storm may lead the observer to the conclusion that the only significant erosion in an area is associated with a few very intense rainstorms. However, more than 30 yr of measurements in several states have shown that the cumulative effects of many moderately-sized storms, as well as the effects of the occasional severe storms, must be taken into account to accurately estimate average annual soil loss (Wischmeier 1962). Thus, the R factor in the USLE must both quantify the raindrop impact and provide information on the amount and rate of runoff likely to be associated with the rain.

More specifically, the R factor is described as a rainfall and runoff factor and is computed as the product of rainfall storm energy (E) and the maximum 30-min rainfall intensity (I_{30}). The product term (EI) is a statistical interaction term that reflects how total energy and peak intensity are combined in each particular storm. Technically, it indicates how particle detachment is combined with transport capacity. Total energy refers to raindrop detachment and peak intensity refers to the peak rate of runoff. The R factor is often misinterpreted as rainfall factor only. However, if one conducts regression analyses with data from small upland areas, I_{30} is often most strongly correlated with runoff volume or peak rate of runoff. To the extent that regression equations summarize a data set and result in prediction ability, I_{30} is a runoff predictor in the R factor.

The energy parameter can be computed from rainfall intensity data using:

$$E = 916 + 331 \log_{10} I \qquad (2)$$

where E is kinetic energy in hundreds of foot-tons per acre-inch and I is intensity in inches per hour for a given time period in which rainfall intensity is constant. Values of E for I greater than 3 inches per hour are assumed to be given as E = 1074 as an upper limit. Equation (2) is applied over each interval in a storm and the sum is rainfall energy. Tabular data for rainfall energy computation are also given in Table II. However, Eq (2) and Table II give E in terms of hundreds of foot-tons per acre so that the cumulative E values (over a storm or over a year) *must* be divided by 100 before multiplication by I_{30} to compute EI and thus the annual value of R by summation.

However, if rainfall intensity data are not available or are unsuitable because of short records, etc., then Figs. 2 and 3 can be used to estimate R. These two figures show the average annual values of the rainfall erosion index for the United States, where the local value of this index generally equals R for the USLE.

Finally, a rough approximation of the value of R is given by

$$R = 27.38 \text{ P ** } 2.17 \ , \qquad (3)$$

where R is an estimate of the average annual rainfall erosion index expressed in (foot-tons per acre) times (inches per hour) and P is the 2-yr, 6-hr rainfall amount in inches. Within the continental United States, values of R range from less than 20 to more than 550 hundreds of foot-tons · inch · $acre^{-1}$ · $hour^{-1}$ · $year^{-1}$ (340 to more than 9361 MJ · mm · ha^{-1} · $hour^{-1}$ · $year^{-1}$, respectively).

D. The Topographic Factor (LS)

Both the length and the steepness of the land slope substantially affect the rate of soil erosion by water. The two effects have been evaluated separately in research and are represented in the soil loss equation by L and S, respectively. In field applications, however, considering the two as a single topographic factor, LS, is more convenient.

The LS factor is the expected ratio of soil loss per unit area from a field slope to that from a USDA unit plot (a 72.6-ft length of uniform 9% slope continuously in a clean-tilled fallow condition) under

TABLE II

KINETIC ENERGY OF RAINFALL EXPRESSED IN FOOT-TONS PER ACRE PER INCH OF RAIN[a] (Wischmeier and Smith 1978)

Intensity inch per hour	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	—	254	354	412	453	485	512	534	553	570
0.1	585	599	611	623	633	643	653	661	669	677
0.2	685	692	698	705	711	717	722	728	733	738
0.3	743	748	752	757	761	765	769	773	777	781
0.4	784	788	791	795	798	801	804	807	810	814
0.5	816	819	822	825	827	830	833	835	838	840
0.6	843	845	847	850	852	854	856	858	861	863
0.7	865	867	869	871	873	875	877	878	880	882
0.8	884	886	887	889	891	893	894	896	898	899
0.9	901	902	904	906	907	909	910	912	913	915
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	916	930	942	954	964	974	984	992	1000	1008
2	1016	1023	1029	1036	1042	1048	1053	1059	1064	1069
3	1074[b]									

[a]Computed by the equation, $E = 916 + 331 \log_{10} I$, where E = kinetic energy in foot-tons per acre per inch of rain, and I = rainfall intensity in inches per hour.
[b]The 1074 value also applies for all intensities greater than 3 in/h (see text).

otherwise identical conditions. Since this factor is dimensionless. LS would have a value of 1.0 for a 72.6-ft uniform slope of 9%. This ratio for specified combinations of field slope length and uniform gradient may be obtained directly from the slope-effect chart (Fig. 4). Enter on the horizontal axis with the field slope length, move vertically to the appropriate percent-slope curve, and read LS on the scale at the left. For example, the LS factor for a 300-ft length of 10% slope is 2.4. Those who prefer a table may use Table III and interpolate between listed values.

Both Fig. 4 and Table III make the assumption that the slopes have essentially a uniform gradient and were derived by the equation:

$$LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065) \quad (4)$$

where

λ = slope length in feet,

θ = angle of slope,

m = 0.2 to 0.5

The value of m is 0.5 if the percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5%, 0.3 on slopes of 1 to 3%, and 0.2 on uniform gradients of less than 1%. The estimates from this equation are based on data from plots with slopes ranging from 3 to 18% steepness and 30 to 300 feet long, resulting in LS values ranging from a low of about 0.2 to a high of about 6.

E. Soil Erodibility Factor (K)

The rate of soil erosion, A, in the soil loss equation, may be influenced more by land slope, rainstorm characteristics, cover, and management

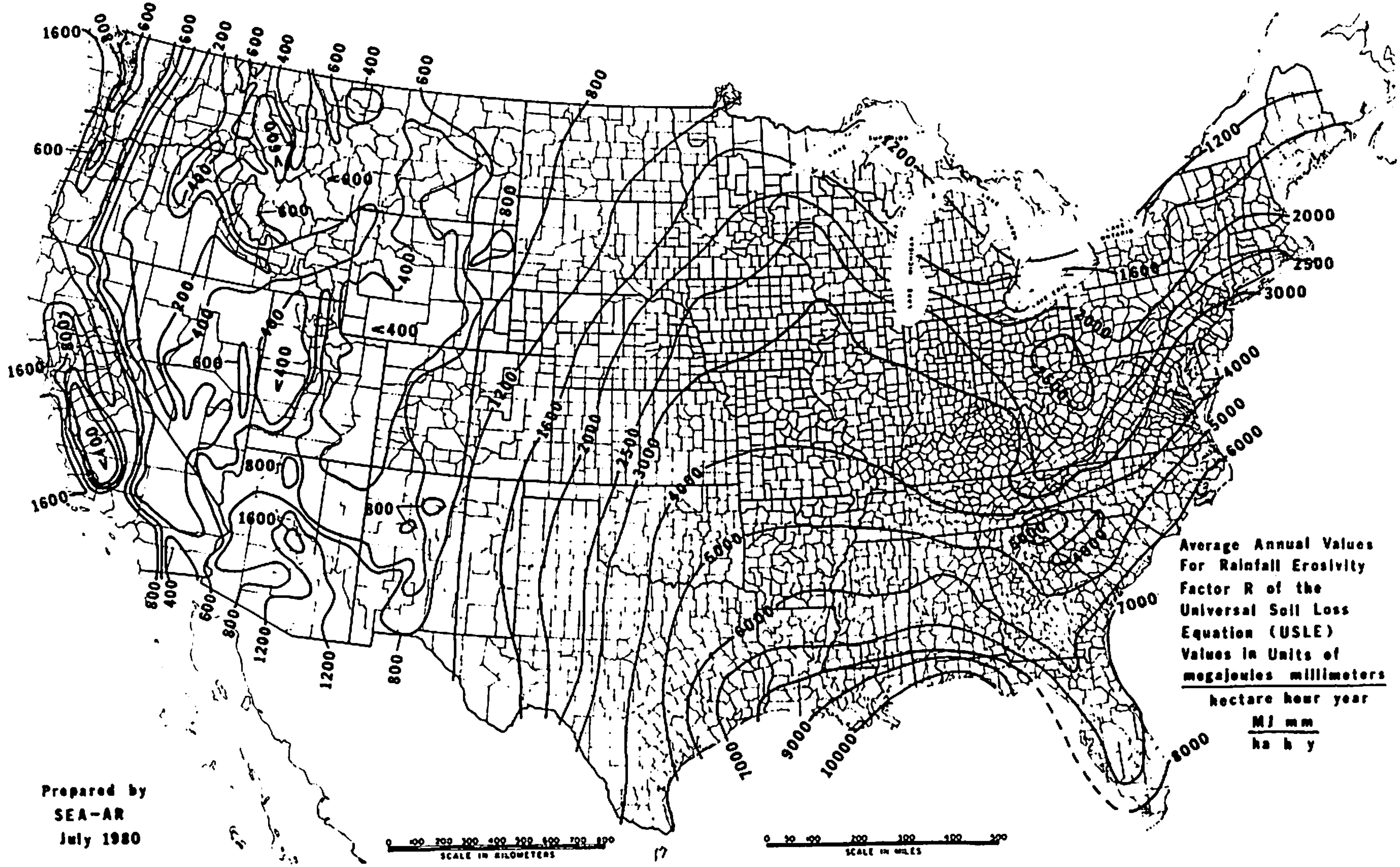


Fig. 2. Average annual values of the rainfall erosion index expressed in SI units.

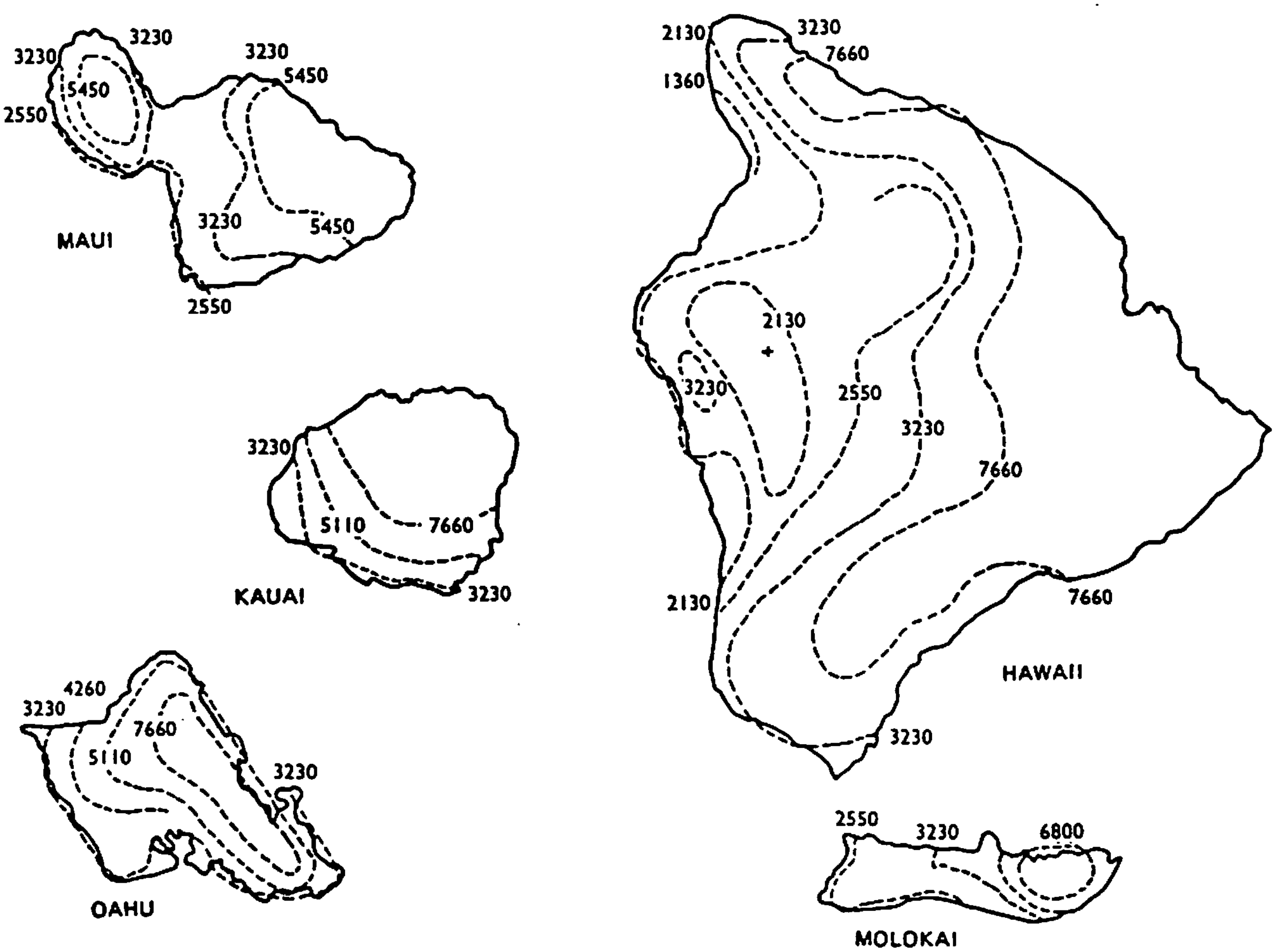


Fig. 3. Estimated average annual values of the rainfall erosion index in Hawaii expressed in SI units (Wischmeier and Smith 1978).

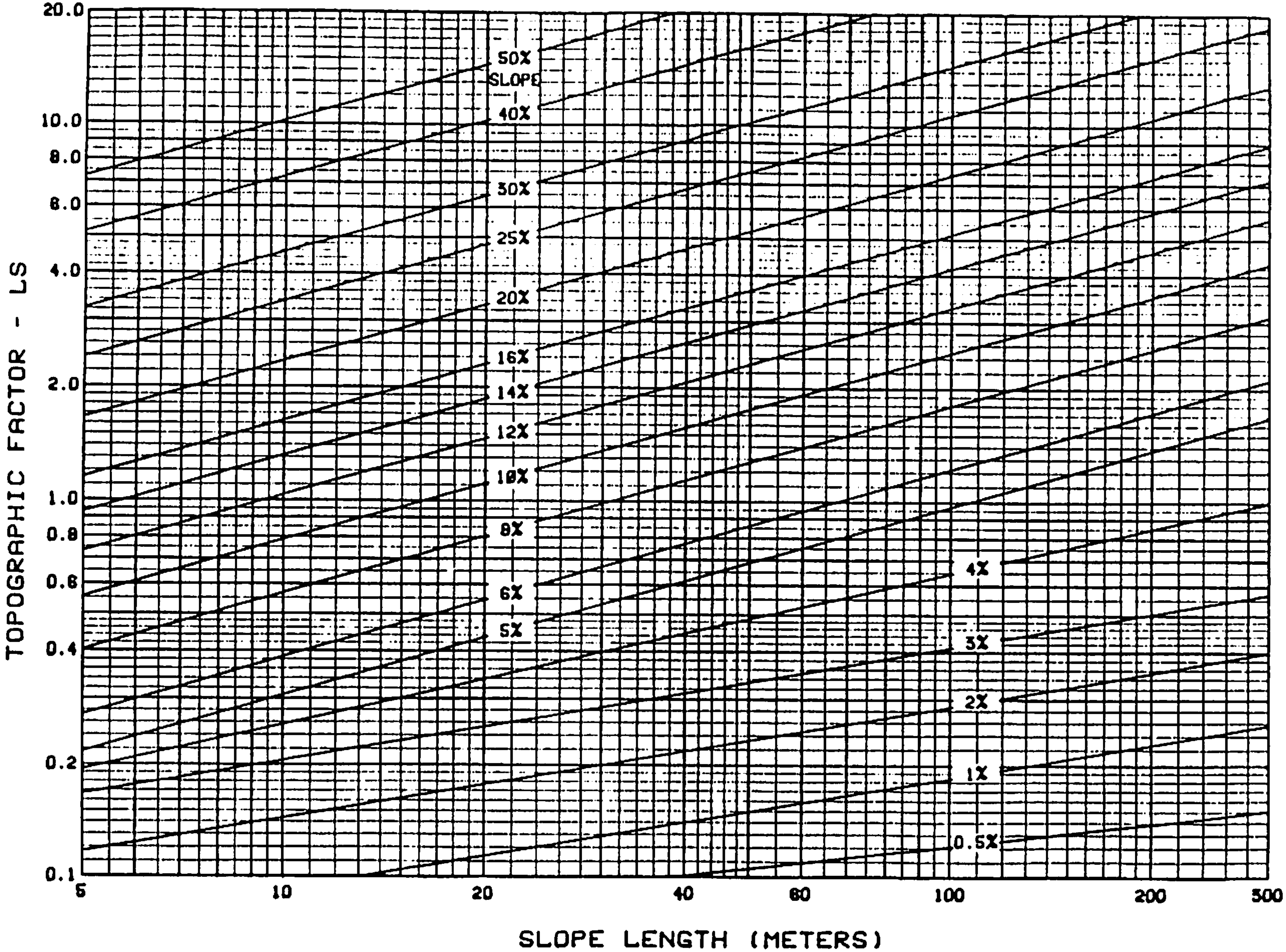


Fig. 4. Slope effect chart (topographic factor, LS). LS = $(\lambda/72.6)^m$ $(65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$ where λ = slope length in feet, θ = angle of slope, and m = 0.2 for gradients <1%, 0.3 for 1 to 3% slopes, 0.4 for 3.5 to 4.5% slopes, and 0.5 for slopes of 5% or steeper (Wischmeier and Smith 1978).

TABLE III

VALUES OF THE TOPOGRAPHIC FACTOR, LS, FOR SPECIFIC COMBINATIONS OF SLOPE LENGTH AND STEEPNESS[a]

(Wischmeier and Smith 1978)

Percent Slope	Slope Length (feet)											
	25	50	75	100	150	200	300	400	500	600	800	1000
0.2	0.060	0.069	0.075	0.080	0.086	0.092	0.099	0.105	0.110	0.114	0.121	0.126
0.5	0.073	0.083	0.090	0.096	0.104	0.110	0.119	0.126	0.132	0.137	0.145	0.152
0.8	0.086	0.098	0.107	0.113	0.123	0.130	0.141	0.149	0.156	0.162	0.171	0.179
2	0.133	0.163	0.185	0.201	0.227	0.248	0.280	0.305	0.326	0.344	0.376	0.402
3	0.190	0.233	0.264	0.287	0.325	0.354	0.400	0.437	0.466	0.492	0.536	0.573
4	0.230	0.303	0.357	0.400	0.471	0.528	0.621	0.697	0.762	0.820	0.920	1.01
5	0.268	0.379	0.464	0.536	0.656	0.758	0.928	1.07	1.20	1.31	1.52	1.69
6	0.336	0.476	0.583	0.673	0.824	0.952	1.17	1.35	1.50	1.65	1.90	2.13
8	0.496	0.701	0.859	0.992	1.21	1.41	1.72	1.98	2.22	2.43	2.81	3.14
10	0.685	0.968	1.19	1.37	1.68	1.94	2.37	2.74	3.06	3.36	3.87	4.33
12	0.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61	4.04	4.42	5.11	5.71
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59	5.13	5.62	6.49	7.26
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68	6.35	6.95	8.03	8.98
18	1.72	2.43	2.97	3.43	4.21	3.86	5.95	6.87	7.68	8.41	9.71	10.9
20	2.04	2.88	3.53	4.08	5.00	5.77	7.07	8.16	9.12	10.0	11.5	12.9

[a] $LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$ where λ = slope length in feet; m = 0.2 for gradients < 1%, 0.3 for 1 to 3% slopes, 0.4 for 3.5 to 4.5% slopes, 0.5 for 5% slopes and steeper; and $\theta \doteq$ angle of slope. (For other combinations of length and gradient, interpolate between adjacent values or see Fig. 4).

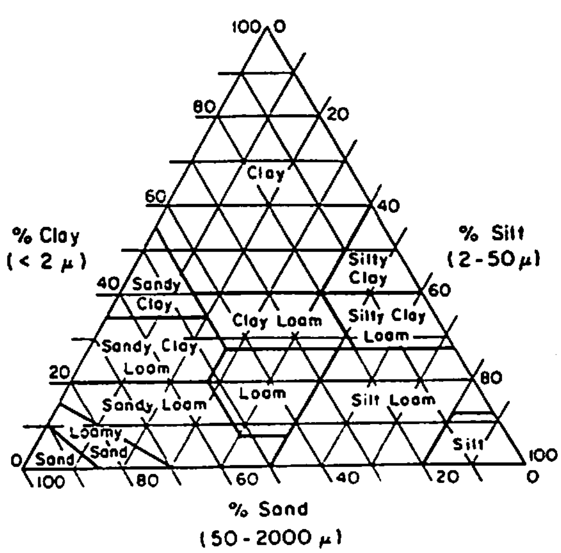


Fig. 5. The soil texture triangle.

than by inherent properties of the soil. However, some soils erode more readily than others even when all other factors are the same. This difference, caused by properties of the soil itself, is referred to as the soil erodibility. Thus, a soil type usually becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction (see Fig. 5 for more detail). Overall, organic matter content ranks next to particle-size distribution as an indicator of erodibility. However, a soil's erodibility is a function of complex interactions of a substantial number of its physical and chemical properties and often varies within a standard texture class.

More specifically, the soil erodibility factor, K, is expressed in units of either ton · acre · hour · hundreds of $acre^{-1}$ · $foot\text{-}ton^{-1}$ · $inch^{-1}$, or metric ton · hectare · hour · $hectare^{-1}$ · MJ^{-1} · mm^{-1} , and is an experimentally-determined quantitative value.

The K factor for a particular soil represents the rate of soil loss per erosion index unit as measured on a USDA unit plot. Thus, under unit plot conditions, LS, C, and P each equal 1.0, and K equals A/R. Direct measurements of K on well-replicated unit plots reflect the combined effects of all the soil properties significantly influencing the ease with which a particular unprotected soil is eroded by rainfall and runoff. However, K is an average value for a given soil, and direct measurement of the factor requires soil loss measurements for a representative range of storm sizes and antecedent soil conditions.

Soil erosion studies have shown that very fine sand (soil particles with diameters ranging from 0.05-0.10 mm) is comparable in erodibility to silt-sized particles and that mechanical analysis data are much more valuable when expressed by an interaction term that describes the proportions in which the sand, silt, and clay fractions are combined in the soil, based on the standard USDA classification. When such mechanical analysis data are used, the nomograph shown in Fig. 6 may be used to estimate the USLE soil erodibility factor. For soils containing less than 70% silt and very fine sand, this nomograph solves the equation:

$$100\ K = 2.1 M^{1.14}(10^{-4})(12-a)+3.25(b-2)+2.5(c-3) \qquad (5)$$

where

M = (% silt and very fine sand) (100% −% clay),

a = percent organic matter,

b = the soil-structure code used in soil classification,

c = the profile-permeability class.

The intersection of the selected percent silt and percent sand lines computes the value of M on the unidentified scale of the nomograph. The data indicate a change in the relation of M to erodibility when the silt and very fine sand fraction exceeds about 70%. This change was empirically reflected by inflections in the percent sand curves at that point but has not been described by a numerical equation.

To use the nomograph to solve for the soil erodibility factor, enter the scale with the appropriate data at the left and proceed to points representing the soil's percent sand (0.10-2.0 mm), percent organic matter, structure code, and permeability class, as illustrated by the dotted line on the nomograph. The horizontal and vertical moves must be made in the listed sequence. Use linear interpolations between plotted lines. For reference, the structure code and permeability classes are defined on the nomograph.

Many agricultural soils have both fine granular topsoil and moderate permeability. For these soils, K may be read from the scale labeled "first approximation of K," and the second block of the graph is not needed. For all other soils, however, the procedure must be completed to the soil erodibility scale in the second half of the graph.

Although the mechanical analysis, organic matter, and structure data (Fig. 6) are usually used for the topsoil in minimally disturbed soil profiles, the K factor can also be evaluated for desurfaced subsoil horizons, such as those found at shallow land burial sites. When this is the case, these data are used for the upper 6 in. of the new soil profile of the trench cap. The permeability class is the permeability for the entire new trench cap profile.

F. The Cover Management Factor (C)

More than 10 000 plot-years of runoff and soil loss data from natural rain (Table I), and additional data from a large number of erosion studies under simulated rainfall, were analyzed to obtain empirical measurements of the effects of cropping system and management on soil loss at successive stages of crop establishment and development. Soil losses measured on the cropped plots were compared with corresponding losses from clean-tilled, continuous fallow to determine the soil loss reductions ascribable to effects of the crop system and management. The reductions were then analyzed to identify and evaluate influential subfactor interactions and correlations. Mathematical relationships observed for one crop or geographic region were tested against data from other research sites. Those found compatible with all the relevant data were used to compute expected soil loss reductions from conditions not directly represented in the overall plot studies.

The cover management factor C of the USLE is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled and continuous fallow and is a measure of the combined effect of *all* cover and management variables affecting soil loss. The C factor is the most difficult factor to estimate (under most conditions, except the unit plot) in the USLE. At a particular site, once K, LS, and P have been measured or specified, then R can be measured or calculated. The C factor is

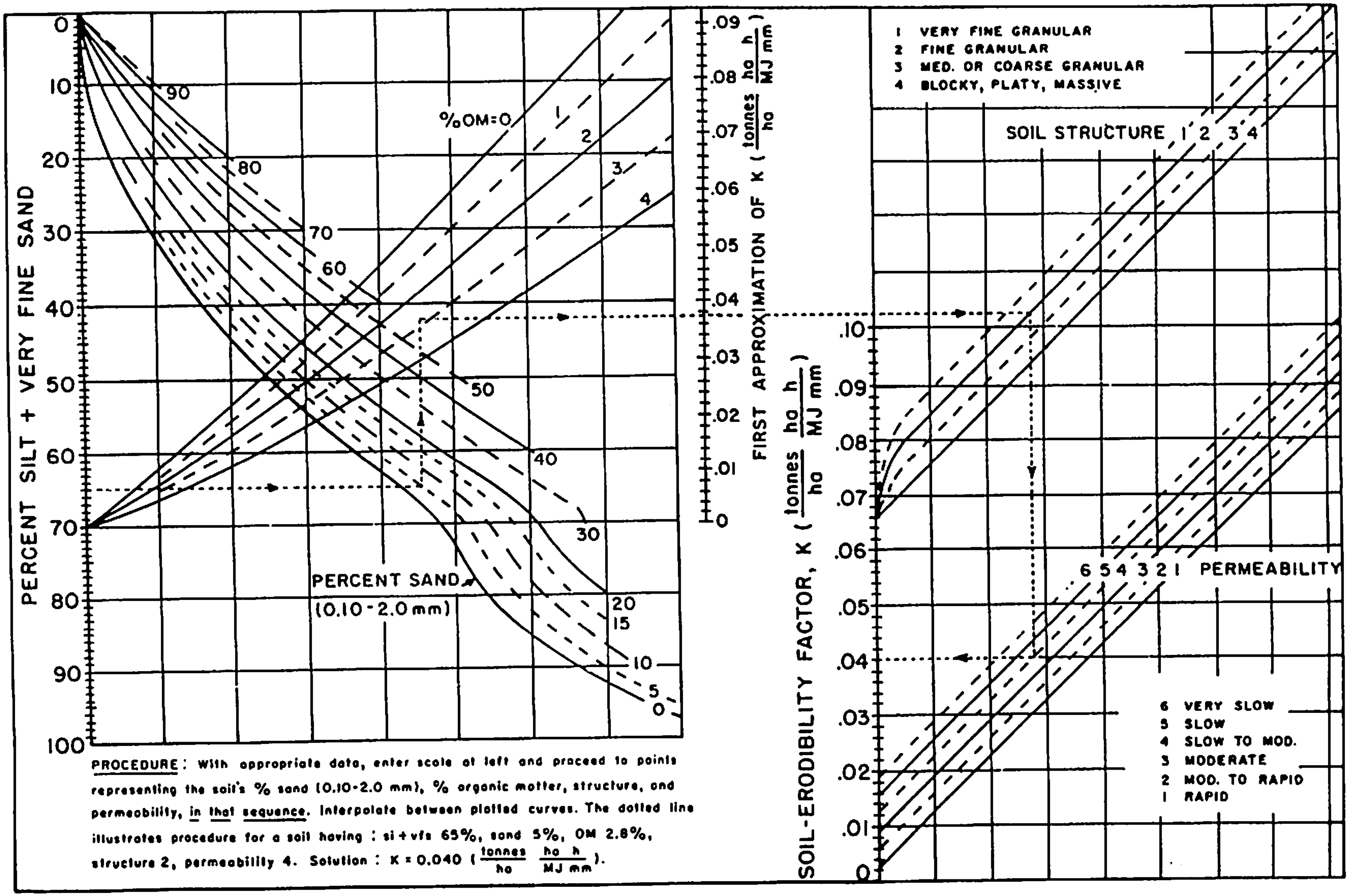


Fig. 6. The soil erodibility nomograph.

then determined over time (cover and management practices take time to implement and their combined and interactive influences may take months or years to stabilize) and on a mostly empirical basis. Moreover, because vegetative cover develops over time and with the seasons, as controlled by plant physiology, climate and weather, management, soil characteristics, etc., it is highly dynamic and highly variable. Therefore, the C factor lumps an enormous amount of information on biological, chemical, physical, and land use or management-induced variability into a single coefficient. Under these conditions, its specification involves a great deal of judgement and subjectivity based upon empirical data and experience. Moreover, the reliability of C factor estimates is a function of all these interactive and ill-defined relationships. True measures of the variability of the C factor estimates are impossible in an objective sense.

The USLE Handbook (Wischmeier and Smith 1978) describes various items affecting estimated C factors as follows: (1) cropstage periods to represent the seasonal changes in effectiveness of plant cover, (2) crop canopy as a measure of the degree of protection provided by the canopy, (3) residue mulch as a measure of "on ground" protection from raindrop impact, (4) incorporated residues affecting the top few inches of soil, (5) tillage as it affects the soil, residues, etc., and (6) land use residual such as the influence of plant roots, organic matter, and other factors of interseasonal importance.

Shallow land burial site preparations that remove all vegetation and also the root zone of the soil leave the surface completely without protection and remove the residual effects of prior vegetation. This condition is comparable to the previously defined continuous fallow condition, and C = 1.0. Roots and residual effects of prior vegetation and partial covers of mulch or vegetation substantially reduce soil erosion. These reductions are reflected in the soil loss prediction by C values of less than 1.0.

Applied mulches immediately restore protective cover on denuded areas and drastically reduce C (Adams 1966, Barnett et al. 1967, Mannering and Meyer 1963, Meyer et al. 1970, Swanson et al. 1967). Soil loss ratios for various percentages of mulch cover on field slopes are given by the upper curve of Fig. 7 where residual effects are insignificant; these ratios equal C. The percentage of surface cover provided by a given rate of uniformly spread straw mulch may be estimated from Fig. 8.

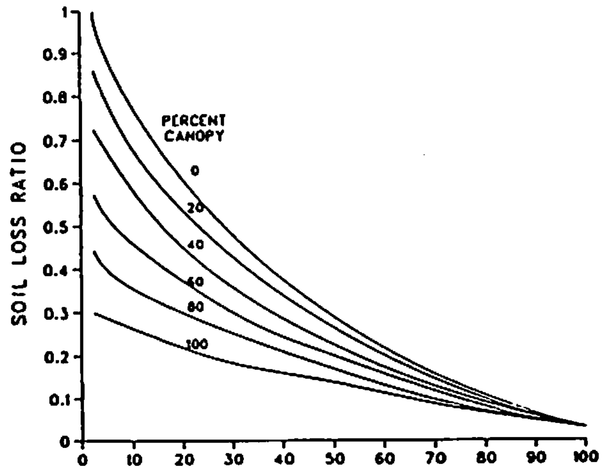


Fig. 7. Combined mulch and canopy effects on soil loss ratio (subfactor for effect of cover) when average fall distance of raindrops from plant canopy to the ground is about 1 m (Wischmeier and Smith 1978).

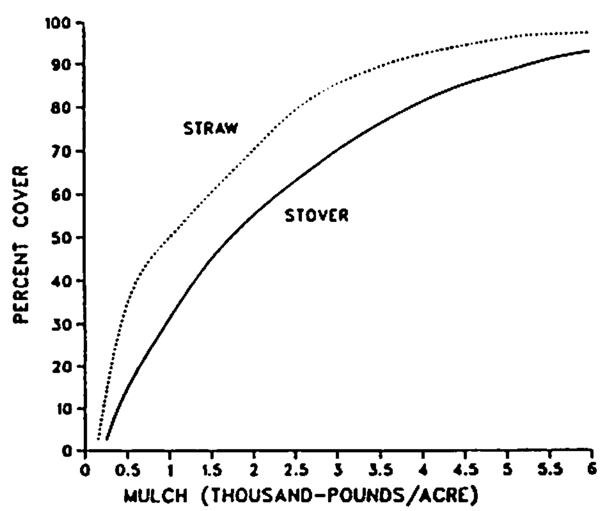


Fig. 8. Relationship of percent cover to dry weight of uniformly distributed residue mulch (Wischmeier and Smith 1978).

Straw or hay mulches applied to steep construction slopes and not tied to the soil by anchoring and tacking equipment may be less effective than equivalent mulch rates on cropland. In Indiana, tests on a 20% slope of scalped subsoil, a 2.3-t rate of unanchored straw mulch allowed soil losses of 12 t/A when 5 in. of simulated rain was applied at 2.5 in./hr on a 35-ft plot (Wischmeier and Meyer, 1973). There was evidence of erosion from flow beneath the straw. Mulches of crushed stone at 135 or more t/A, or wood chips at 7 or more t/A, were more effective.

Table IV presents approximate C values for straw, crushed stone, and woodchip mulches on construction slopes where no canopy cover exists, and also shows the maximum slope lengths on which these values may be assumed to be applicable.

Soil loss ratios for many conditions on SLB, construction, and developmental areas can be obtained from Table IV if good judgment is exercised in comparing the surface conditions with those of specified agricultural conditions. Time intervals analogous to cropstage periods will be defined to begin and end with successive construction or management activities that appreciably change the surface conditions.

The observed soil loss ratios for given conditions often varied substantially from year to year because of influence of unpredictable random variables and experimental error. The percentages listed for Table V are the best available averages for a wide variety of specified agricultural conditions, only a few of which might be applicable to SLB systems. To make the table inclusive enough for general field use, expected ratios had to be computed for cover, residue, and management combinations that were not directly represented in the plot data. This was done by using empirical relationships of soil losses to the subfactors and interactions discussed in the preceding subsection. The user should recognize that the tabulated percentages are subject to appreciable experimental error and could be improved through additional research. However, because of the large volume of data considered in developing the table, the listed values should be near enough to the true averages to provide highly valuable planning and monitoring guidelines. A ratio derived locally from 1-year rainfall simulator tests on a few plots would not necessarily more accurately represent the true average for that locality. Small samples are more subject to bias by random variables and experimental error than are larger samples.

TABLE IV

MULCH FACTORS AND LENGTH LIMITS FOR CONSTRUCTION SLOPES[a]

Type of Mulch	Mulch Rate (Tons/Acre)	Land Slope (%)	Factor C	Length Limit[b] (ft)
None	0	all	1.0	—
Straw or hay,	1.0	1-5	0.20	200
tied down by	1.0	6-10	0.20	100
anchoring and				
tacking	1.5	1-5	0.12	300
equipment[c]	1.5	6-10	0.12	150
	2.0	1-5	0.06	400
	2.0	6-10	0.06	200
	2.0	11-15	0.07	150
	2.0	16-20	0.11	100
	2.0	21-25	0.14	75
	2.0	26-33	0.17	50
	2.0	34-50	0.20	35
Crushed stone,	135	<16	0.05	200
¼ to 1½ in	135	16-20	0.05	150
	135	21-33	0.05	100
	135	34-50	0.05	75
	240	<21	0.02	300
	240	21-33	0.02	200
	240	34-50	0.02	150
Wood chips	7	<16	0.08	75
	7	16-20	0.08	50
	12	<16	0.05	150
	12	16-20	0.05	100
	12	21-33	0.05	75
	25	<16	0.02	200
	25	16-20	0.02	150
	25	21-33	0.02	100
	25	34-50	0.02	75

[a]From Meyer and Ports (1976). Developed by an interagency workshop group on the basis of field experience and limited research data.
[b]Maximum slope length for which the specified mulch rate is considered effective. When this limit is exceeded, either a higher application rate or mechanical shortening of the effective slope length is required.
[c]When the straw or hay mulch is not anchored to the soil, C values on moderate or steep slopes of soils having K values greater than 0.30 should be taken at double the values given in this table.

TABLE V

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e]							
				F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Corn after C, GS, G, or COT in Meadowless Systems Moldboard plow, conv till:										
1	RdL, sprg TP	4500	—	31	55	48	38	—	—	20	23
2		3400	—	36	60	52	41	—	24	20	30
3		2600	—	43	64	56	43	32	25	21	37
4		2000	—	51	68	60	45	33	26	22	47
5	RdL, fall TP	HP[b]	—	44	65	53	38	—	—	20	—
6		GP	—	49	70	57	41	—	24	20	—
7		FP	—	57	74	61	43	32	25	21	—
8		LP	—	65	78	65	45	32	26	22	—
9	RdR, sprg TP	HP	—	66	74	65	47	—	—	22	56[g]
10		GP	—	67	75	66	47	—	27	23	62
11		FP	—	68	76	67	48	35	27	—	69
12		LP	—	69	77	68	49	35	—	—	74
13	RdR, fall TP	HP	—	76	82	70	49	—	—	22	—
14		GP	—	77	83	71	50	—	27	23	—
15		FP	—	78	85	72	51	35	27	—	—
16		LP	—	79	86	73	52	35	—	—	—
17	Wheeltrack pl, RdL, TP[h]	4500	—	—	31	27	25	—	—	18	23
18		3400	—	—	36	32	30	—	22	18	30
19		2600	—	—	43	36	32	29	23	19	37
20		2000	—	—	51	43	36	31	24	20	47
21	Deep offset disk or disk plow	4500	10	—	45	38	34	—	—	20	23
22		3400	10	—	52	43	37	—	24	20	30
23		2600	5	—	57	48	40	32	25	21	37
24		2000	—	—	61	51	42	33	26	22	47
25	No-till plant in crop residue[i]	6000	95	—	2	2	2	—	—	2	14
26		6000	90	—	3	3	3	—	—	3	14
27		4500	80	—	5	5	5	—	—	5	15
28		3400	70	—	8	8	8	—	8	6	19
29		3400	60	—	12	12	12	12	9	8	23
30		3400	50	—	15	15	14	14	11	9	27
31		2600	40	—	21	20	18	17	13	11	30
32		2600	30	—	26	24	22	21	17	14	36

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e] F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Chisel, shallow disk, or fld cult as only tillage:										
33	On moderate slopes	6000	70	—	8	8	7	—	—	7	17
34			60	—	10	9	8	—	—	8	17
35			50	—	13	11	10	—	—	9	18
36			40	—	15	13	11	—	—	10	19
37			30	—	18	15	13	—	—	12	20
38			20	—	23	20	18	—	—	16	21
39		4500	70	—	9	8	7	—	—	7	18
40			60	—	12	10	9	—	—	8	18
41			50	—	14	13	11	—	—	9	19
42			40	—	17	15	13	—	—	10	20
43			30	—	21	18	15	—	—	13	21
44			20	—	25	22	19	—	—	16	22
45		3400	60	—	13	11	10	—	10	8	20
46			50	—	16	13	12	—	12	9	24
47			40	—	19	17	16	—	14	11	25
48			30	—	23	21	19	—	17	14	26
49			20	—	29	25	23	—	21	16	27
50			10	—	36	32	29	—	24	20	30
51		2600	50	—	17	16	15	15	13	10	29
52			40	—	21	20	19	19	15	12	30
53			30	—	25	23	22	22	18	14	32
54			20	—	32	29	28	27	22	17	34
55			10	—	41	36	34	32	25	21	37
56		2000	40	—	23	21	20	20	15	12	37
57			30	—	27	25	24	23	19	15	39
58			20	—	35	32	30	28	22	18	42
59			10	—	46	42	38	33	26	22	47

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO
CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e] F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	On slopes >12%										
60	Lines 33-59 × factor of:	—	—	—	1.3	1.3	1.1	1.0	1.0	1.0	1.0
	Disk or harrow after spring chisel or fld cult:										
	Lines 33-59 × factor of:										
61	On moderate slopes	—	—	—	1.1	1.1	1.1	1.0	1.0	1.0	1.0
62	On slopes >12%	—	—	—	1.4	1.4	1.2	1.0	1.0	1.0	1.0
	Ridge plant[j]:										
	Lines 33-59 × factor of:										
63	Rows on contour[k]	—	—	—	0.7	0.7	0.7	0.7	0.7	0.7	0.7
64	Rows U/D slope <12%	—	—	—	0.7	0.7	1.0	1.0	1.0	1.0	1.0
65	Rows U/D slope >12%	—	—	—	0.9	0.9	1.0	1.0	1.0	1.0	1.0
	Till plant:										
	Lines 33-59 × factor of:										
66	Rows on contour[k]	—	—	—	0.7	0.85	1.0	1.0	1.0	1.0	1.0
67	Rows U/D slope <7%	—	—	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Strip till ¼ of row spacing:										
68	Rows on contour[k]	4500	60[g]	—	12	10	9	—	—	8	23
69		3400	50	—	16	14	12	—	11	10	27
70		2600	40	—	22	19	17	17	14	12	30
71		2000	30	—	27	23	21	20	16	13	36
72	Rows U/D slope	4500	60[g]	—	16	13	11	—	—	9	23
73		3400	50	—	20	17	14	—	12	11	27
74		2600	40	—	26	22	19	17	14	12	30
75		2000	30	—	31	26	23	20	16	13	36
	Vari-till:										
76	Rows on contour[k]	3400	40	—	13	12	11	—	—	11	22
77		3400	30	—	16	15	14	14	13	12	26
78		2600	20	—	21	19	19	19	16	14	34

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e] F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Corn after WC of rygrass or wheat seeded in C stubble										
	WC reaches stemming stage:										
79	No-till pl in killd WC	4000	—	—	7	7	7	—	7	6	m
80		3000	—	—	11	11	11	11	9	7	
81		2000	—	—	15	15	14	14	11	9	
82		1500	—	—	20	19	18	18	14	11	
	Strip till ¼ row space										
83	Rows U/D slope	4000	—	—	13	12	11	—	11	9	m
84		3000	—	—	18	17	16	16	13	10	
85		2000	—	—	23	22	20	19	15	12	
86		1500	—	—	28	26	24	22	17	14	
87	Rows on contour[k]	4000	—	—	10	10	10	—	10	8	m
88		3000	—	—	15	15	15	15	12	9	
89		2000	—	—	20	20	19	19	15	12	
90		1500	—	—	25	24	23	22	17	14	
91	TP, conv seedbed	4000	—	36	60	52	41	—	24	20	m
92		3000	—	43	64	56	43	31	25	21	
93		2000	—	51	68	60	45	33	26	22	
94		1500	—	61	73	64	47	35	27	23	
	WC succulent blades only:										
95	No-till pl in killed WC	3000	—	—	11	11	17	23	18	16	m
96		2000	—	—	15	15	20	25	20	17	
97		1500	—	—	20	20	23	26	21	18	
98		1000	—	—	26	26	27	27	22	19	
99	Strip till ¼ row space	3000	—	—	18	18	21	25	20	17	m
100		2000	—	—	23	23	25	27	21	18	
101		1500	—	—	28	28	28	28	22	19	
102		1000	—	—	33	33	31	29	23	20	

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e]: F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Corn in Sod-Based Systems										
	No-till pl in killed sod:										
103	3 to 5 times hay yld	—	—	—	1	1	1	—	1	1	1
104	1 to 2 tons hay yld	—	—	—	2	2	2	2	2	2	2
	Strip till, 3-5 ton M:										
105	50% cover, tilled strips	—	—	—	2	2	2	—	2	2	4
106	20% cover, tilled strips	—	—	—	3	3	3	—	3	3	5
	Strip till, 1-2 ton M:										
104	40% cover, tilled strips	—	—	—	4	4	4	4	4	4	6
108	20% cover, tilled strips	—	—	—	5	5	5	5	5	5	7
	Corn After Soybeans										
109	Sprg TP, conv till	HP	—	40	72	60	48	—	—	25	29
110		GP	—	47	78	65	51	—	30	25	37
111		FP	—	56	83	70	54	40	31	26	44
112	Fall TP, conv till	HP	—	47	75	60	48	—	—	25	—
113		GP		53	81	65	51	—	30	25	—
114		FP	—	62	86	70	54	40	31	26	—
115	Fall & sprg chisel or cult	HP	30"	—	40	35	29	—	—	23	29
116		GP	25	—	45	39	33	—	27	23	37
117		GP	20	—	51	44	39	34	27	23	37
118		FP	15	—	58	51	44	36	28	23	44
119		LP	10	—	67	59	48	36	28	23	54
120	No-till pl on crop res'd	HP	40"	—	25	20	19	—	14	11	26
121		GP	30	—	33	29	25	22	18	14	33
122		FP	20	—	44	38	32	27	23	18	40

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e] F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Beans After Corn										
123	Sprg TP, RdL, conv till	HP	—	33	60	52	28	—	20	17	
124		GP	—	39	64	56	41	—	21	18	
125		FP	—	45	68	60	43	29	22	—	
126	Fall TP, RdL, conv till	HP	—	45	69	57	38	—	20	17	
127		GP	—	52	73	61	41	—	21	18	
128		FP	—	59	77	65	43	29	22	—	
	Chisel or fld cult:	o	o	o	o	o	o	o	o		
	Beans after beans	p	p	p	p	p	p	p	p		
	Grain after C, G, GS, COT[g]										
129	In disked residues:	4500	70	—	12	12	11	7	4	2	r
130		3400	60	—	16	14	12	7	4	2	
131			50	—	22	18	14	8	5	3	
132			40	—	27	21	16	9	5	3	
133			30	—	32	25	18	9	6	3	
134			20	—	38	30	21	10	6	3	
135		2600	40	—	29	24	19	9	6	3	r
136			20	—	43	34	24	11	7	4	
137			10	—	52	39	27	12	7	4	
138		2000	30	—	38	30	23	11	7	4	r
139			20	—	46	36	26	12	7	4	
140			10	—	56	43	30	13	8	5	
141	In disked stubble, RdR	—	—	—	79	62	42	17	11	6	r
142	Winter G after fall TP, RdL	HP	—	31	55	48	31	12	7	5	r
143		GP	—	36	60	52	33	13	8	5	
144		FP	—	43	64	56	36	14	9	5	
145		LP	—	53	68	60	38	15	10	6	

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

Line No.	Cover, crop sequence, and Management[a]	Spring Residue[b] (lb)	Cover After Plant[c] (%)	Soil Loss Ratio[d] for Cropstage Period and Canopy Cover[e] F (%)	SB (%)	1 (%)	2 (%)	3:80 (%)	90 (%)	96 (%)	4L[f] (%)
	Grain After Summer Fallow										
146	With grain residues	200	10	—	70	55	43	18	13	11	
147		500	30	—	43	34	23	13	10	8	
148		750	40	—	34	27	18	10	7	7	
149		1000	50	—	26	21	15	8	7	6	
150		1500	60	—	20	16	12	7	5	5	
151		2000	70	—	14	11	9	7	5	5	
152	With row crop residues	300	5	—	82	65	44	19	14	12	
153		500	15	—	62	49	35	17	13	11	
154		750	23	—	50	40	29	14	11	9	
155		1000	30	—	40	31	24	13	10	8	
156		1500	45	—	31	24	18	10	8	7	
157		2000	55	—	23	19	14	8	7	5	
158		2500	65	—	17	14	12	7	5	4	
	Potatoes										
159	Rows with slope	—	—	43	64	56	36	26	19	16	
160	Contoured rows, ridged when canopy cover is about 50%[k]	—	—	43	64	28	18	13	10	8	

[a]Symbols: B = soybeans; C = corn, conv till = plow, disk, and harrow for seedbed; cot = cotton; F = rough fallow, fld cult = field cultivator; G = small grain; CS = grain sorghum; M = grass and legume meadow, at least 1 full year; pl = plant; RdL = crop residues left on field; RdR = crop residues removed; SB = seedbed period; sprg = spring; TP = plowed with moldboard; WC = winter cover crop; — = insignificant or an unlikely combination of variables.

[b]Dry weight per acre after winter loss and reductions by grazing or partial removal: 4500 lb represents 100 to 125 bu corn; 3400 lb, 75 to 99 bu; 2600 lb, 60 to 74 bu; and 2000 lb, 40 to 59 bu, with normal 30% winter loss. For RdR or fall-plow practices, these four productivity levels are indicated by HP, GP, FP, and LP, respectively (high, good, fair, and low productivity). In lines 79 to 102, this column indicates dry weight of the winter-cover crop.

TABLE V (cont)

RATIO OF SOIL LOSS FROM CROPLAND TO CORRESPONDING LOSS FROM CONTINUOUS FALLOW

[c]Percentage of soil surface covered by plant residue mulch after crop seeding. The difference between spring residue and that on the surface after crop seeding is reflected in the soil loss ratios as residues mixed with the topsoil.

[d]The soil loss ratios, given as percentages, assume that the indicated crop sequence and practices are followed consistently. One-year deviations from normal practices do not have the effect of a permanent change. Linear interpolation between lines is recommended when justified by field conditions.

[e]Cropstage periods are as defined in the text. The three columns for cropstage 3 are for 80, 90, and 96 to 100% canopy cover at maturity.

[f]Column 4L is for all residues left on field. Corn stalks partially standing as left by some mechanical pickers. When residues are reduced by grazing, take ratio from lower spring-residue line.

[g]Period 4 values in lines 9 to 12 are for corn stubble (stover removed).

[h]Inversion plowed, no secondary tillage. For this practice, residues must be left and incorporated.

[i]Soil surface and chopped residues of ***matured*** preceding crop undisturbed except in narrow slots in which seeds are planted.

[j]Top of old row ridge sliced off, throwing residues and some soil into furrow areas. Reridging assumed to occur near end of cropstage 1.

[k]Where lower soil loss ratios are listed for rows on the contour, this reduction is in addition to the standard field contouring credit. The P value for contouring is used with these reduced loss ratios.

[l]Field-average per cent cover; probably about three-fourths of per cent cover on undisturbed strips.

[m]Divide the winter-cover period into cropstages for the seeded cover and use lines 132-145.

[n]Spring residue may include carryover from prior corn crop.

[o]Use values from lines 33 to 62 with appropriate dates and lengths of cropstage periods for beans in the locality.

[p]Values in lines 109 to 122 are best available estimates, but planting dates and lengths of cropstages may differ.

[q]When meadow is seeded with the grain, its effect will be reflected through higher percentages of cover in cropstages 3 and 4.

[r]Ratio depends on per cent cover.

Table V is designed to provide the details needed by a trained agronomist to develop simple handbook tables of C values for conditions in specific climatic areas. The agronomist will first determine, for the particular climatic area, the number of weeks normally required for the plant canopies to attain 10, 50, and 75% surface cover, respectively. Linear interpolation between ratios listed in the table is recommended where appropriate.

Agronomists have divided the cropstage year into a series of periods in which the C factor is considered uniform because the effectiveness of plant cover to reduce soil erosion changes with time. Thus, soil loss ratios for the computation of C in Table V were evaluated for the following six cropstage periods:

Period F (rough fallow)—Inversion plowing to secondary tillage.

Period SB (seedbed)—Secondary tillage for seedbed preparation until the crop has developed 10% canopy cover.

Period 1 (establishment)—End of SB until crop has developed a 50% canopy cover.

Period 2 (development)—End of period 1 until canopy cover reaches 75%

Period 3 (maturing crop)—End of period 2 until crop harvest. This period was evaluated for three levels of final crop canopy.

Period 4 (residue or stubble)—Harvest to plowing or new seeding.

Water erosion is a serious problem also in subhumid and semiarid regions. Inadequate moisture and periodic droughts reduce the periods when growing plants provide good soil cover and limit the quantities of plant residue produced. Erosive rainstorms are not uncommon, and they are usually concentrated within the season when cropland is least protected. Because of the difficulty of establishing rotation meadows and the competition for available soil moisture, sod-based rotations are often impractical. One of the most important opportunities for a higher level of soil and moisture conservation is through proper management of available residues. The effect of mulch-tillage practices in these areas can be evaluated from lines 129 to 158 of Table V.

Establishing vegetation on the denuded areas, such as on a new SLB trench cap, as quickly as possible is highly important. A good sod has a C value of 0.01 or less (Table VI), but such a low C value can be obtained quickly only by laying sod on the area, at a substantial cost. When grass or small grain is started from seed, the probable soil loss for the period while cover is developing can be computed by the procedure outlined for estimating cropstage-period soil losses. If the seeding is on topsoil, without a mulch, the soil loss ratios given in line 141 of Table V are appropriate for cropstage C values. If the seeding is on a desurfaced area, where residual effects of prior vegetation are no longer significant, the ratios for periods SB 1 and 2 are 1.0, 0.75 and 0.50, respectively, and line 141 applies for cropstage 3. When the seedbed is protected by a mulch, the pertinent mulch factor from the upper curve of Figure 7 is applicable until good canopy cover is attained. The combined effects of vegetative mulch and low-growing canopy are given in Figure 9. When grass is established in small grain, it can usually be evaluated as established meadow about 2 months after the grain is cut.

Figures 7 and 9 and Table V assume that slope-length limits for full effectiveness of residue mulches at the stated rates are not exceeded. Beyond these limits, the subfactor for mulch effect approaches 1.0. The length limits vary inversely with mulch rate, runoff depth and velocity, but have not been precisely defined by research.

Within each climatic zone there are periods during the year when highly erosive rainfall episodes are expected (subject to localized and short-termed weather patterns) and periods of poor to good plant cover. Therefore, for the same soil, topography, rainfall energy, etc., if the degree of correspondence between rainfall periods and plant growth stages varies between regions, then the value of C for the same cropping system will vary between the regions. Under these conditions, it is necesary to derive C factors for the localized climatic and plant growth relationships (see Wischmeier and Smith 1978: discussion on climatic adjustments for seasonal variations in EI).

Research efforts are underway throughout the United States and in several other countries to determine C factors under a variety of conditions. Two general approaches are used separately and in combination. First is the subfactor approach wherein C for a particular situation is estimated based on the known influence of component processes via a subfactor approach. The second method is to transport portable rainfall simulators to various locations to derive on-site estimates of C factors using simulated rainfall (see description of our field research in

TABLE VI

FACTOR C FOR PERMANENT PASTURE, RANGE, IDLE LAND, OR GRAZED WOODLAND[a]

Vegetative Canopy: Type and height[b]	Vegetative Canopy: Percent cover[c]	Cover that contacts the soil surface: Type[d]	Percent ground cover: 0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	0.45	0.24	0.15	0.091	0.043	0.011
Tall grass, weeds or short brush with average drop fall height of <3 ft[e]	25	G	0.36	0.17	0.09	0.038	0.013	0.003
		W	0.36	0.20	0.13	0.083	0.041	0.011
	50	G	0.26	0.13	0.07	0.035	0.012	0.003
		W	0.26	0.16	0.11	0.076	0.039	0.011
	75	G	0.17	0.10	0.06	0.032	0.011	0.003
		W	0.17	0.12	0.09	0.068	0.038	0.011
Appreciable brush or bushes, with average drop fall height of 6½ ft	25	G	0.40	0.18	0.09	0.040	0.013	0.003
		W	0.40	0.22	0.14	0.087	0.042	0.011
	50	G	0.34	0.16	0.08	0.038	0.012	0.003
		W	0.34	0.19	0.13	0.082	0.041	0.011
	75	G	0.28	0.14	0.08	0.036	0.012	0.003
		W	0.28	0.17	0.12	0.078	0.040	0.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft	25	G	0.42	0.19	0.10	0.041	0.013	0.003
		W	0.42	0.23	0.14	0.089	0.042	0.011
	50	G	0.39	0.18	0.09	0.040	0.013	0.003
		W	0.39	0.21	0.14	0.087	0.042	0.011
	75	G	0.36	0.17	0.09	0.039	0.012	0.003
		W	0.36	0.20	0.13	0.084	0.041	0.011

[a]The listed C values assume that the vegetation and mulch are randomly distributed over the entire area. For grazed woodland with high buildup of organic matter in the topsoil under permanent forest conditions, multiply the table values by 0.7. For areas that have been mechanically disturbed by root plowing, implement traffic, or other means, use Table V.

[b]Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

[c]Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[d]G = cover at surface is grass, grasslike plants, or decaying compacted duff.
W = cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

[e]The portion of a grass or weed cover that contacts the soil surface during a rainstorm and interferes with water flow over the soil surface is included in cover at the surface; the remainder is included in canopy cover.

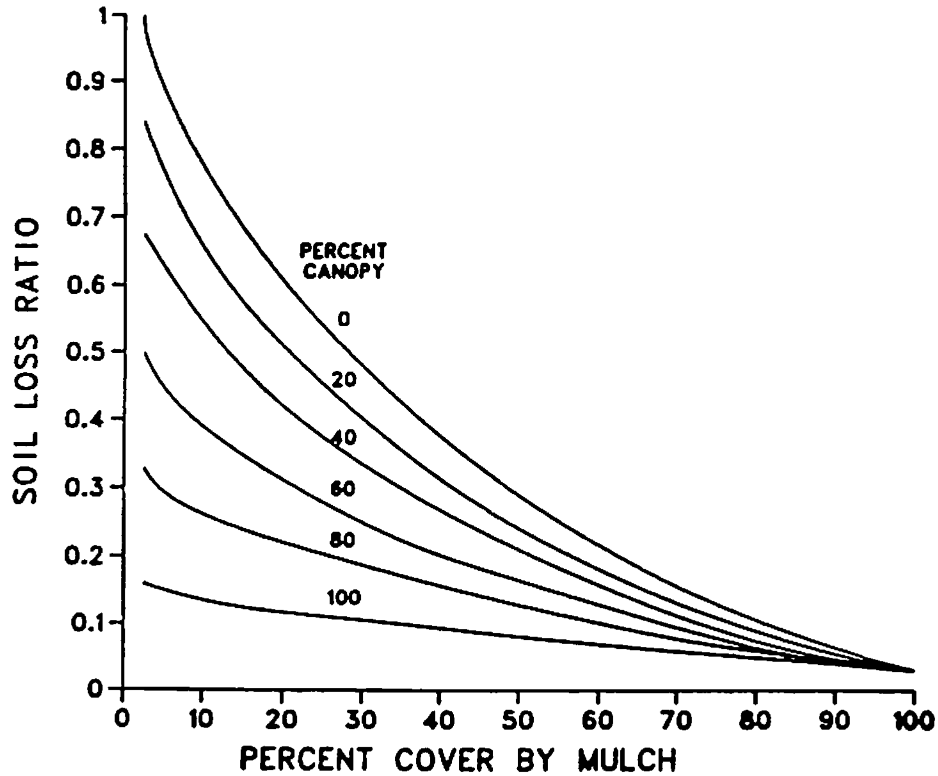


Fig. 9. Combined mulch and canopy effects on soil loss ratio (subfactor for effect of cover) when average fall distance of raindrops from plant canopy to the ground is about 0.5 m (Wischmeier and Smith 1978).

Sec. V). These efforts are producing additional estimates of C factors beyond those summarized in the USLE Handbook.

G. The Support Practice Factor (P)

In general, whenever sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil it can carry. Contour tillage, stripcropping on the contour, and terrace systems are the most important of these supporting cropland practices. Stabilized waterways for the disposal of excess rainfall are a necessary part of each of these practices.

By definition, factor P in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up- and downslope culture. Improved tillage practices, sod-based rotations, fertility treatments, and leaving greater quantities of crop residues on the field contribute materially to erosion control and frequently provide the major control. However, these measures are considered to be conservation cropping and management practices, and the benefits derived from them are included in the C factor.

A workshop at Purdue University in 1956 adopted a series of contour P values that varied with percent slope (Wischmeier and Smith 1978). The P values were based on available data and field observations, which were supplemented by group judgment. Subsequent experience indicated only a few minor changes. Current recommendations are given in Table VII. They are average values for the factor on the specified slopes. Specific-site values may vary with soil texture, type of vegetation, residue management, and rainfall pattern, but data have not become available to make the deviations from averages numerically predictable.

TABLE VII

P VALUES AND SLOPE-LENGTH LIMITS FOR CONTOURING
(Wischmeier and Smith 1978)

Land Slope (%)	P Value	Maximum Length[a] (ft)
1 to 2	0.60	400
3 to 5	0.50	300
6 to 8	0.50	200
9 to 12	0.60	120
13 to 16	0.70	80
17 to 20	0.80	60
21 to 25	0.90	50

[a]Limit may be increased by 25% if residue cover after vegetation plantings will regularly exceed 50%.

Full contouring benefits are obtained only on fields relatively free from gullies and depressions other than grassed waterways. Effectiveness of this practice is reduced if a field contains numerous small gullies and rills that are not obliterated by normal tillage operations. In such instances, land smoothing should be considered before contouring. Otherwise, a judgment value greater than shown in Table VII should be used when computing the benefits for contouring.

After the 1956 workshop, the Soil Conservation Service prepared reference tables for use with the Corn Belt slope-practice procedure. They included guides for slope-length limits for effective contouring. These limits are also given in Table VII. Data to establish the precise limits for specific conditions are still not available. However, the P values given in Table VII assume slopes short enough for full effectiveness of the practice. Their use for estimating soil loss on unterraced slopes that are longer than the specified table limits specified is speculative.

For highly disturbed field systems such as construction and shallow land burial sites, the P factor will usually have a value of 1.0. Erosion-reducing effects of shortening slopes or reducing slope gradients can generally be accounted for through the LS factor.

If the lower part of a grass or woodland slope on a SLB development area can be left undisturbed while the upper part is being developed, the procedure outlined for computing the value of LSC on irregular slopes is applicable, and sediment deposition on the undisturbed strip must be accounted for separately. For prolonged construction periods, such as are routinely found at SLB sites, buffer strips of grass, small grain, or high rates of anchored mulch may also be feasible to induce deposition within the area. Such deposition is important for water quality or off-site sediment control but it should be evaluated from soil-transport factors rather than by a P factor.

H. General Comment on the USLE

The USLE, as an empirically-derived and data-based model, shares the strengths and weaknesses of such procedures. In terms of its main factors (RLSKCP), it is a linear equation but in terms of the effect of physical features and management practices on the factors, it is nonlinear. For example, LS is a nonlinear function of slope length and steepness and C is a nonlinear function of the percentage of mulch cover.

The USLE is intended to estimate long-term average annual soil loss from upland areas. The emphasis in development of the equation was on agricultural areas of the humid United States. Users and potential users should keep these two factors in mind in application of the USLE.

The USLE has, for decades, provided a focus and a methodology of conducting erosion and soil conservation research. As a method for focusing research and as a method of summarizing research data representing complex processes and interactions, the USLE has been very useful. The USLE is the most widely known and accepted method of predicting erosion and of evaluating the influence of erosion control methods. The equation and its associated methodology will probably be used in these ways for the foreseeable future. However, the USLE should not be seen as a true and final representation of erosion, erosion prediction, and erosion research. The USLE is a step in our continuing efforts to develop understanding and improved models to estimate erosion and sediment yield.

The USLE is best used to estimate relative soil losses under various land use and management practices. In the SLB context this means that the USLE can be used to rank the relative effectiveness of alternative erosion control methods. Once the best one or two methods are selected, then additional on-site data can be taken to better quantify the specific USLE factors and soil loss rates. An alternative would be to apply a more sophisticated model (for example, the CREAMS model (Knisel 1980)) to make more intensive investigations once the USLE has been used to rank the relative effectiveness.

IV. EXTENSION OF THE UNIVERSAL SOIL LOSS EQUATION TO SHALLOW LAND BURIAL SYSTEMS IN THE WEST

The eleven western states encompass an area of 1 176 714 square miles. They comprise a complex combination of geologic, topographic, climatic, and vegetative features. This region includes the highest (14 495 ft, Mt. Whitney, California) and the lowest (−280 ft, Badwater, California) elevations, the highest (134°F, Furnace Creek, California) and the lowest (−70°F, Rogers Pass, Montana) recorded temperatures, and the highest (147 inches, Wynoochee, Washington) and the lowest (<2 inches, Death Valley, California) recorded annual precipitation in the United States, excepting Hawaii and Alaska. The complexity of these features has favored the development of a repetitive distribution pattern for a large number of different kinds of soils (Agricultural Experiment Stations 1964), which do vary from soils found in the Eastern states.

The data originally used to develop the USLE were extensive, including 10 000 plot-years of data from natural runoff plots and small watersheds for a wide range of soils, slope length and steepness, crops, and management practices common to croplands in the Eastern United States. The data used to extend the USLE to the West and to rangeland were limited in comparison with the original data (Wischmeier 1974, Wischmeier 1975). Notice that only one western state (Washington) is listed in this original data base (Table I).

Although the USLE was originally developed for cropland in the Eastern United States, its use today has been successfully extended to construction sites, rangeland, forest lands, and surface mines in all parts of the US and in several foreign countries (Foster 1982). However, all of these applications of the USLE, such as for shallow land burial, must consider the significance, meaning, and derivation of each of its factors as they relate to conditions that might be significantly different from those that produced the original USLE data set.

For example, consider the use of the rainfall and runoff factor, R, for a land management application in the West. Several areas of the West are characterized by infrequency of rainfall and by very large spatial variability of rainfall. Foster (1982) suggests that accurate estimates for specific events are required when annual soil loss is dominated by one or two storms in a year, which should result in a reexamination of the R factor for critical specific events.

Many landslopes that could be used for SLB in the West exceed 20 or 25%, which is the upper limit of the data used to develop the slope steepness factor, S, in the USLE. However, the results of one field study (Meyer et al. 1975) demonstrated that soil loss from interrill erosion did not increase greatly for observed slopes between 15 and 30%. Foster (1982) summarized several similar studies and recommended using the basic relationships expressed in Equation (4), recognizing that soil loss from steep slopes may be overestimated.

Obvious differences between the midwestern soils, which were used to derive the nomograph for the soil erodibility factor, K, and the western soils, raise questions about the transferability of the nomograph. Western soils are sometimes covered by erosion pavement, which is not found on many eastern soils. In addition, variations in eastern and western rainfall patterns could result in different K values for the same soil located in the two climates (Foster 1982). The effects of these two differences on K have not been studied.

Another potential problem with the values of K involves its use of a clean-tilled plot as a reference point. Most shallow land burial topsoils would not be cultivated and, if they were tilled, the disturbance is less intense and more infrequent than is tillage of agricultural soils. Thus, tilled fallow does not represent a typical SLB condition, but it may be a necessary reference if the large amount of information on K derived from cropland soils is to be transferred to SLB conditions. This implies that a new reference plot should be defined for SLB conditions and its relationship to the current tilled plot should be defined.

The only solution to the previously-listed problems of extending the USLE to these areas is through the use of rainfall simulators because there is not a 10 000 plot-year data base for soils of the West and for SLB systems. Rainfall simulator studies are necessary to experimentally determine the K and C USLE parameters for a rapidly changing soil surface on a SLB trench or in a natural western ecosystem. Thus, using rainfall simulator data, we can, with a great deal of accuracy and under controlled conditions, make reasonable estimates of K and C for many different conditions on various sites, and conveniently determine how these values change with time.

V. RAINFALL SIMULATOR STUDIES AT LOS ALAMOS

A. Introduction

Our study investigated the water balance and erosional behavior of SLB trench caps for several cover conditions. Plots were established at the Los Alamos Engineered Test Facility (ETF) and were subjected to simulated rainfall to generate infiltration, runoff, and erosion. The effects of antecedent soil water content were evaluated, and the soil erodibility factor, K, and the cover management factor, C, of the USLE were estimated for our trench cap configuration. In addition, using neutron moisture gauge techniques, fluctuations in soil water content within and below the trench cap were monitored as a function of time and cover treatment.

B. Description of Field Experiment and Experimental Techniques

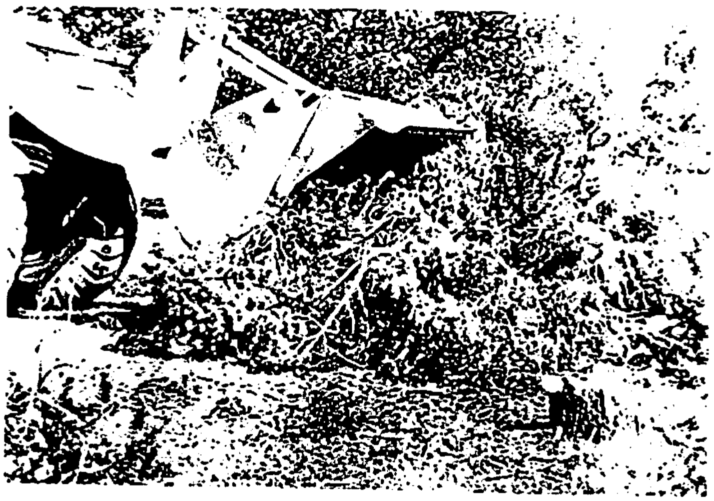
A 15- by 63-m simulated trench cap was constructed (Fig. 10) at the ETF in Los Alamos, New Mexico (DePoorter 1981) to closely match trench caps used for shallow land burial at Los Alamos (Warren 1980). The configuration of this trench cap consisted of a 15-cm layer of backfilled Hackroy series topsoil, which had been stockpiled at the site, underlain by a 90-cm layer of crushed Bandelier tuff backfill that was classified as belonging to geologic mapping unit 3 (Rogers 1977). Both layers were installed with dominant downhill slopes of 7%. We compared the hydrologic behavior of this highly disturbed system with an adjacent undisturbed soil profile that had natural cover. The Hackroy sandy loam was classified as a Lithic Aridic Haplustalf (clayey, mixed, mesic family), which formed in material weathered from Bandelier tuff on mesa tops (Nyhan et al. 1978). The native overstory vegetation is mainly piñon pine (*Pinus edulis* Engelm.), one-seeded juniper [*Juniperus monosperma* (Engelm.) Sarg.], and scattered ponderosa pine (*Pinus ponderosa* Laws.). Our natural study plots also contained blue grama [*Bouteloua gracilis* (H.B.K) Lag.], dropseed [*Sporobolus cryptandrus* (Torr.) Gray], snakeweed [*Gutierrezia microcephala* (D.C.) Gray], pinque [*Hymenoxys richardsonii* var. *floribunda* (Gray) Parker], and prickly pear (*Opuntia polyacantha* Haw.).

The criteria for erosion plot selection were based on the requirements set forth during the original development of the USLE on rangelands (Wischmeier and Smith 1978) and on the constraints of the rainfall simulator (Simanton and Renard 1982). The eight experimental plots on the simulated trench cap and the two natural plots were each 3.1- by 11-m, with the long axis parallel to the slope. Each plot pair on the trench cap was constructed on centers located 17 m apart and with metal plot borders as described previously (Simanton and Renard 1982). Runoff from the plots was collected in troughs, which diverted the runoff into a runoff-measuring flume with a FW-1 water-level recorder that measured continuous stage height.

Immediately after the rain simulator runs, percentages of plant cover on the plots with barley and natural cover were determined from color photographs taken above and from the side of the plots. For the 1982 study, this process involved projecting a photograph of the plot area on a grid with about 7000 intersections and determining the number of occurrences of vegetation at these intersections. Percent plant cover was then calculated for each plot. A similar procedure was used to evaluate plant and gravel cover in the 1982 study, with the exception that the grid used had 385 intersections.

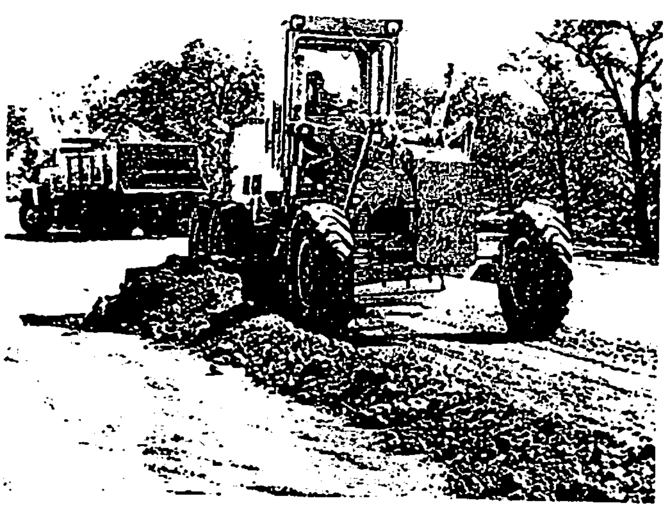
Rainfall simulators, such as the one used in this study, are useful to determine USLE parameters for a rapidly changing soil surface such as that found on trench caps covering waste materials. Rainfall simulators have been used extensively to collect soil erodibility data, to measure the effect of cropping and tillage on soil erosion, and to determine the effects of various soil treatments on soil erosion (Alberts et al. 1980, Foster et al. 1968, Laflen 1982, Meyer et al. 1972, Wischmeier and Mannering 1969, Wischmeier et al. 1971). The rainfall simulator used in this study (Fig. 11) was a trailer-mounted rotating boom simulator capable of applying either 60 or 120 mm h^{-1} of water (Swanson 1965). Ten arms radiating from a central stem support 15 nozzles, which spray downward from an average height of 2.4 m. They apply about 0.25 ℓs^{-1} of water and produce drop-size distributions and impact velocities similar to those of natural rainfall (Swanson 1979), resulting in rainfall energies at about 80% of those of natural rainfall.

Rainfall amount and application rate were measured using a modified recording rain gauge



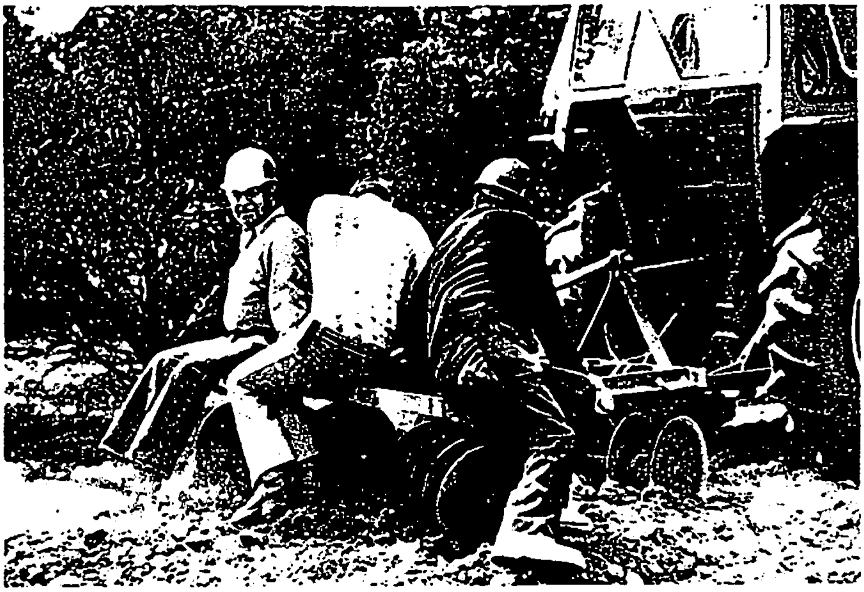
(a) Removing piñon-juniper vegetation.

(b) Grading crushed tuff portion of trench cap.



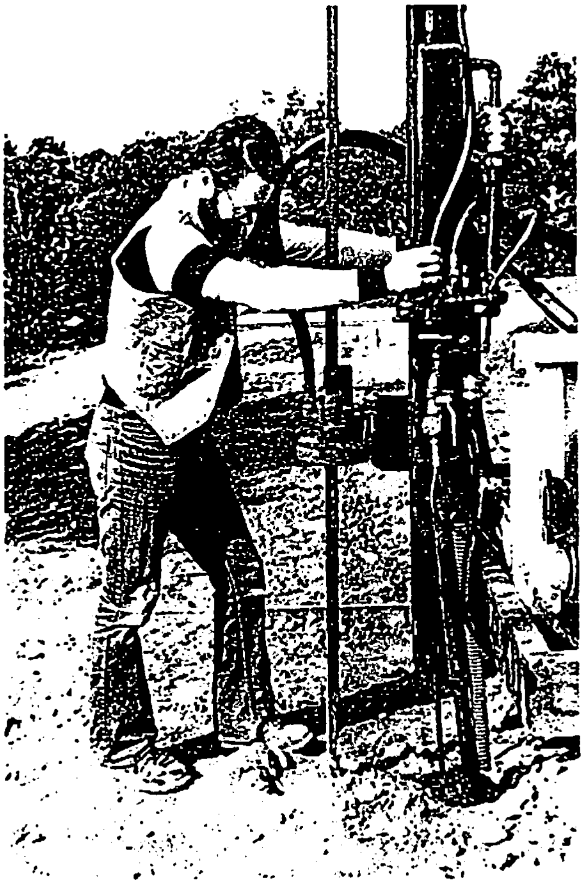
(c) Addition of soil layer to trench cap.

Fig. 10. Construction phases of simulated trench cap at the Los Alamos ETF.



(d) Disking trench cap topsoil.

(e) Installation of metal erosion plot borders.



(f) Drilling holes for neutron moisture gauge access tubes.

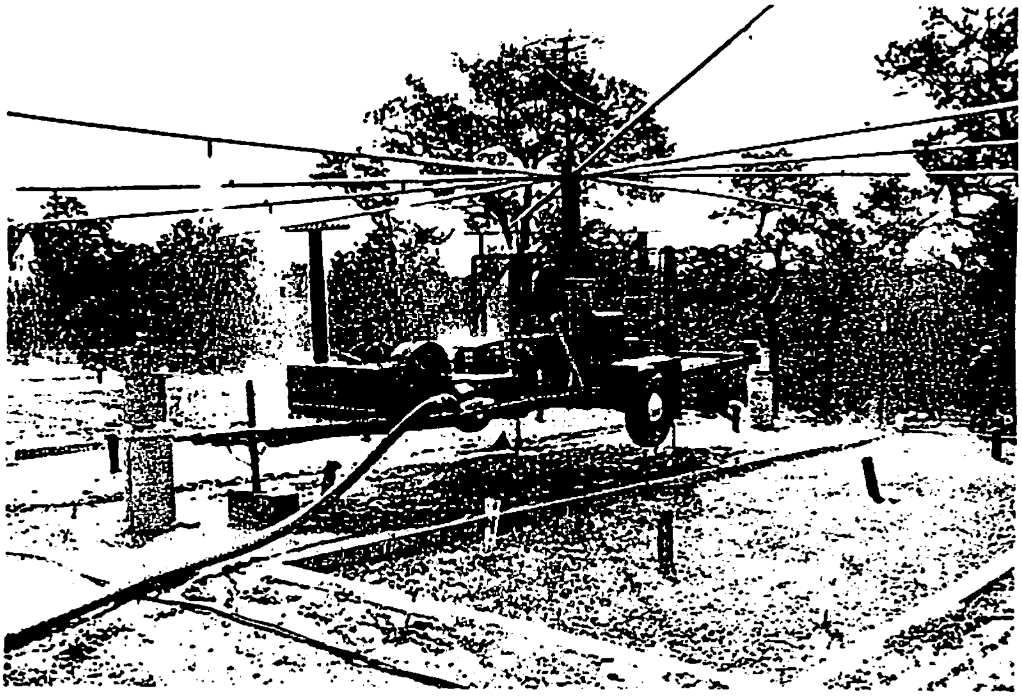


Fig. 11. Rotating boom rainfall simulator used in erosion plot research.

placed between each plot pair. The rain gauge was modified for increased sensitivity by doubling the rainfall collection area and enlarging the recorded time scale. The distribution of rainfall over each erosion plot was measured with four gauges that recorded rainfall amount near each of the plot corners.

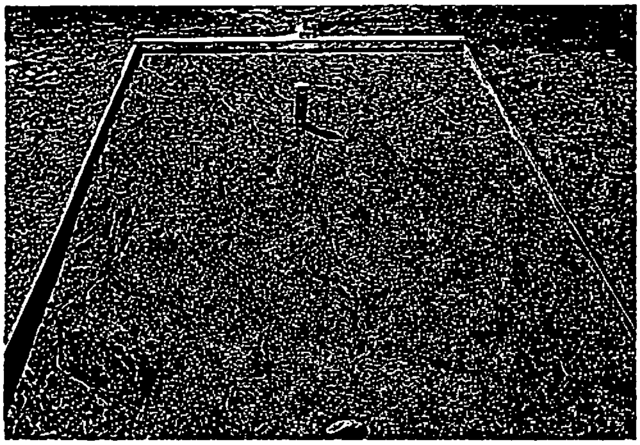
The rain simulator run sequence consisted of an initial 60-min rainfall simulation at existing levels of soil water (dry soil surface), a 30-min run 24 h later (wet soil surface), and another 30-min run after a 30-min delay (very wet soil surface). The simulated rainfall rate was always about 60 mm h^{-1}.

Soil loss for each simulated rainstorm was calculated as the product of runoff rate and the concentration of sediment in the runoff. The flumes used to measure runoff have a capacity of about 4 ℓ s^{-1}, with water level recorders modified according to Simanton and Renard (1982). During the rising and falling portions of the hydrograph, 1-ℓ samples were collected every 30 to 40 s. After runoff rate became nearly steady, samples were collected every 10 min. The sediment concentration in each runoff sample was determined by weighing the sample, allowing about 40 days for the sediment particles to settle to the bottom of the sample jars, decanting the water, and weighing the sample jar and dried sediment after they were dried at 60°C for three days.

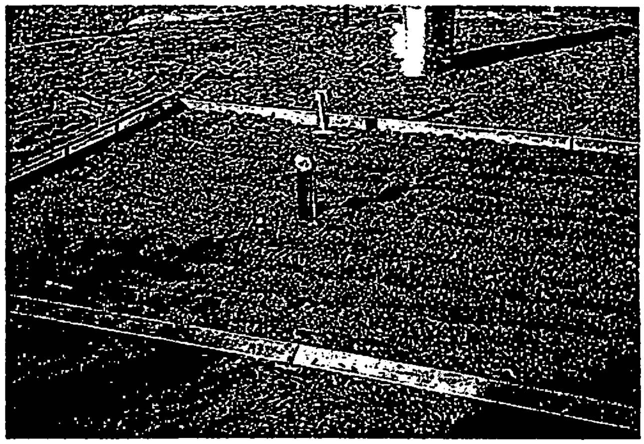
The soil water content beneath the surface of the trench cap was monitored with a Troxler Model 3221-A moisture gauge (Troxler Electronic Laboratories, Inc., Research Triangle Park, North Carolina). A total of three moisture gauge access tubes (with a length of 1.67 m, outside diameter of 5.1 cm, and wall thickness of 1.7 mm) were emplaced in each erosion plot at distances of 1.8-, 5.3-, and 8.9-m from the upper end of each plot.

C. Rain Simulator Studies During 1982

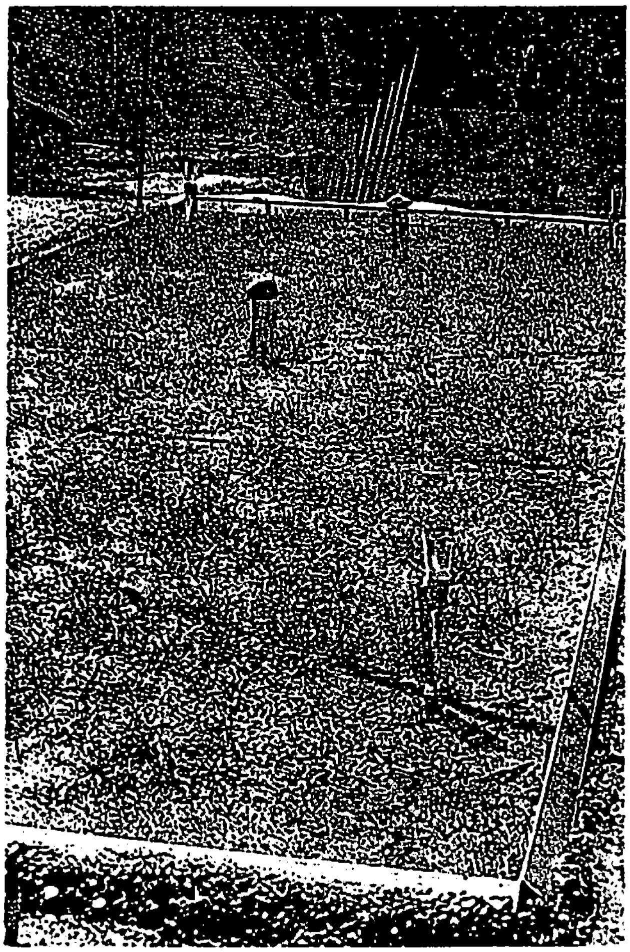
Three treatments were imposed on the eight plots on the trench cap (Fig. 12; Nyhan et al., 1984). Two plots received an up- and downslope disking (cultivated treatment). Both standard tilled plots were comparable, except for lengthened slope, to the 22.1-m USLE unit plot of continuous tilled fallow (used to determine the USLE soil erodibility factor). Two other plots were not tilled and also had no vegetative cover (bare soil treatment). To determine the influence of vegetation on soil erosion, four plots



(a) Bare soil surface treatment.



(b) Cultivated surface treatment.



(c) Barley cover treatment.

(d) Natural cover treatment.

Fig. 12. Surface treatments on erosion plots in 1982.

were seeded with barley (*Hordeum vulgare* L.) at a seeding rate of 22 g m^{-2}, and received a simultaneous surface application of 20-10-5 (N-P-K) fertilizer at a rate of 13.5 g m^{-2}.

1. Hydrograph and Sedigraph Data. The hydrographs, sediment concentrations, and sedigraphs for the rain simulator runs are presented in Fig. 13 and in Fig. 14 for the erosion plots with natural cover. During the period of gradually increasing runoff in the dry surface runs on both plots, sediment concentrations remained relatively constant (3.5 to 4.1 g ℓ^{-1}) so that sediment discharge rates gradually increased to a maximum of 64.9 g min^{-1} (Figs. 13 and 14). In the successive wet and very wet runs, runoff occurred more promptly after the start of the rain than did previous runoff events on the plots, reflecting the decreased infiltration rate into increasingly wet soil profiles. Peak sediment concentrations, ranging from 4.0 to 5.4 g ℓ^{-1}, and peak sediment discharge rates, ranging from 97 to 109 g min^{-1}, did not occur until the final very wet run, clearly showing the effect of antecedent moisture.

The differences between the results from these two replicated plots with natural vegetative cover (Figs. 13 and 14), located only 3 m apart, are indicative of variability in infiltration, runoff, and erosion encountered in rainfall simulator studies in rangelands (Simanton and Renard 1982). Subtle differences in sediment concentrations, discharge rates, and times before the start of runoff in these two plots resulted in a coefficient of variation [(standard deviation/mean) × 100] in soil loss rates of 39%.

Hydrograph, sediment concentration, and sedigraph data are presented in Figs. 15 through 17 for typical rain simulator runs on the trench cap with cultivated, bare soil, and barley cover treatments, respectively.

During the simulator run on the dry soil surface on the cultivated plot (Fig. 15), discharge rates increased to 40 to 46 mm hr^{-1}, and sediment concentrations ranging from 84 to 108 g ℓ^{-1} were observed. This resulted in maximum sediment discharge rates of 2677 g min^{-1} for this rain simulator event (Fig. 15). This suggests that sediment transport/deposition processes and interactions during the events were dynamic, which in turn, suggests the occurrence (as was observed along the bottom 3 m of the plot after the three applied rainstorms) of sediment redistribution processes near and in the furrows that formed on the plot.

Although the effect of antecedent soil water content on discharge rate was observed on the cultivated plot, a smaller difference in discharge rates occurred on this plot between the wet and very wet soil surface simulator runs (Fig. 15) than for the natural cover plots (Figs. 13 and 14). However, antecedent soil water content consistently affected the amount of time before runoff began once rainfall started.

Although discharge rates for the bare soil (Fig. 16), barley cover (Fig. 17), and cultivated (Fig. 15) treatments were similar, sediment concentrations varied considerably between treatments. Maximum sediment concentrations from the smooth bare, soil plot were only 60 g ℓ^{-1}, much less than the 108 g ℓ^{-1} concentration that occurred on the cultivated plot. Sediment concentrations from the plot with barley cover (Fig. 17) were lower, ranging from 15 to 22 g ℓ^{-1} during peak runoff for the dry soil surface run and from 20 to 26 g ℓ^{-1} during the wet and very wet simulator runs.

The hydrograph and sedigraph data for each rain simulator run were integrated over time and the average runoff and soil loss amounts for each surface treatment are shown in Table VIII.

Only 14 mm of runoff occurred during the dry soil surface run from the plots with natural vegetative cover, resulting in a runoff/precipitation ratio of 0.26, whereas soil loss was 1.47 kg (Table VIII). In contrast, the runoff/precipitation ratios for all of the trench cap plots ranged from 0.75 to 0.99, suggesting that less than 25% of the water infiltrated the trench cap during the simulated rain. In making these comparisons in the absolute values of the runoff/precipitation ratios, we expect CV's associated with each ratio to range from about 10 to 15%; however, additional research needs to be performed in the errors associated with all of the estimates presented in Table VIII.

Average soil losses for each simulator run on the natural plots ranged from 0.7 to 3.4% of the losses on the cultivated plots, whereas losses from the bare soil and barley cover treatments were 64 to 67% and 29 to 38% of the losses from the cultivated plots (Table VIII). The coefficient of variation (CV) in total soil loss between replicated plots ranged from only 14 to 23% on these plots, compared with the larger variation observed on the natural plots.

The influence of antecedent soil water content on water erosion can also definitely be shown for all of the trench cap plots. Thus, soil loss rates increased

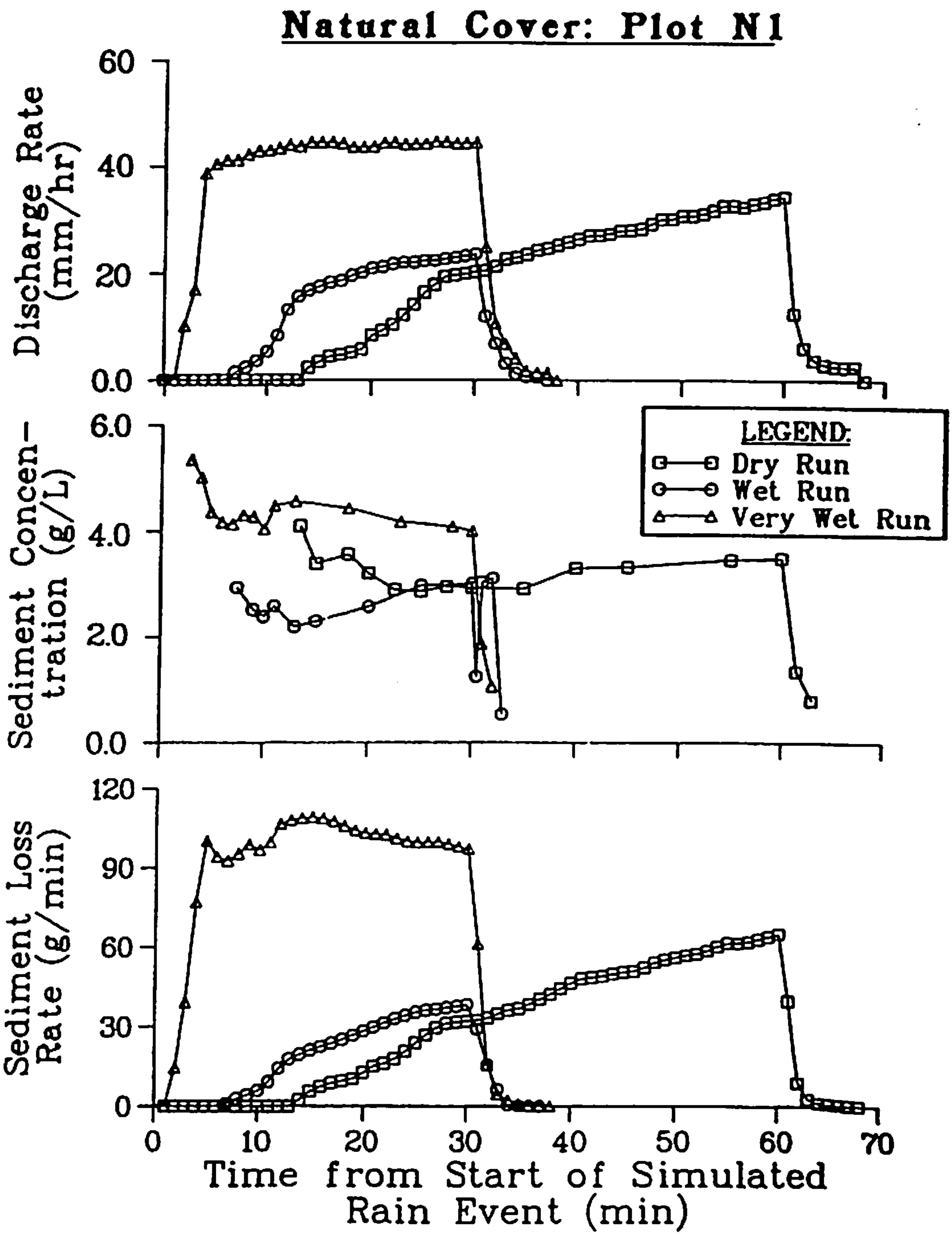


Fig. 13. Hydrograph, sediment concentration, and sedigraph data from natural cover plot N1 (1982 data).

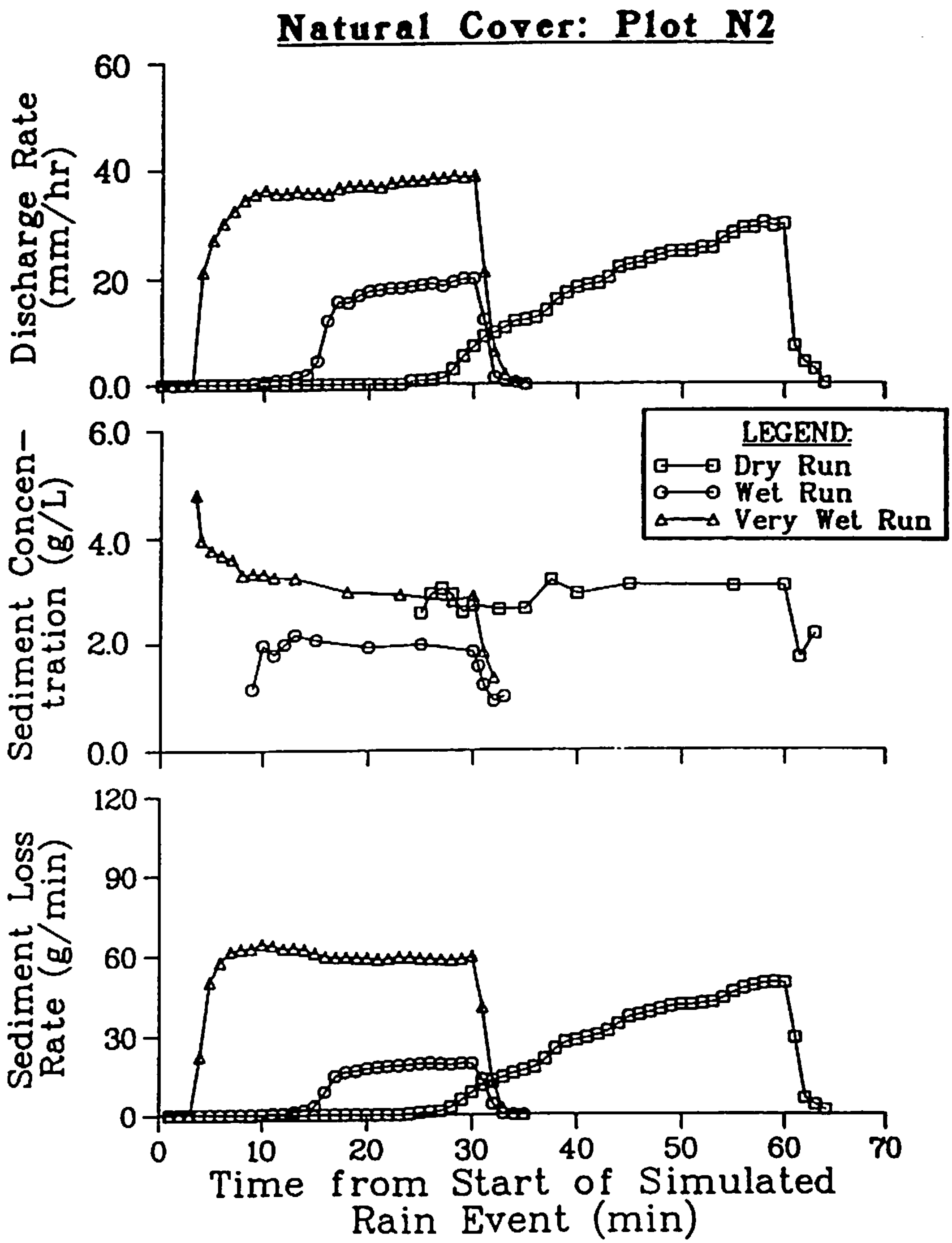


Fig. 14. Hydrograph, sediment concentration, and sedigraph data from natural cover plot N2 (1982 data).

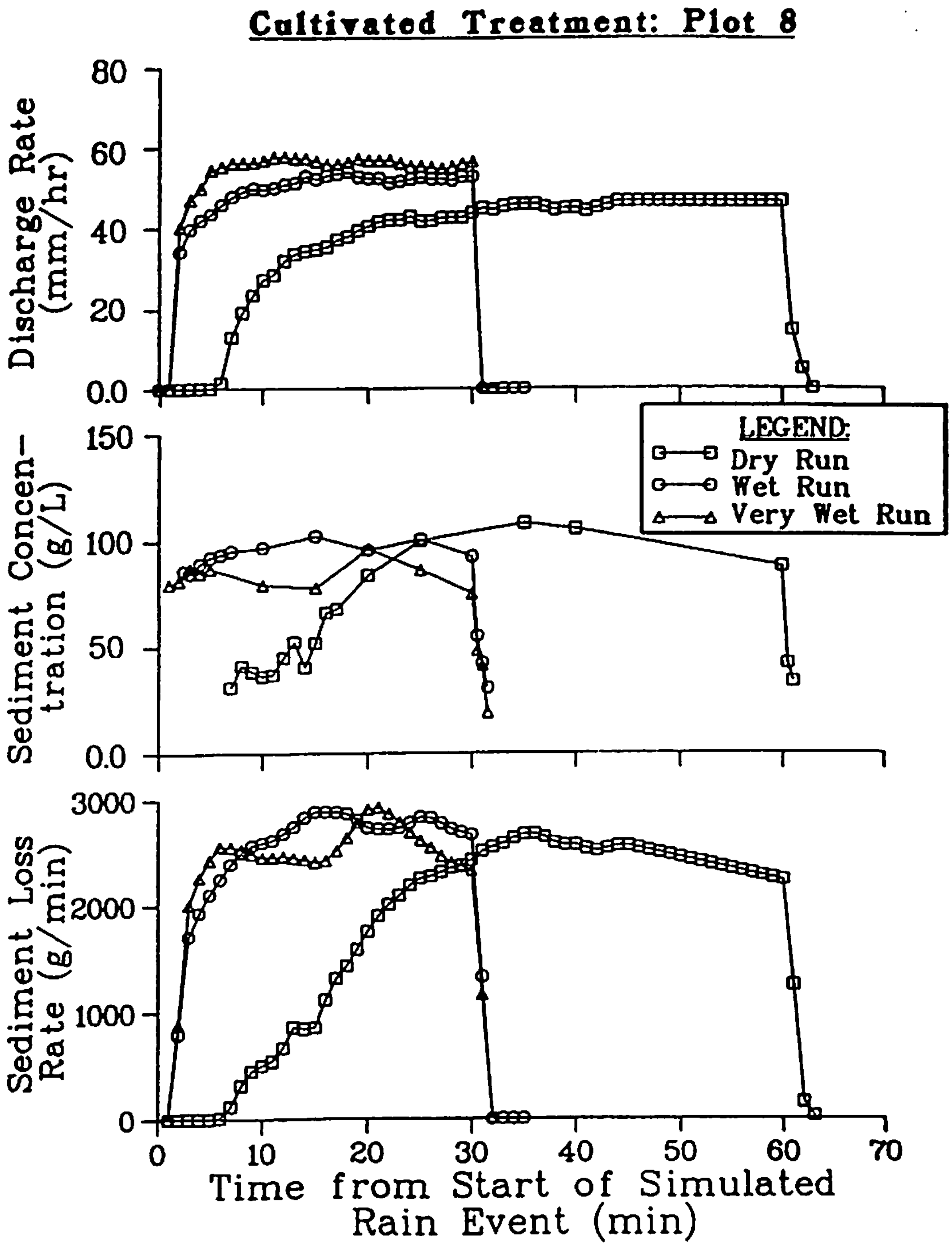


Fig. 15. Hydrograph, sediment concentration, and sedigraph data from plot 8 with cultivated treatment (1982 data).

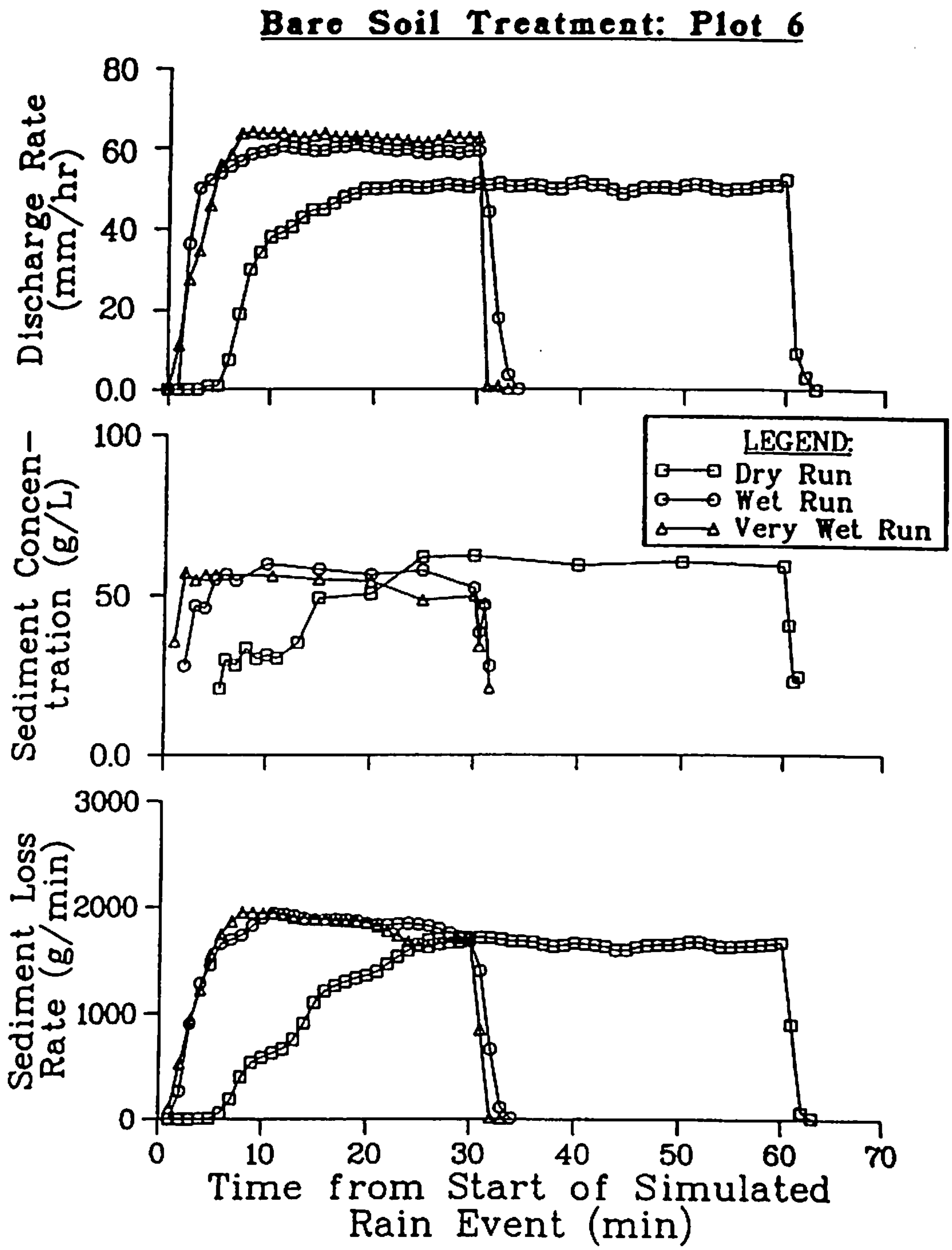


Fig. 16. Hydrograph, sediment concentration, and sedigraph data from plot 6 with bare soil treatment (1982 data).

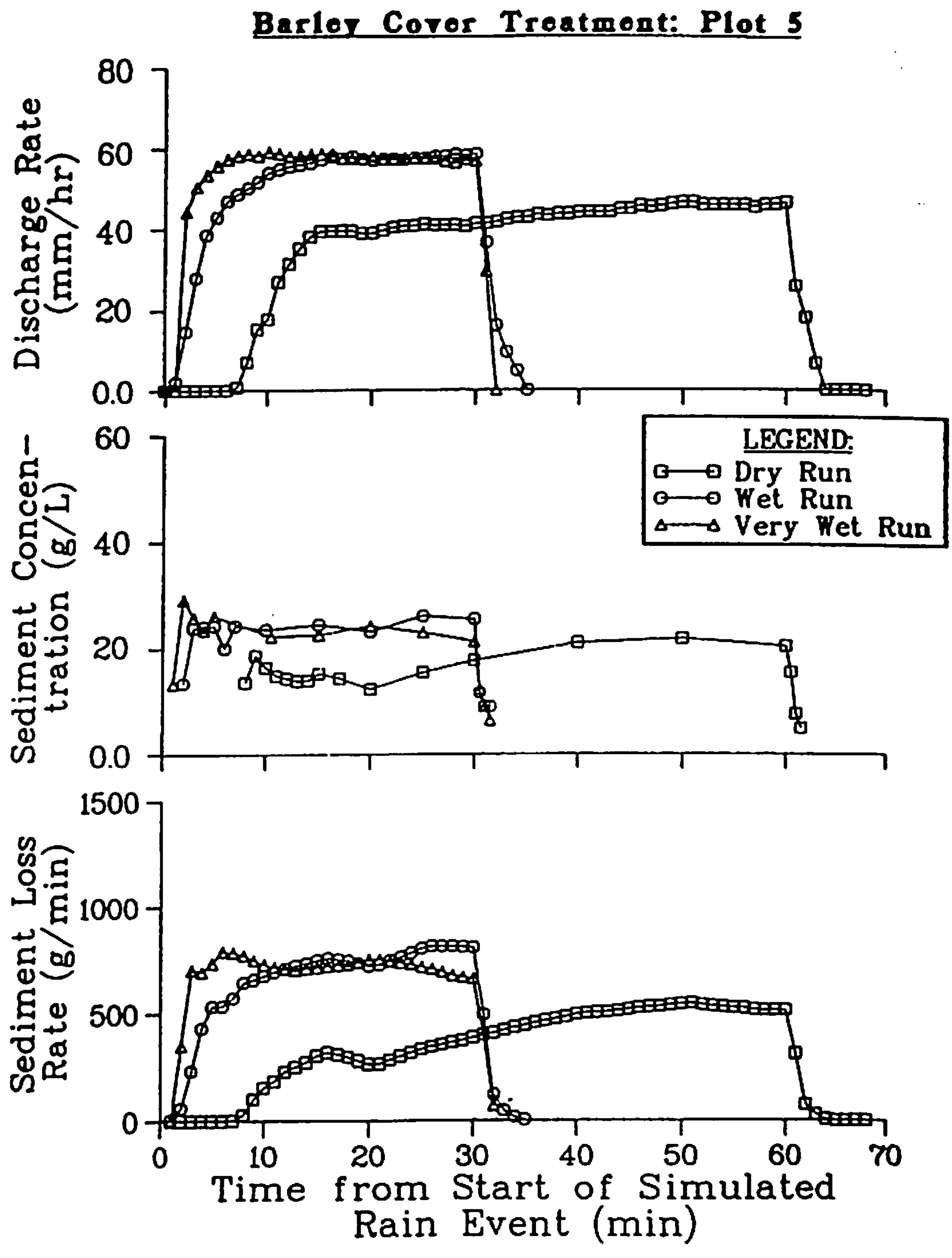


Fig. 17. Hydrograph, sediment concentration, and sedigraph data from plot 5 with barley cover (1982 data).

TABLE VIII

AVERAGE RUNOFF, RUNOFF/PRECIPITATION RATIOS, AND SOIL LOSS FOR RAIN SIMULATOR RUNS ON DRY, WET, AND VERY WET SOIL SURFACES ON EROSION PLOTS AS A FUNCTION OF SURFACE TREATMENT[a] (1982 data)

Treatment (No. of plots)	Average Runoff (mm)			Average Runoff/ Precipitation Ratios			Average Soil loss (kg)		
	Dry Surface	Wet Surface	Very Wet Surface	Dry Surface	Wet Surface	Very Wet Surface	Dry Surface	Wet Surface	Very Wet Surface
Natural Cover (2)	14.5	6.0	18.7	0.26	0.28	0.65	1.47	0.46	2.24
Cultivated (2)	44.1	25.0	27.2	0.82	0.93	0.94	104.93	65.37	66.09
Bare Soil (2)	46.7	26.8	28.4	0.90	0.92	0.99	70.55	41.88	44.58
Barley Cover (4)	37.9	26.5	27.6	0.75	0.92	0.95	30.56	23.43	24.84

[a]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}.

by 19 to 53% between the dry and wet soil surface simulator runs and only increased 1 to 7% between the wet and very wet soil surface runs (Table VIII).

2. **Soil Erodibility and Cover Management Factors.** 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 USLE. Values for K were calculated from the measured soil losses from the cultivated plots and the energy and intensity of the simulated rainstorms applied to these plots. Soil losses from the three rain 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 storm energy × rainfall intensity (EI) factor (storm erosivity factor) for the runoff of the three simulated rainstorms was calculated (Meyer and McCune 1958) as the product of the energy of the rainstorms (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 CV of 16% (n=6). This K value agrees quite well with the estimate of 0.079 Mg ha h ha^{-1} MJ^{-1} mm^{-1}, which we determined from the soil erodibility nomograph (Fig. 6).

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 IX). Soil loss ratios ranged from 0.27 to 0.43 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 (Table V), and for the natural vegetation in local rangelands, having soil loss ratio values of 0.01 to 0.08 (Table VI).

Soil loss ratios are obviously more than just a function of vegetative cover, as evidenced by the

TABLE IX

SOIL LOSS, COVER MANAGEMENT FACTOR (C), AND PLANT COVER ESTIMATES FOR THE TRENCH CAP PLOTS WITH BARLEY COVER AND THE NATURAL PLOTS (1982 DATA)

Plot Number	Total Soil Loss[a] (Mg ha^{-1})	C Factor[b]	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

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

large difference between soil loss ratios for the barley on the trench cap and the cover on the natural plots (Table IX). 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 by canopy, also ranged from 63 to 78% cover, yet much smaller soil losses were observed on these plots than on the barley plots.

Several subfactors of the cover-management 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 preparations, such as those that occurred on our trench cap plots, remove 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 (cryptograms) 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 sandier topsoil found on the natural plots. These factors influenced the infiltration-runoff relationships on these two types of soils and surfaces (Table VIII, see section E for more detail).

In time, 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 our undisturbed natural plots. Thus, the time required for the revegetated trench cap surfaces to reduce soil erosion as effectively as do the natural systems has major implications in waste management decisions at these sites. Clearly, more research is needed to investigate how the subfactors of the cover management factor and the soil erodibility factor 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.

3. **Summary.** Soil erosion and hydrologic relationships of a trench cap used for SLB of radioactive wastes were investigated and compared with similar data for an undisturbed, natural soil system. The hydrograph and sedigraph measurements generated during simulated rain events demonstrated that antecedent soil water content of the surface soils significantly affected infiltration and erosion rates for all erosion plots. Values of apparent runoff/precipitation ratios were much lower on the plots with natural cover (0.26-0.65) than plots on the highly disturbed trench cap (0.82-0.99). It must be stated again that ratios as high as 0.99 may be influenced by measurement errors; nonetheless, these ratios are higher on the disturbed plots. Soil losses from the plots were influenced more by variations in sediment concentrations than by discharge rates. Variation in soil loss between replicated plot treatments was less on the trench cap plots (14-23%) than on the natural plots (39%). Soil loss from the plots with natural cover was about 2% of that from the cultivated plots on the trench cap, and the soil loss from plots with the bare soil and barley cover treatments on the trench cap had 66 and 33%, respectively, less soil loss than did the cultivated plots.

The soil erodibility K factor and soil loss ratios for the cover management C factor of the USLE were quantified from the soil loss data. An average K value of 0.085 Mg ha h ha^{-1} MJ^{-1} mm^{-1} was estimated from our cultivated plot data, with a CV of 16%. Soil loss ratio values for the barley plots on the trench cap were about 20 times larger than corresponding soil loss ratios for the natural plots.

D. Rain Simulator Studies During 1983

Four treatments were imposed on the eight erosion plots by the end of July 1983 (Fig. 18). 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 soil 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 covers on soil erosion, two plots were prepared as the bare soil treatment and they then received a gravel (<13 mm diameter) cover at an application rate of 60 t/A (gravel cover treatment). The influence of partial gravel covers 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).

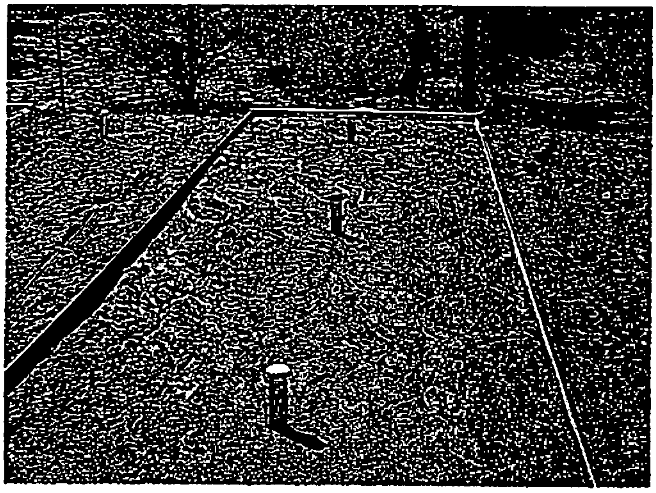
1. **Hydrograph and Sedigraph Data.** Hydrograph, sediment concentration, and sedigraph data are presented in Figs. 19 through 22 for typical rain simulator runs on the trench cap with cultivated, bare soil, gravel cover, and gravel and plant cover treatments.

During three rain simulator runs on the cultivated plot (Fig. 19), maximum discharge rates ranged from 63 to 66 mm hr^{-1}, and maximum sediment concentrations ranging from 63.6 to 75.5 g ℓ^{-1} were observed. This resulted in maximum sediment loss rates for the three simulator runs on this plot that ranged from 2210 to 2476 g min^{-1}—similar to the data collected on this plot in the previous year (Fig. 15).

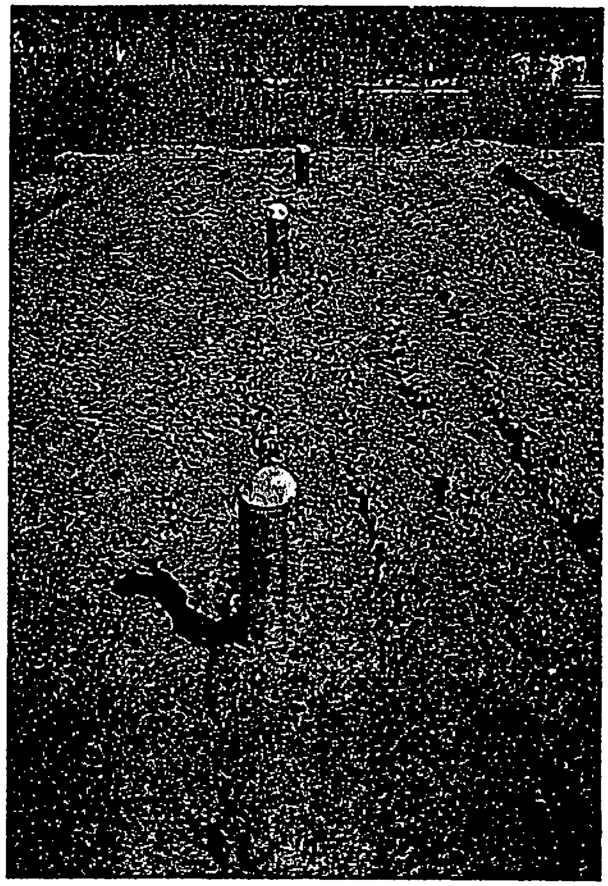
In contrast to the cultivated treatment, sediment concentrations observed in the bare soil plot usually ranged from only 30-50 g ℓ^{-1} (Fig. 20). These data were also similar to the data collected on this plot in 1982.

The plants with gravel cover exhibited maximum sediment concentrations and loss rates that were 13 to 24 times smaller than on the plots with the cultivated treatment (Figs. 21 and 22). The hydrograph data from these plots showed, in comparison with the other treatments, a marked delay in the amount of time it took until runoff ceased. A series of gravel dams located along the entire length of the erosion plot prolonged the length of runoff on these plots to 8 to 14 minutes after the end of the simulated rainfall (Figs. 21 and 22). Since the wheatgrass was only about 30 days old at the time of the August 1983 simulator runs, very little difference was expected or observed in the hydrograph and sedigraph results between the two surface gravel application treatments.

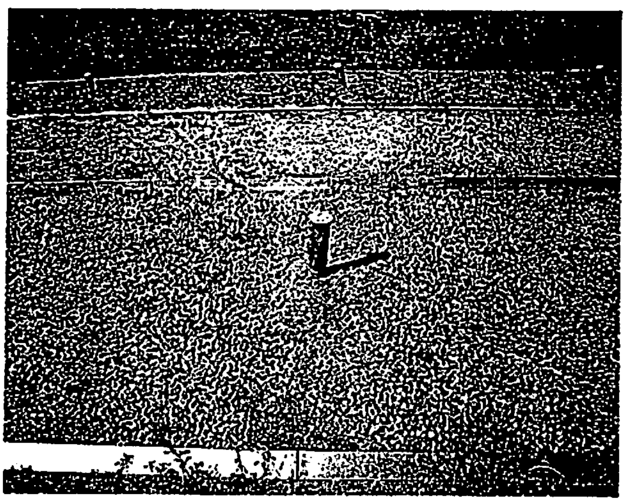
The hydrograph and sedigraph data for the dry, wet, and very wet soil surface simulator runs were integrated over time and the average runoff and soil loss amounts for each surface treatment are shown in Table X.



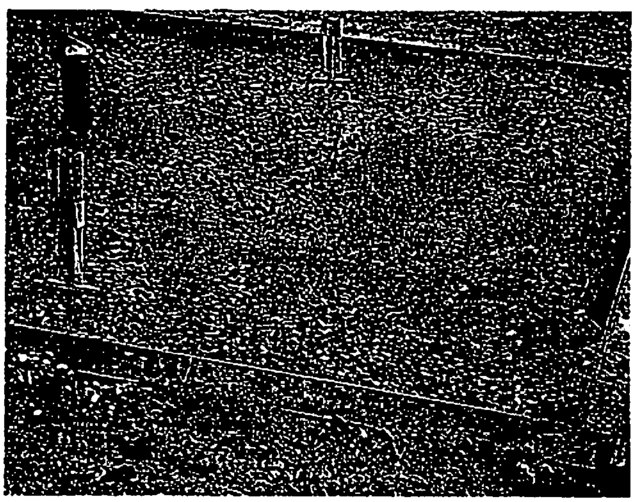
(a) Bare soil surface treatment.



(b) Cultivated surface treatment.



(c) Gravel cover treatment.



(d) Gravel plus wheatgrass cover treatment.

Fig. 18. Surface treatments on erosion plots in 1983.

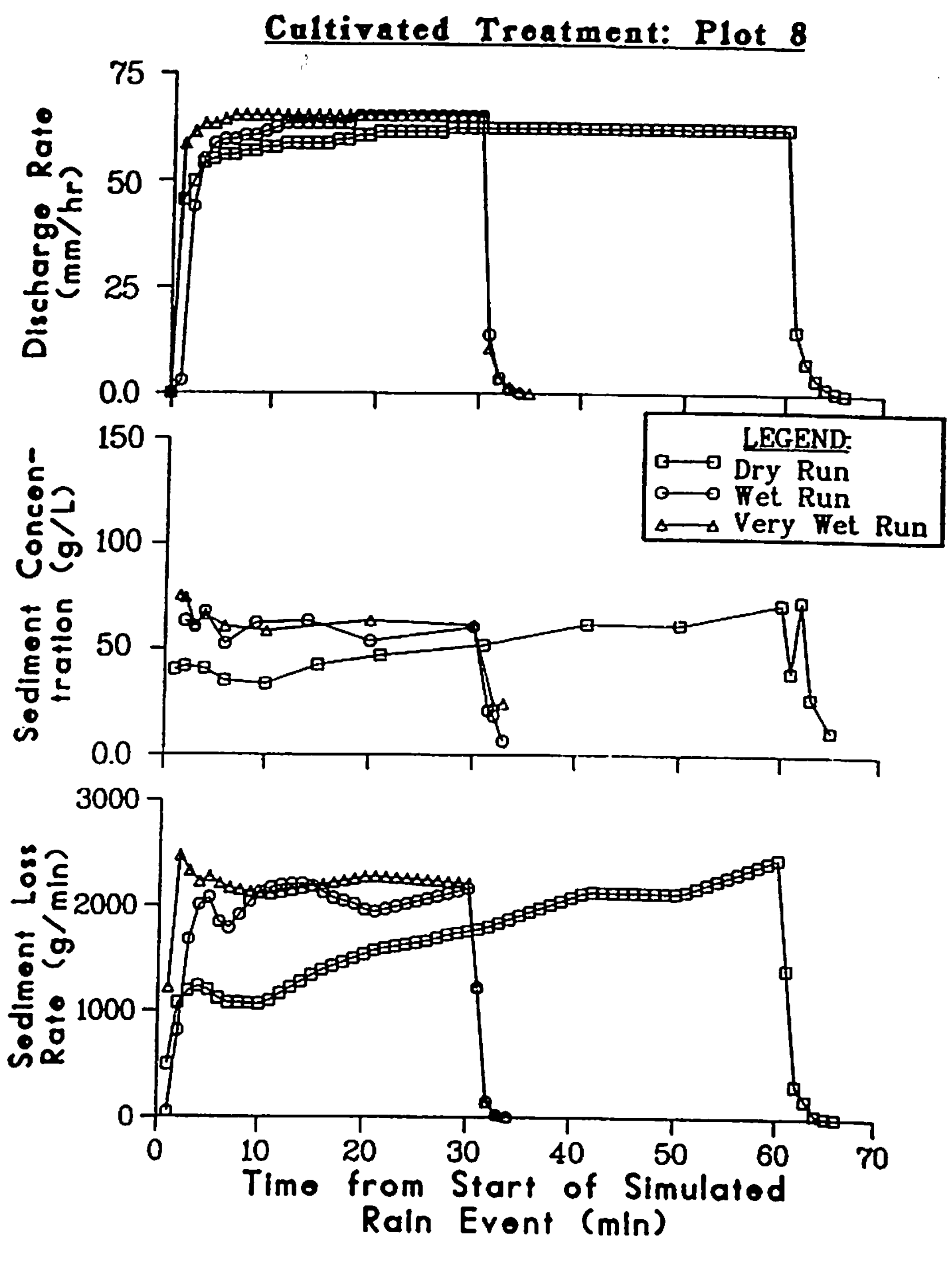


Fig. 19. Hydrograph, sediment concentration, and sedigraph data from plot 8 with cultivated treatment (1983 data).

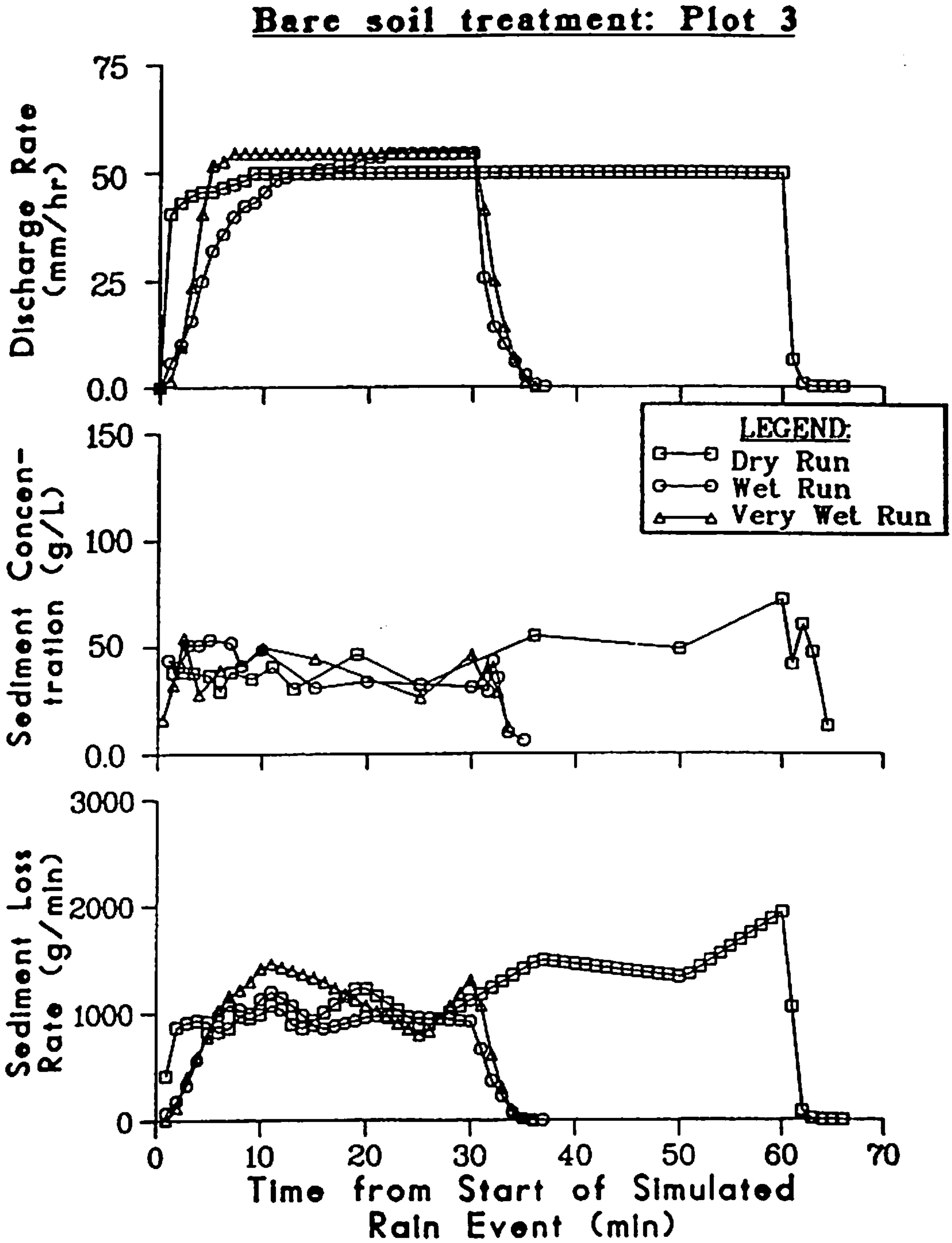


Fig. 20. Hydrograph, sediment concentration, and sedigraph data from plot 3 with the bare soil treatment (1983 data).

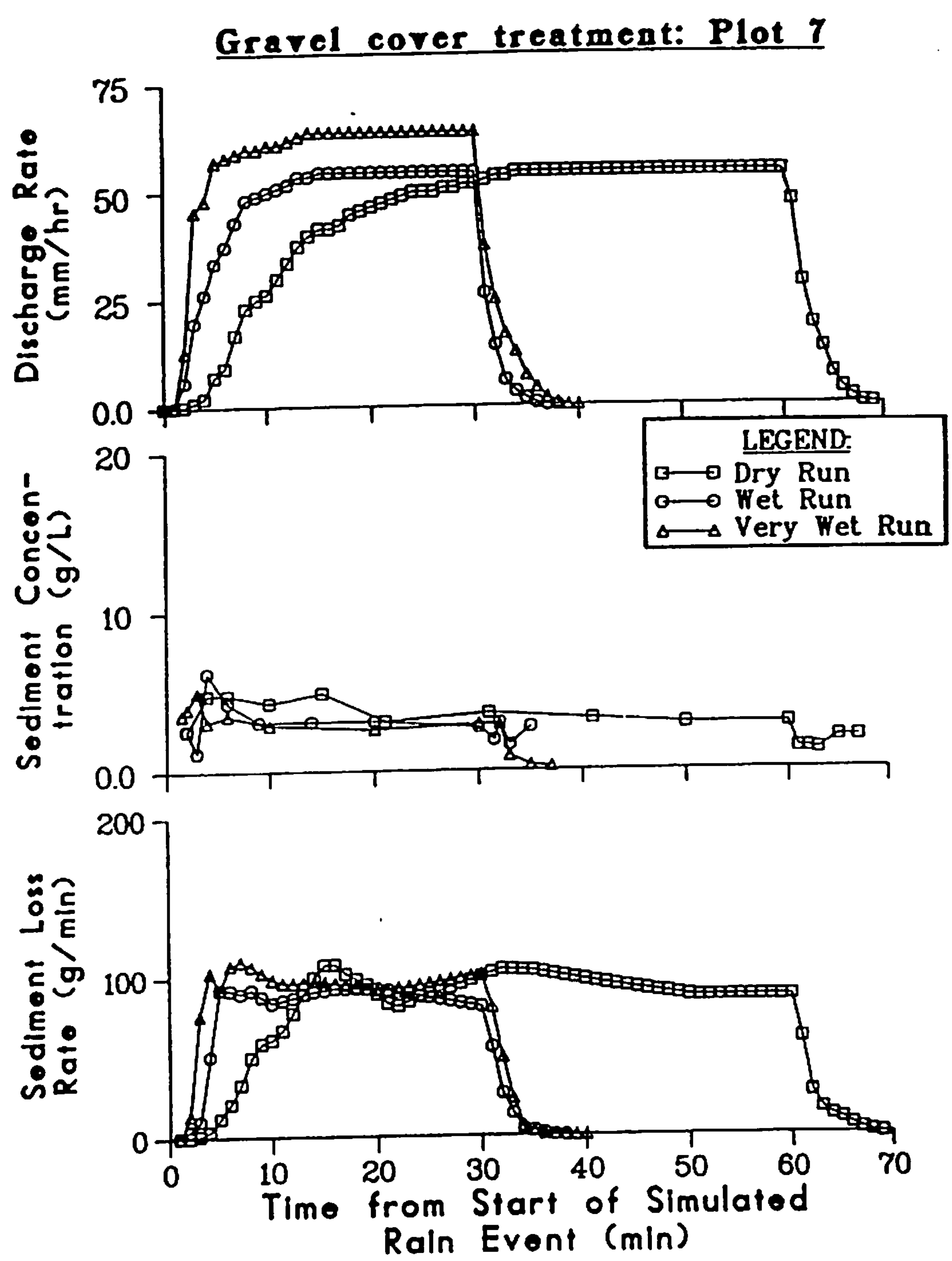


Fig. 21. Hydrograph, sediment concentration, and sedigraph data from plot 7 with the gravel cover treatment (1983 data).

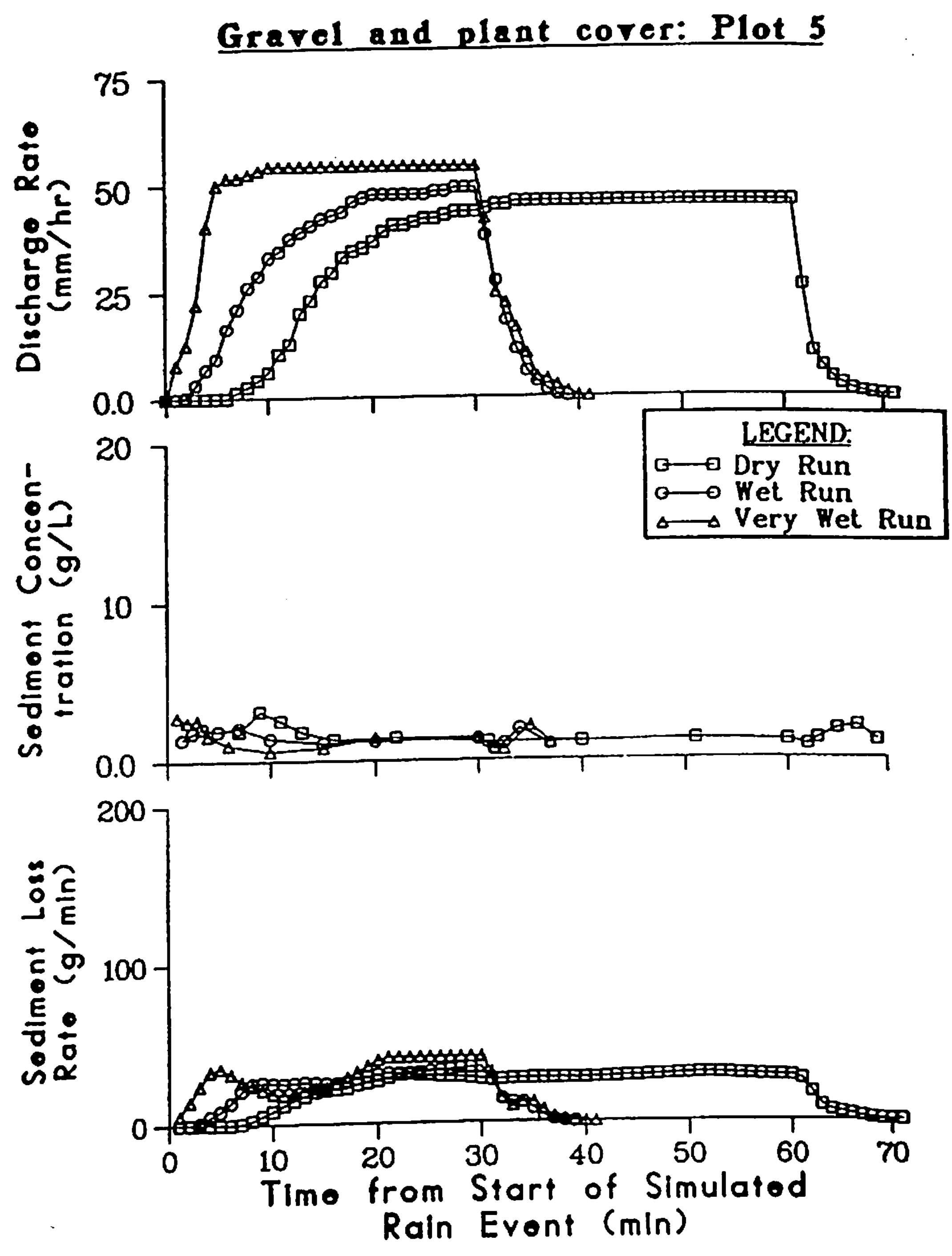


Fig. 22. Hydrograph, sediment concentration, and sedigraph data from plot 5 with the gravel/plant cover treatment (1983 data).

TABLE X

AVERAGE RUNOFF, RUNOFF/PRECIPITATION RATIOS, AND SOIL LOSS FOR RAIN SIMULATOR RUNS PERFORMED IN 1983 ON DRY, WET, AND VERY WET SOIL SURFACES ON EROSION PLOTS AS A FUNCTION OF SURFACE TREATMENT[a]

	Average Runoff (mm)			Average Runoff/ Precipitation Ratios			Average Soil loss (kg)		
Treatment (No. of plots)	Dry Surface	Wet Surface	Very Wet Surface	Dry Surface	Wet Surface	Very Wet Surface	Dry Surface	Wet Surface	Very Wet Surface
Cultivated (2)	60.4	28.0	30.7	0.99	0.99	0.99	96.17	53.22	59.70
Bare Soil (2)	51.1	23.6	27.2	0.90	0.79	0.92	60.23	26.69	33.27
Gravel (2)	46.2	23.3	28.3	0.84	0.80	0.97	5.08	1.92	2.37
Gravel Plus Wheatgrass (2)	47.2	25.8	29.0	0.82	0.85	0.99	3.91	1.55	1.21

[a]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}.

An average of 60.44 mm of runoff occurred on the two erosion plots with the cultivated surface treatment, resulting in an apparent runoff/precipitation ratio of over 0.90 and a total soil loss of 96 kg for the dry soil surface simulator run (Table X). Similar runoff/precipitation ratios were observed on the wet and very wet soil surface simulator runs on these plots, as well as for most of the other surface treatments. The only exception to this trend occurred on the dry and wet rain simulator runs on gravel and gravel plus wheatgrass treatments, where average runoff/precipitation ratios ranged from 0.80 to 0.85, or somewhat less than on the cultivated and bare soil plots (Table X). Thus, the effect of the gravel on these two surface treatments dramatically reduced the amount of soil loss from the erosion plots but increased the amount of precipitation that infiltrated the trench cap surface (Table X, see section E for more detail). However, in making comparisons in the absolute values of the runoff/precipitation ratios, it should be noted that we expect CV's associated with each ratio to range from about 10 to 15%; this is clearly an area where additional research needs to be performed.

No significant differences were observed in the soil losses between the gravel surface treatment and the gravel plus wheatgrass treatment. The average soil loss from the gravel treatment was 2.89 metric tons/ha with a standard deviation of 0.46 metric tons/ha, whereas the gravel plus wheatgrass plots exhibited an average soil loss of 2.05 metric tons/ha with a standard deviation of 1.45 metric tons/ha. This is undoubtedly because the 30-day-old wheatgrass plants on the plots were too small to reduce water erosion in the 1983 simulator runs. Subsequent simulator runs on these plots would undoubtedly show a treatment difference because a very good stand of vegetation currently exists on these plots which would probably result in even less soil loss than would be observed from the gravel treatment.

No significant differences in soil loss were detected on the bare soil surface treatment between the 1982 and 1983 simulator runs. In late June 1982, the two bare soil plots exhibited an average (± standard deviation) soil loss of 48.29 ± 10.76 metric tons/ha. These plots were then left unchanged through a winter and most of the following summer, and they exhibited an average (± standard deviation) soil loss of 36.98 ± 6.88 metric tons/ha in August 1983. Although statistically significant differences in the soil losses with time could not be demonstrated, the trend of these data does support the common field observation that soil loss from a bare soil surface does decrease with time because of soil reconsolidation (Dissmeyer and Foster 1980).

2. Soil Erodibility and Cover Management Factors. Values for K of the USLE were calculated from the measured soil losses from the cultivated erosion 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 CV 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 (Fig. 6)

We calculated estimates of the USLE cover management factor, which reflect the soil loss ratio from a plot with certain amounts of gravel and/or plant cover to the corresponding loss from the clean-tilled, unprotected soil of a unit plot (Table XI). 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 of gravel plus wheatgrass. The gravel and plant cover estimates responsible for these reductions in soil loss are also presented in Table XI, which demonstrates that gravel cover estimates ranged from 70 to 75%, with the young, small wheatgrass plants contributing very little additional cover in the two plots with the 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), shown in Fig. 9 (upper curve of figure), 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 XI). 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 landslope 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.

3. Summary. The erosion plots studies on the simulated trench cap during 1983 focused on comparing the soil loss and hydrologic relationships of soil surfaces with partial covers of gravel and wheatgrass with those of unprotected, bare soil surfaces. An

TABLE XI

SOIL LOSS, COVER MANAGEMENT FACTOR (C), AND GRAVEL AND PLANT COVER ESTIMATES FOR THE TRENCH CAP PLOTS WITH GRAVEL AND GRAVEL PLUS WHEATGRASS COVERS (1983 DATA)

Plot Number	Total Soil Loss[a] Mg ha^{-1}	C Factor[b]	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	29(20)[c]
5	1.47	0.016	70	32(23)

[a]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.
[b]Total soil loss from the vegetated plot/average total soil loss from the cultivated erosion plots.
[c]Numbers in parentheses 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.

application rate of 60 t/A resulted in a 95 to 98% decrease in the amount of soil lost from an unprotected, clean-tilled plot with up- and downslope disking. A surface treatment containing a 30-day-old stand of wheatgrass in addition to this gravel cover resulted in a similar reduction in soil loss. Although the partial gravel cover treatment dramatically reduced the amount of soil erosion from the simulated trench cap, this treatment also increased the amount of precipitation that infiltrated the trench cap during the rain simulator runs.

No significant differences were found between the amounts of soil loss on the erosion plots with the bare soil treatment observed in 1982 and the 1983 soil losses.

Determination of the K factor was repeated in the 1983 rain simulator runs and no significant difference was found between these values and the 1982 K factor estimate.

E. Subsurface Soil Water Monitoring Data.

Because the hydrologic processes at the surface of a SLB trench cap influence the management of the subsurface hydrologic processes, we decided to monitor the long-term changes in soil water content beneath the erosion plots. Basically, surface treatments that increased evaporation and evapotranspiration processes would seem to be favorable waste management alternatives. However, the actual choice of a means for increasing evaporation at a SLB site depends on the stage of the process one wishes to regulate, whether it be the first stage, in which the effect of meteorological conditions on the soil surface dominate the process, or the second stage, in which the rate of water supply to the trench cap surface, determined by the transmitting properties of the profile, becomes the rate-limiting factor (Hillel 1980). Methods designed to influence one of these two stages do not necessarily influence the other stage. In addition, an entirely different set of parameters influences the rates and amounts of water transpired by plant cover.

The soil water content in and below the simulated trench cap was monitored using neutron moisture-gauge techniques. Measurements of soil water content were collected in three locations in each of the eight erosion plots, as well as in two 3.1- by 11-m locations between the plot pairs that had received an 8.0-cm thick cover of base course on top of the trench cap. Soil water determinations were performed at sampling depths in the topsoil (15 cm depth), in the crushed tuff (30-, 46-, 61-, 76-, 91-, and 107-cm depths) and in the undisturbed tuff beneath the simulated trench cap (122-, 137-, and 152-cm depths), as shown in Fig. 23.

More than two years of neutron moisture gauge data (average values for three plot locations) from

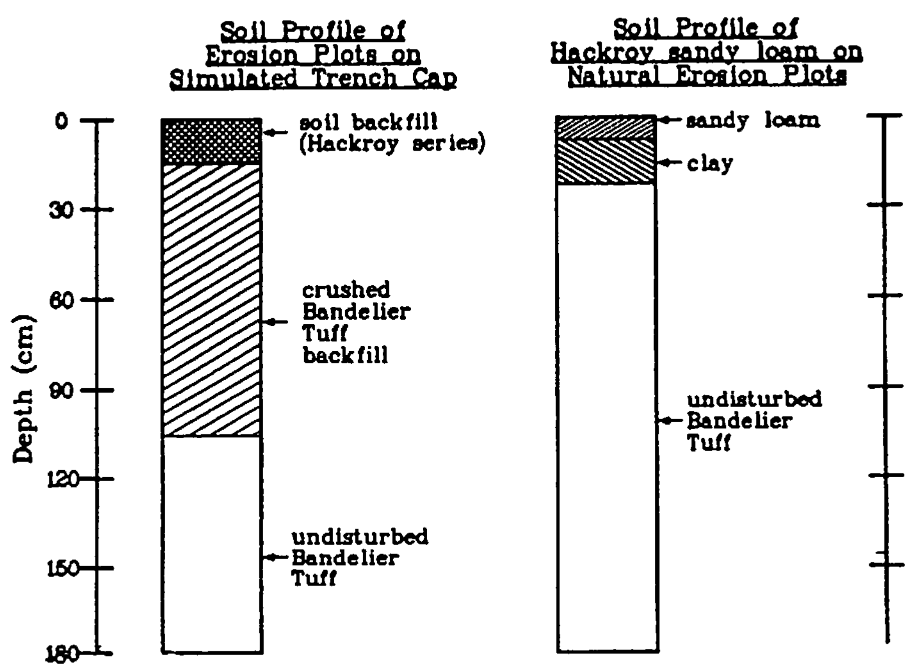


Fig. 23. Soil profile descriptions of the simulated trench cap and the erosion plots with natural plant cover.

erosion plot 6, which received the smooth bare soil treatment (with no vegetative cover), are presented in Fig. 24. These data confirm that, for the bare soil treatment, very little infiltration of water occurred during the 1982 simulator runs (Table VIII). Thus, in spite of the fact that approximately 110 mm of water was applied to each of these plots on June 22 and 23, very little increase in soil water was detected at any depth over that observed before the simulated rainfall on June 21. Interestingly enough, after the December 14 readings, large increases in soil moisture were found up to 122 cm below the surface of the trench cap as a result of melting snow. As the spring and summer of 1983 passed, the soil water levels in the top 76 cm of the trench cap decreased because of evaporation, and then again increased to greater than 30% water with the addition of precipitation to the trench cap in the late summer rainy season. The final soil water content at the bottom of the trench cap (91-107 cm depth) increased during this same period to 23-27%, and the undisturbed tuff beneath the trench cap attained water content values of 12-16% (Fig. 24).

Tillage for seedbed preparation, weed control, or other purposes is the most common soil management process. We observed on our erosion plots with the cultivated (tilled) treatment that the disking process resulted in an opening and loosening of the tilled layer and decreased the occurrence of the extensive cracks observed at the surface of the erosion plots with the bare soil treatment. The soil water values from an erosion plot that was tilled (both in June 1982 and July 1983) increased because of snow melt and, generally similar trends were observed as for the bare soil plot. However, the final soil water content at the bottom of the simulated trench cap and beneath the cap was considerably less for the cultivated plot than for the bare soil plot, i.e., water content values ranging from only 14 to 20% were observed at the bottom of the trench cap, and values ranging from only 8 to 10% were observed beneath the trench cap (Fig. 25). Thus, the overall effect of tillage on the trench cap seemed to be that of enhancing desiccation of the SLB trench cap.

This desiccation effect of tillage might have been much less dramatic if a longer time interval for reconsolidation had occurred between tillages of the erosion plots. We observed very little difference in the appearance of the bare soil treatment and the tilled plots after the tilled plots were exposed to one snowmelt sequence in both 1983 and 1984. Thus, the net effect of tillage might have depended on the duration of this process and concurrent decreased soil cracking, as well as the documented effects of depth, degree, and frequency of tillage (Hillel 1980).

Gravel mulching is an old method of reducing soil erosion and can be very effective in water conservation, both by enhancing infiltration (Table X) and by suppressing evaporation, even in layers as thin as 5-10 mm (Hillel 1980). The initial evaporation rate under a mulch is usually reduced (Hillel 1980), so water would be saved in a SLB trench cap with gravel cover if rains are frequent. However, for the extended rainless periods found in some parts of the western US, a gravel mulch may keep the soil surface more moist but may result in no net increase of water in the soil profile.

Our field studies involving gravel covers included three surface treatments on the simulated trench cap (Fig. 23). An 8-cm thick cover of base course was emplaced in 1982, and two erosion plots received a partial gravel cover treatment in 1983. Since we initially anticipated that these two surface treatments would result in larger amounts of water infiltrating the trench cap, we decided to add a third treatment (gravel plus wheatgrass), in which the wheatgrass might eventually transpire a portion of this additional water infiltrating the trench cap.

The base course treatment exhibited some interesting trends in soil water content (Fig. 26). Unlike any of the other surface treatments on the trench cap, the base course treatment resulted in a large amount of water infiltrating the upper layers of the trench cap during the 1982 and 1983 rain simulator runs, as well as when natural rain and snow melt occurred (Fig. 26). After about two years, this resulted in volumetric water content values ranging from 27 to 33% in the top 76-cm of the trench cap, 17 to 21% at the bottom of the trench cap (91- and 107-cm), and from 11 to 12% beneath the trench cap. Thus, the overall effect of the base course was to almost immediately enhance the water content in the upper layers of the trench cap relative to the bare soil treatment; however, lower water content values were observed from 91- to 152-cm under the base course treatment than at similar depths in the erosion plots with the bare soil treatment (Figs. 24 and 26). Although additional data analysis is currently underway, this base course effect is probably caused by (1) considerable evaporation of most of the water added to the trench by a large number of small rainstorms upon interception of the rain water by the base course and (2) horizontal flow of water from larger rainstorms beneath the base course layer.

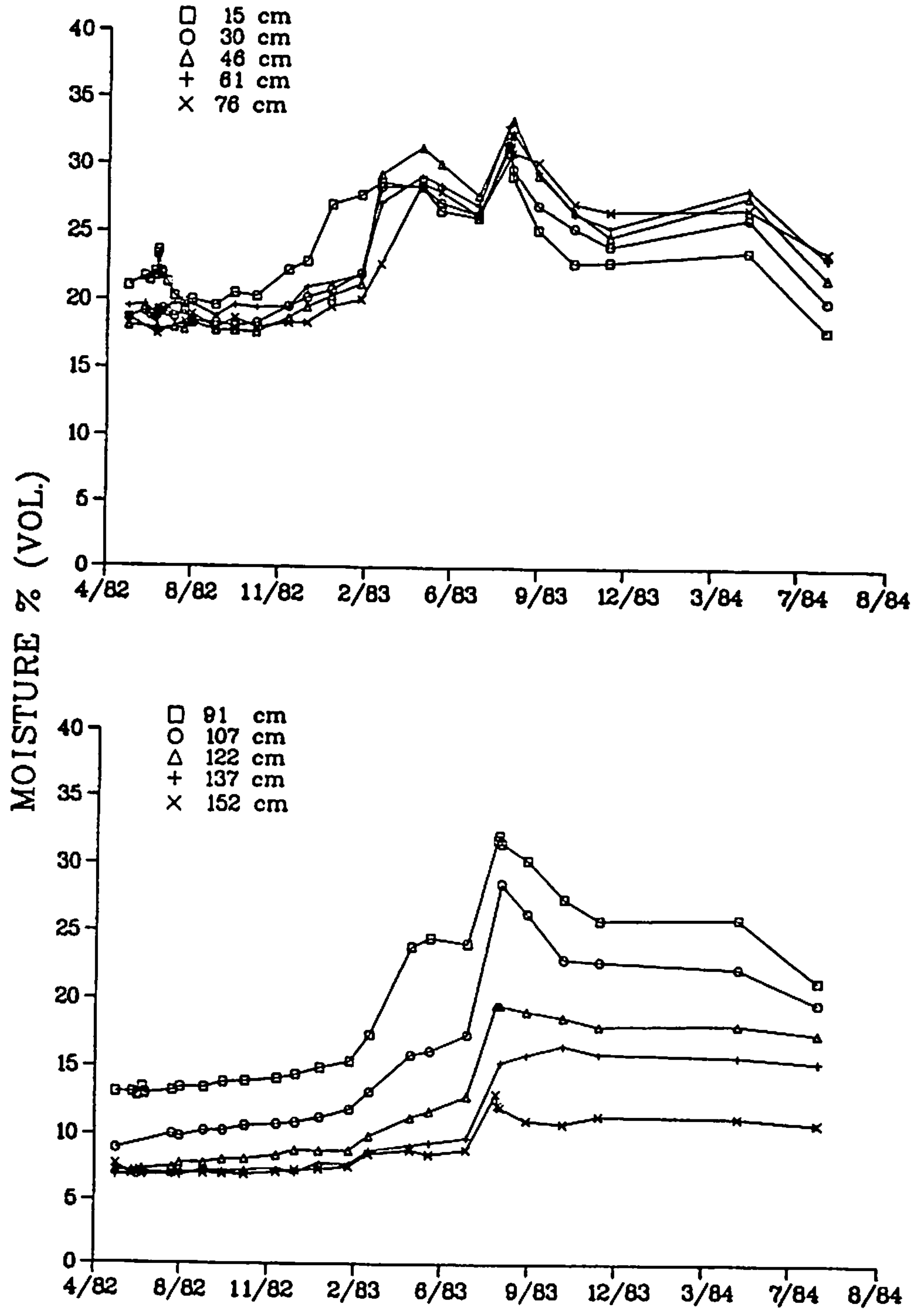


Fig. 24. Subsurface soil water content data from plot 6 with the bare soil treatment.

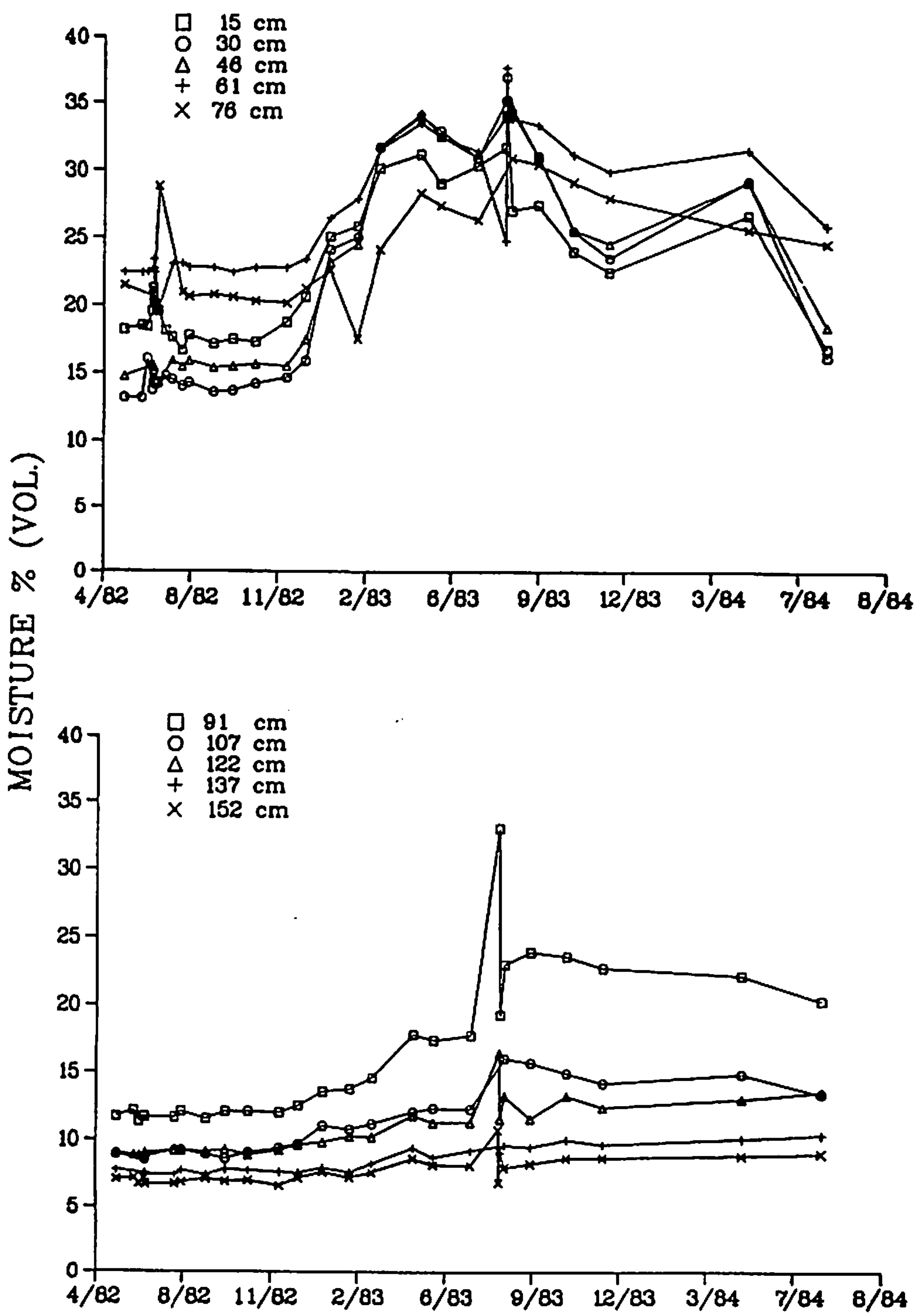


Fig. 25. Subsurface soil water content data from plot 1 with the cultivated treatment.

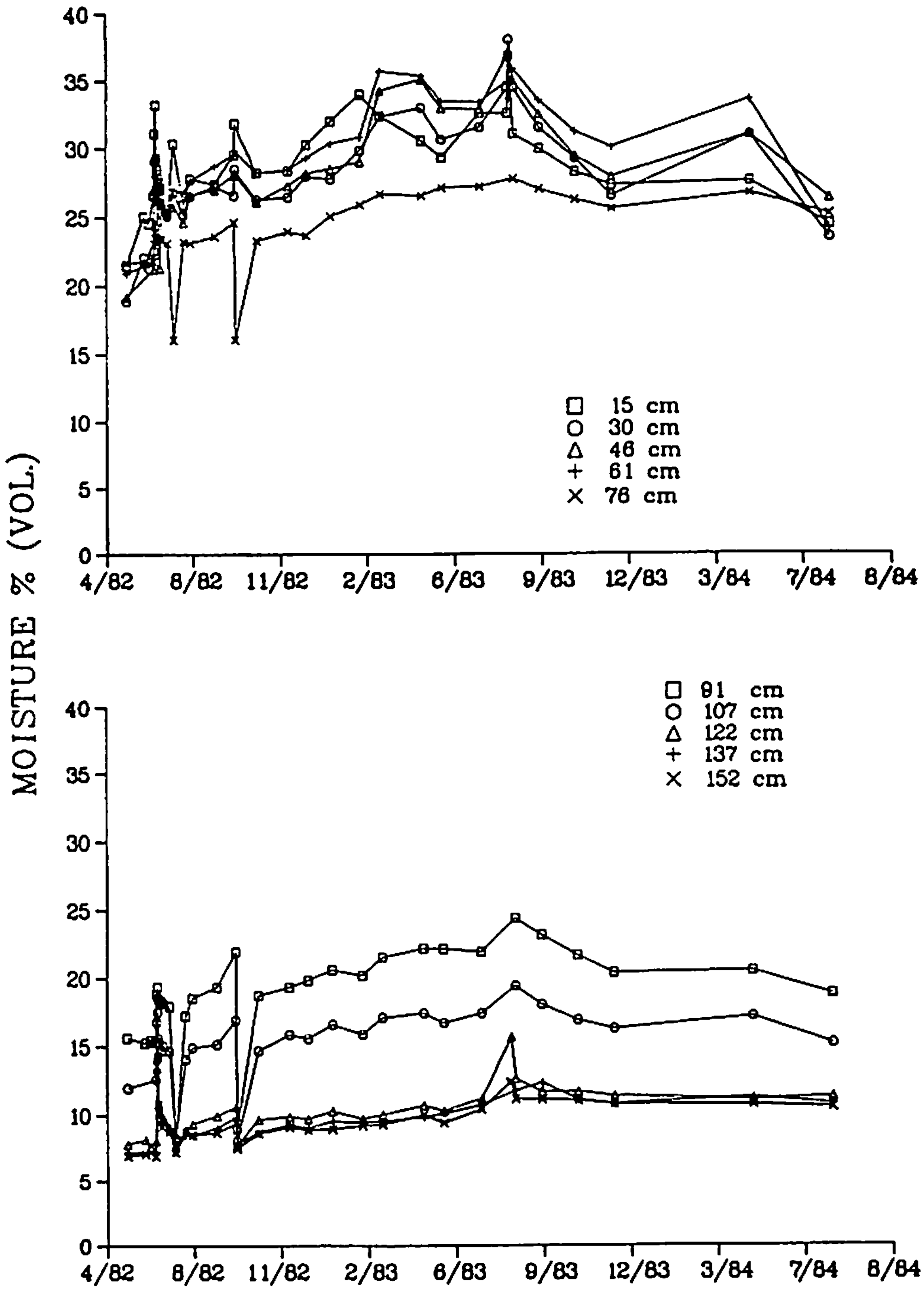


Fig. 26. Subsurface soil water content data from plot 9 with the base course treatment.

The second surface treatment involving gravel consisted of a 71 to 75% cover of less than 13-mm diameter, which was applied to the erosion plots in 1983 (Table XI). The field data for this gravel treatment show a dramatic decrease in soil erosion but an immediate increase in water infiltrating the trench cap during the 1983 rain simulator runs (Table X), which is also apparent from the neutron moisture gauge data collected for this treatment (Fig. 27). Just as was observed for the base course treatment (Fig. 26), the soil water content under the gravel treatment after the 1983 simulator runs was near saturation in the upper layers (15- to 76-cm sampling depths) of the trench cap and only decreased to values of 26 to 30% by March 1984 (Fig. 27). A little less infiltration was observed with depth for the gravel treatment than for the base course treatment, i.e., lower values of soil water content were observed at the 91-cm depth for the gravel treatment (Fig. 27) than for the base course plots (Fig. 26). Otherwise, the amounts of water that infiltrated the entire trench cap into the underlying, undisturbed tuff for these two treatments were both similar and less than the corresponding amounts of water that infiltrated the trench cap with the bare soil treatment (Fig. 24).

The soil water data for the third gravel-related cover treatment, a cover of gravel plus wheatgrass, are presented in Fig. 28. No significant differences in the vertical distribution of water in the trench cap were observed between this surface treatment and the gravel cover treatment during the growing season. Similarly, no significant differences were observed during the 1982 growing season in the vertical distributions of water between the erosion plots with the bare soil treatment (Fig. 24) and the plots with the cover of barley (Figs. 27 and 28). Thus, the amount of water transpired by either the relatively young cover of wheatgrass in 1983 or the barley cover in 1982 was evidently small enough that this change could not be observed. However, in the future we expect to see a significant reduction in the soil water content in the upper layers of the trench cap as the wheatgrass roots are more successful at penetrating the clay loam topsoil and grow into the trench cap.

One influence of the presence of plants on the vertical distribution of water in the trench cap was observed. During the first snowmelt received by the erosion plots in early 1983, the plots with the dormant cover of barley (Figs. 27 and 28) had larger amounts of water infiltrating the trench cap than did the erosion plots with the bare soil treatment (Fig. 24). Similarly, during the 1984 snowmelt period, the erosion plots with the gravel plus wheatgrass cover (Fig. 28) had higher soil water content values in the upper portions of the trench cap than the plots with just gravel cover (Fig. 27). Thus, the barley or wheatgrass roots seem to have penetrated the clay loam topsoil during the first growing season and, in the late winter, the dormant roots then seem to provide channels through which snowmelt water can infiltrate the upper layers of the trench cap.

VI. EXAMPLE APPLICATIONS AT SLB SITES

The five USLE examples given in this section should provide an understanding of how the USLE and this manuscript can be used to make estimates of expected average annual soil loss rates and how the various factors affect the magnitude of those estimates. Moreover, the examples illustrate the general type of problems for which the USLE provides a quick and easy method of deriving solutions.

Examples 1 and 2 illustrate how the USLE is used to calculate average annual soil loss and how the manuscript is used to estimate the influence of soil management practices (tillage vs undisturbed soil in these examples) on the C factor. Example 3 illustrates the influence of vegetative cover on the C factor and Example 4 considers methods to estimate the C factor for a specified rate of gravel mulch as an engineering practice used to control erosion. Example 5 illustrates how to estimate various combinations of slope length and steepness for a SLB site given a tolerable soil loss, T. Example 6 illustrates the influence of antecedent soil water content on the estimated value of K and discusses methods of adjusting for this effect.

A. Example 1—Bare Soil Surface on a Freshly Tilled SLB Trench.

Given: A uniform hillslope on a SLB trench cap in the Four Corners area with: (1) Slope steepness of about 10% and length of 100 ft, (2) A sandy clay soil with 45% clay, 5% silt, 20% very fine sand, and 50% sand, and (3) cover treatment practices characterized a bare soil tilled up- and downslope.

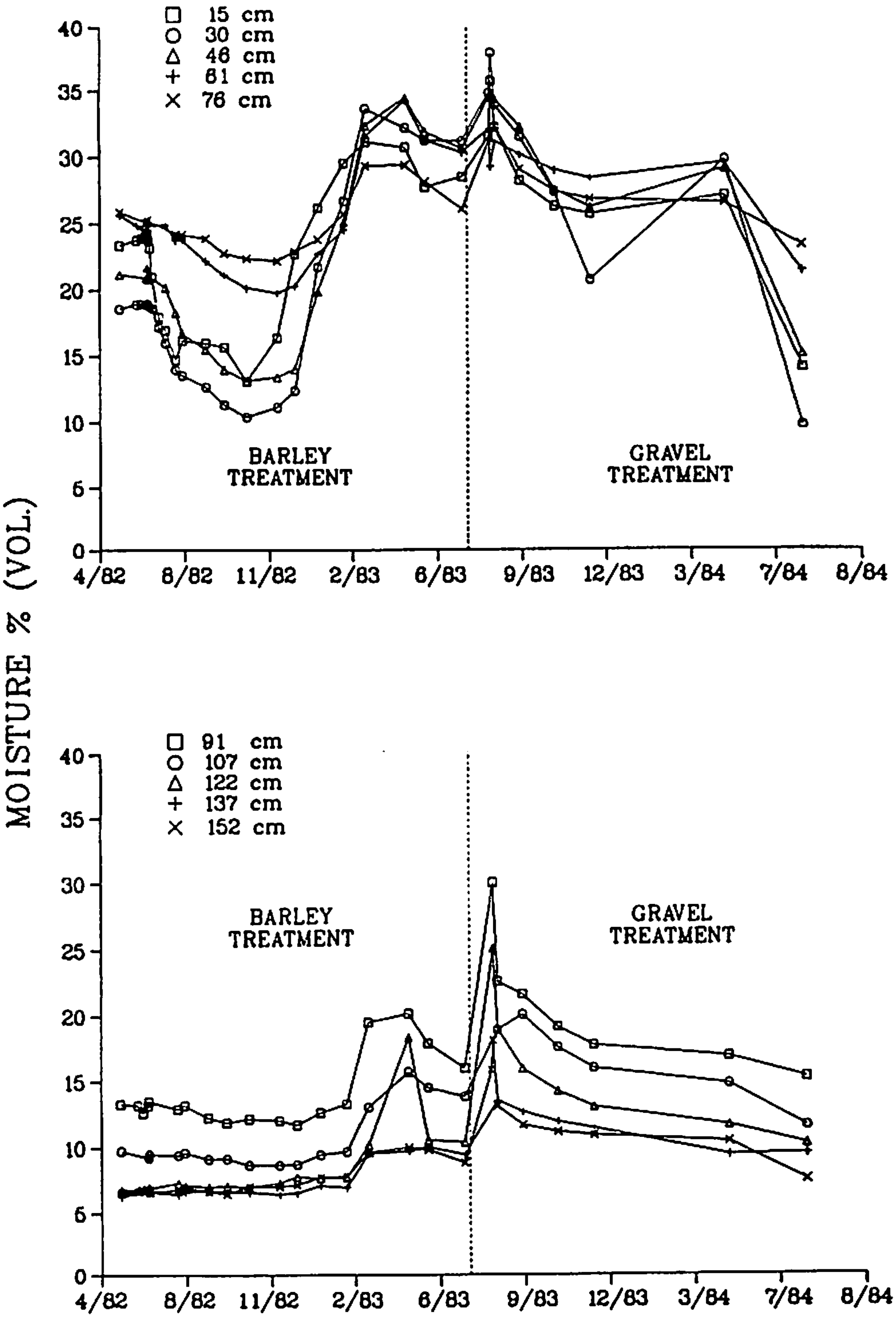


Fig. 27. Subsurface soil water content data from plot 2 with the barley cover and gravel cover treatments.

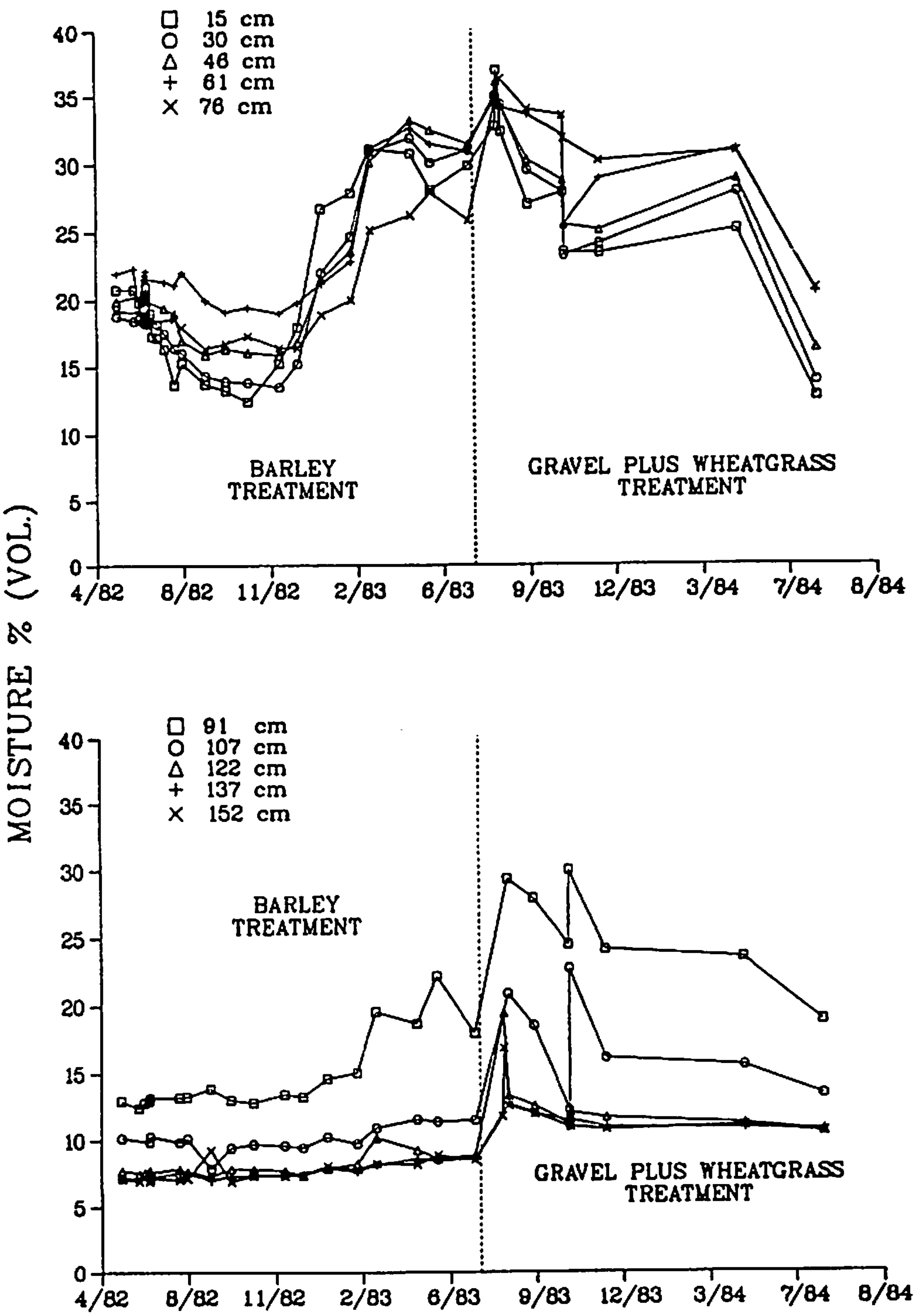


Fig. 28. Subsurface soil water content data from plot 4 with the barley and gravel plus wheatgrass treatments.

Find: The average annual soil loss expected under these conditions.

Solution: From Fig. 2, estimate an average annual R value of about 400 in SI units, corresponding to a value of 24 in customary US units. Given 25% silt and very fine sand, assume 1% organic matter, a fine granular structure, and slow permeability. Enter Fig. 6 and estimate a K value of 0.024 in SI units, corresponding to a value of 0.18 in customary US units. From Fig. 4, estimate the LS factor at about 1.4. As the slope is tilled up- and downslope similar to a unit plot, estimate the C factor as 1.0. Finally, because no engineering practices are involved, use a value of 1.0 for P. We can now apply the USLE as follows:

$$A = RKLSCP ,$$

which is

$$A = (24)(0.18)(1.4)(1.0)(1.0) = 6.0 \text{ t/A/yr}$$

as the estimated long-term average annual soil loss.

B. Example 2—Undisturbed Bare Soil Surface on a SLB Trench Cap

Given: The conditions in Example 1, except assume no tillage or other disturbances for several years and no vegetation is allowed to grow on the hillslope (chemical fallow) of the trench cap.

Find: The average annual soil loss under these conditions and the percent change in soil loss from Example 1.

Solution: The only USLE factor affected by the change in management (tillage to chemical fallow) is the C factor. Table VI lists C factors for permanent pasture, range, idle land, or grazed woodland. Bare soil means no appreciable canopy and zero percent ground cover, so enter row 1, column 4 of Table VI to estimate the C factor as 0.45. Because all other factors remained unchanged, the average annual soil loss under these conditions is 45% of the soil loss in Example 1 or A = 2.7 t/A/yr. Therefore, by not disturbing the soil, the estimated average annual soil loss was reduced from about 6 to about 3 t/A/yr.

C. Example 3—Grass Cover on SLB Trench Cap in the Texas Panhandle

Given: The conditions in Example 1, except the hillslope of the SLB trench is in the upper Texas Panhandle and we are able to establish and maintain a good grass cover (~40% ground cover).

Find: The average annual soil loss.

Solution: From Fig. 2, the average annual R values in the Texas Panhandle range from about 1600 to 2500 in SI units, corresponding to values of 94 to 147 in customary US units. From Table VI for 40% ground cover with grass and no appreciable canopy, the C factor is 0.10. Under these conditions the USLE is

$$A = RKLSCP,$$

which, for the stated conditions, becomes

$$A = (R)(0.18)(1.4)(0.1)(1.0) ,$$

or A = 0.025 R. For the given range of 94 to 147 for R, this means that the estimate for A varies from 2.4 to 3.68 t/A/yr.

D. Example 4—Gravel Mulch on a SLB Trench Cap

Given: A trench cap with a 50 ft hillslope at 12% steepness near Memphis, Tennessee. The soil is a sandy loam with 10% clay, 20% silt, 20% very fine sand, 70% sand, and about 1% organic matter.

Find: The average annual soil loss from undisturbed bare soil and from bare soil covered with a gravel mulch at the rate of about 70 t/A.

Solution: Gravel with an average diameter of 1 inch and a specific gravity of 165 lb/ft^3 has the following particle characteristics: volume = 0.000303 ft^3, weight = 0.05 lb, and cross-sectional area = 0.00545 ft^2. Seventy t/A is equivalent to 3.21 lb/ft^2 of gravel per square foot of surface area, or about 35% coverage of the soil surface. The USLE factors for the given conditions are: R = 5000 in SI units, corresponding to 294 in customary US units; K = 0.038

in SI units, corresponding to 0.29 in customary US units; LS = 1.3; and P = 1.0. From Table VI, the C factor for undisturbed bare soil is 0.45. If gravel mulch at 35% ground cover acts the same as vegetative cover, interpolation between 20% and 40% ground cover in the first row of Table VI produces an estimate for C of about 0.12. Table VI lists C factors for gravel mulch as 0.05 for 135 t/A and 0.02 for 240 t/A. Extrapolating these data back to a value of 70 T/A on log-log paper produces an estimated C factor of 0.17. Therefore, the estimate of C for 70 t/A of gravel mulch is about 0.12 to 0.17. With the specified values the USLE becomes

$$A = (294)(0.29)(1.3)(C)(1.0) ,$$

or A = 111 C. For C in the range 0.12 to 0.17, the estimated average annual soil loss with gravel mulch is 13.3 to 18.8 t/A/yr. Undisturbed bare soil with C = 0.45 would produce an estimate of about 50 t/A/yr. Thus, 70 t/A of gravel mulch would probably reduce the average annual soil loss by about a factor of 3. If we assumed disturbed soil conditions, then this rate of gravel mulch might reduce the average annual soil loss by a factor of about 7.

E. Example 5—Freshly-Tilled Bare Soil Surface on a SLB Trench

Given: The conditions in Example 1, except assume erosion is to be limited to a predetermined tolerance, T, which replaces the term, A, in the USLE, and which is set equal to 5.0 t/A/yr.

Find: The combinations of slope length and steepness required to meet the tolerable soil loss of 5.0 t/A/yr.

Solution: We now apply the USLE as follows:

$$LS = (T)/(R)(K)(C)(P) ,$$

which is

$$LS = (5)/(24)(0.18)(1.0)(1.0) = 1.2 .$$

From Fig. 4, we see that the site engineer has several choices, such as: 16% slope, 18 ft slope length; 12% slope, 43 ft slope length; 8% slope, 144 ft slope length; and 5% slope, 492 ft slope length.

F. Example 6—Determination of the K Factor on a SLB Trench from Rain Simulator Data Collected on Soil Surfaces Varying in Moisture Content.

Given: Conditions present on a 3.05 × 10.7 m tilled erosion plot on a SLB trench cap with a 7% slope. For this 60 min rain simulator run on the dry soil surface, a value of 606 mm · MJ · hr^{-1} · ha^{-1} was observed, with a corresponding soil loss of 32.28 t/ha. A 30-min rain simulator run was performed 24 hr later on the wet soil surface of the same plot, from which an EI value of 307 mm/hr · MJ/ha and a soil loss of 20.11 t/ha was observed.

Find: Values of K for both simulator runs.

Solution: Because K involves soil loss estimates with reference to the unit plot, we must first adjust the soil loss for these conditions. According to Fig. 4, the LS factor estimate for 10.7 m slope length of the erosion plot with a 7% slope is equal to 0.50. Thus, the adjusted A soil loss values are 32.28 t/ha ÷ 0.5 = 64.56 t/ha for the dry simulator run, and 20.11 t/ha ÷ 0.5 = 40.22 t/ha for the wet simulator run.

The estimates of K can then be calculated as ratios of these adjusted A values to the corresponding EI values. For the simulator run on the dry soil surface,

$$K = 64.56 \text{ t/ha} \div 606 \ \frac{\text{mm}}{\text{hr}} \cdot \frac{\text{MJ}}{\text{ha}} = 0.11 \ \frac{\text{t} \cdot \text{ha} \cdot \text{h}}{\text{ha} \cdot \text{MJ} \cdot \text{mm}}$$

and similarly, for the wet soil surface,

$$K = 40.22 \text{ t/ha} \div 307 \ \frac{\text{mm}}{\text{hr}} \cdot \frac{\text{MJ}}{\text{ha}} = 0.13 \frac{\text{t} \cdot \text{ha} \cdot \text{h}}{\text{ha} \cdot \text{MJ} \cdot \text{mm}} .$$

These K factor calculations reflect the observation (Wischmeier and Smith 1978) that when rain falls on a relatively dry, freshly tilled soil, most of the water may infiltrate before runoff begins, resulting in a low average soil loss per unit of EI for that storm. Similarly, when rainfalls on presaturated soil, such as in the rain simulator run with the wet soil surface, runoff begins quickly, and most of the rain becomes runoff. These rains usually produce above average soil loss per EI unit.

VII. RECOMMENDATIONS FOR APPLICATION OF EROSION CONTROL TECHNOLOGIES AT SHALLOW LAND BURIAL SITES IN THE WEST

The site operator of the SLB facility must first choose a soil loss equation or erosion/sediment yield model to predict soil losses within his site. On-site information must be gathered in the field to estimate various site parameters needed to predict soil erosion. The operator must then select a tolerable soil loss from the trench cap and choose an erosion control program to limit erosion to this predetermined tolerance.

A. Selecting a Soil Loss Equation or an Erosion/Sediment Yield Model

The major purpose of the 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, but the factors of a soil loss equation like the USLE are much different to evaluate for large, complex watersheds.

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 percent, 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.

The accuracy of the USLE was previously determined by using the information presented in Section III to estimate long-term average soil losses for erosion plots and comparing these with observed soil losses on each plot (Wischmeier and Smith, 1978). About 53% of the differences were less than 1.0 t/A and 84% were less than 2.0 t/A, with a mean annual soil loss of 11.3 t/A for this 2300 plot-year sample. Of those differences that exceeded 1 t/A, 67% were from comparisons with short plot records.

However, if this degree of accuracy of the USLE is inadequate, and if estimates of soil loss from specific storms (see Example 6, Section VI), sediment yield from complex areas within the SLB site, and characteristics of eroded and transported sediment are required, more detailed models like CREAMS (Knisel 1980) must be used. CREAMS, a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, was first applied to SLB of low-level radoactive 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 (Lane 1984), unlike the USLE, addresses the influence of antecedent soil water content on sediment, nutrient, and pesticide losses on a storm-by-storm basis.

Interactions of these processes can be expressed in a CREAMS water balance equation for the trench cover profile as follows:

$$\frac{dS}{dt} = P-Q-ET-L\ , \tag{6}$$

where

S = soil moisture,
P = precipitation,
Q = runoff,
ET = evapotranspiration,
L = seepage or percolation, and
t = time.

The rate of change in soil moisture (as stored in the cover profile) is equal to the difference between input, P and output, Q, ET, and L. Units of the terms in Eq (6) are generally expressed as volume per unit area per unit time, or equivalently, depth/time (e.g., mm per day, month, or year). The amount of soil moisture, S, stored in the profile is a function of the water holding capacity of the soil, plant rooting depth, and the antecedent and current values for the variable on the right side of Eq (6). Precipitation, P, is a function of the climate at a particular waste burial site and is highly variable in time and space. Evapotranspiration, ET, is a function of climatic variables (e.g., precipitation, temperature, solar radiation), soil properties, vegetation type, and soil moisture. Percolation, L, is a function of soil properties and soil moisture.

However, researchers and users should not see either the USLE or CREAMS as a final representation of erosion prediction. Both USLE and CREAMS are but steps in our continuing efforts to develop improved models to estimate erosion and sediment yield for improved SLB of waste products.

B. Obtaining On-Site Information

To compute the USLE-predicted average annual soil loss from a particular SLB, the first step is to refer to the tables, charts, and techniques discussed in Section III, and select the values of R, K, LS, C, and P that apply to the specific conditions at that field site.

The R factor is estimated from Figs. 2 and 3, and the LS factor is evaluated for the trench cap from either Fig. 4 or Table III. The value of the P factor was also discussed in Sec. III, and usually has a value of 1.0 for SLB systems.

Both the K and the C factors can either be determined experimentally for the field site, using the previously described research techniques with rainfall simulators (Sec V), or by use of the soil erodibility nomograph (Fig. 6), and Figs. 7 through 9, and Tables IV through VI.

In evaluating both the K and C factors for the SLB site, the site operator should contact both the soil test laboratory at the local land-grant university and the Soil Conservation Service of the US Department of Agriculture. These two organizations will give the site operator information on local soils, how to collect representative samples of the trench cap soil to a depth of 6 in., and provide soil assays and site evaluations so that the K and C factors can be successfully estimated from the information presented in Sec III.

The data presented for the determination of the C factor in Figs. 7 through 9 and Tables IV through VI are averages for cropstage or vegetative cover periods that cover several weeks to several months. Early in the development of a plant cover on the trench cap, the ratio will usually be higher than the average because the development of cover is gradual. Later in the period, it will be lower than average. In a poor growing season, the ratio will be above average because cover and water use by transpiration are below normal. In a favorable growing season, the ratio will be below average. Cover effect in a specific year may be substantially influenced by abnormal rainfall. A plant canopy or conservation tillage practice may delay the start of runoff long enough to be 100% effective for moderate storms on a given field and yet allow substantial erosion by prolonged runoff periods, just as was oberved during the Los Alamos rain simulator studies (Sec V).

C. Selecting a Tolerable Soil Loss

The term "soil loss tolerance" denotes the maximum amount of soil erosion that will permit the SLB trench cap to maintain its integrity over the projected life of the SLB site. This term was originally used to designate the maximum amount of erosion that would permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith 1978). In either case, when erosion is to be limited by a predetermined tolerance, T, the term, A, in the USLE is replaced by T.

Current criteria by McCormack and Young (1980) for assigning T values are:

(1) An adequate rooting depth must be maintained for plant growth. Soils with impervious B horizons are given lower T values than are those with deep permeable subsoils.

(2) Soils that have significant yield reductions, if the surface layer is removed by erosion, are given lower T values than are soils that have only minor yield reductions if the surface is removed.

According to McCormack and Young (1980), a maximum T value of 5 t/A has been selected for the following reasons:

1. Soil losses in excess of 5 t/A/yr affect the maintenance, cost, and effectiveness of water control structures that can be damaged by sediment.

2. Excessive sheet nutrients are accompanied by gully formation in many places.

3. Loss of plant nutrients is considered excessive.

4. On most soils, conservation practices can keep soil losses below 5 t/A/yr.

In evaluating the long-term impact of soil erosion on SLB trench caps, these T values may be reasonable, especially since it is necessary to make assumptions about rates of soil formation, most of which have not been proven by research. However, Wight and Lovely (1982) point out that rangelands in arid and semiarid climates are inherently more fragile than eastern croplands, and are characterized as having slow soil formation processes. They also indicated that even small increases in soil losses on rangelands can initiate accelerated soil erosion trends, because soil losses are accompanied by reduced production of protective vegetation.

However, after additional research is performed in the western states to satisfactorily incorporate the unique features of rangelands into T values (Wight and Lovely 1982), the T values for SLB sites must meet the additional waste management implications suggested by Eq (6). Thus, a tolerable soil loss of 5 t/A/yr or less would probably be acceptable if erosion control measures on the surface of the trench cap did not enhance infiltration of rain water into and through the underlying waste materials. The SLB trench design must accomodate a tolerable soil loss from the surface of the trench cap and must also have an adequate thickness and corresponding water holding capacity to minimize subsurface water flow. The T values must be related to the performance of migration barriers (Lane and Nyhan 1984) and biointrusion barriers (Hakonson et al. 1982) located within the trench cap, as well as the ability of various plant covers to enhance loss of water from the trench cap by evapotranspiration processes.

D. Selecting an Erosion Control Program

An erosion control program can be developed for a SLB site by considering two rewritten versions of the USLE, with the term A in the equation replaced by the soil loss tolerance term T:

$$LS = T/RKCP \qquad (7)$$

$$CP = T/RKLS \qquad (8)$$

Use of Eq (7) involves selecting various slope steepness and length fractures for the new SLB trench cap as described in Example 5 of Section VI.

Substituting the SLB site values of the fixed USLE factors in Eq (8) and solving for CP gives the maximum value that the product, CP, may assume under the specified field conditions. With no supporting practices, P = 1, and the most intensive plant cover plant that can be safely used on the field is one for which C just equals this value. When a supporting practice like contouring or stripcropping is added, the computed value of T/RKLS is divided by the practice factor, P, to obtain the maximum permissible cover and management factor value. Terracing increases the value of T/RKLS by decreasing the value L or LS.

Many practicing site operators may prefer to use handbook tables. C-value tables for specific geographic areas are centrally prepared by persons who are experienced in the procedures outlined in the preceding sections and who obtain the needed data from Tables V and VI. Values of T/RKLS are also centrally computed and arranged in two-way classification, as illustrated in customary US units in Table XII for R = 180, K = 0.32, and T = 5. Similar tables are prepared for other combinations of R, K, and T.

The site operator working in the field usually carries a pocket-sized handbook, which includes the R value(s), T and K soil values, applicable tables of T/RKLS values, and a table of C values for the area. These items will provide all the information needed to use this procedure as a guide for selecting conservation practices in each field. Solving the equation or performing field computations rarely will be necessary.

Example. The first step is to ascertain the soil type, percent slope, and slope length for the field being planned. From these handbook data, the site operator can then obtain the values of R, K, and T. To complete the illustration, assume that R = 180, K = 0.32, T = 5, and the field slope is 400 ft long with a nearly uniform gradient of 6%. For this combination, the T/RKLS table shows a value of 0.064 for straight-row planting with the land slope (Table XII). This is the maximum C value that will hold the average annual soil loss from that field within the 5-t/A tolerance limit, if no supporting practices are used. Consulting the C value table will show that a C as low as 0.064 can be attained only with well-managed, sod-based plant cover systems, or with no-till planting in residue covers of at least 70%.

A logical improvement is to add contouring. Table VII shows a slope-length limit of 200 ft (250 ft if residue cover after seeding exceeds 50%) for contouring on 6% slope. Therefore, the P value of 0.5 for contouring will not be applicable on the 400-ft slope without terracing. Construction of three, equally-spaced terraces across the slope would divide it into four 100-ft slope lengths. Shortening the slope lengths to 100 ft will assure contour effectiveness and will also reduce the site value of L. For a 100-ft length of 6% slope planted on the contour, Table XII shows a T/RKLS value of 0.26. Any combination of cropping and management practices having a C value less than 0.26 will now be acceptable. Consulting the table of C values will show that with the terraces and contouring, the site operator can recommend a range of

TABLE XII

MAXIMUM PERMISSIBLE C VALUES (T/RKLS) FOR
R = 180, K = 0.32 and T = 5
(all values expressed in US customary units)

Gradient percent	50	75	100	150	200	250	300	400
	Values for slope lengths (feet)							
	STRAIGHT ROW							
2	0.53	0.47	0.43	0.38	0.35	0.33	0.31	0.28
4	0.29	0.24	0.22	0.18	0.16	0.15	0.14	0.12
6	0.18	0.15	0.13	0.11	0.091	0.082	0.074	0.064
8	0.12	0.10	0.087	0.072	0.062	0.055	0.050	0.044
10	0.090	0.073	0.063	0.052	0.045	0.040	0.037	0.032
12	0.068	0.056	0.048	0.039	0.034	0.030	0.028	0.024
14	0.054	0.044	0.038	0.031	0.027	0.024	0.022	0.019
16	0.043	0.035	0.030	0.025	0.022	0.019	0.018	0.015
	CONTOURED[a]							
2	0.89	0.78	0.72	0.64	0.58	0.55	0.52	0.47
4	0.57	0.49	0.43	0.37	0.33	0.30	0.28	0.25
6	0.36	0.30	0.26	0.21	0.18	0.16	b	—
8	0.25	0.20	0.17	0.14	0.12	0.11	—	—
10	0.15	0.12	0.11	0.086	b	—	—	—
12	0.11	0.093	0.080	0.065	—	—	—	—
14	0.077	0.062	0.054	b	—	—	—	—
16	0.062	0.050	0.044	—	—	—	—	—

[a]The values for the contoured treatment are T/RKLSP, where P is dependent on percent slope (see Table VII).
[b]Omission of values indicates that the slope-lengths exceed the limits for effectiveness of contouring. Use corresponding values from upper half of table.

possibilities for land use and management. If a system with a C value appreciably less than 0.26 is selected, a higher level of conservation will be attained than is required by the 5-t/A tolerance limit.

Had the slope length in the example been only 200-ft, the contour P value of 0.5 (Table VII) would have been applicable without the terraces. Table XII shows that this combination would have permitted use of any system having a C value less than 0.18.

Thus, by this procedure a site operator lists all the alternative plant cover and management combinations that would control erosion at an acceptable level. Study of this list will show how an erosion control program can be improved and increase SLB site performance. In addition, the site operator should set up a program for long-term monitoring of the C factor, once selection of all the USLE factors has been made for the SLB site. This program should ensure that normal plant succession and soil formation processes allow the site to meet the selected tolerable soil losses from the surface of the trench cap over the lifetime of the site.

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Appendix A

Conversion Factors for Universal Soil Loss Equation (USLE) Factors (Foster et. al., 1981)

To Convert From:	*U.S. Customary Units*	*Multiply By:*	*To Obtain:*	*SI Units*
Rainfall intensity, i or I	inch / hour	25.4	millimeter / hour	mm[a] / h
Rainfall energy per unit of rainfall, e	foot·tonf / acre·inch	2.638×10^{-4}	megajoule / hectare·millimeter	MJ[b] / ha·mm
Storm energy, E	foot·tonf / acre	0.006701	megajoule / hectare	MJ[c] / ha
Storm erosivity, EI	foot·tonf·inch / acre·hour	0.1702	megajoule·millimeter / hectare·hour	MJ·mm / ha·h
Storm erosivity, EI	hundreds of foot·tonf·inch[d] / acre·hour	17.02	megajoule·millimeter / hectare·hour	MJ·mm / ha·h
Annual erosivity, R[e]	hundreds of foot·tonf·inch / acre·hour·year	17.02	megajoule·millimeter / hectare·hour·year	MJ·mm / ha·h·y
Soil erodibility, K[f]	ton·acre·hour / hundreds of acre·foot·tonf·inch	0.1317	metric ton·hectare·hour / hectare·megajoule·millimeter	t·ha·h / ha·MJ·mm
Soil loss, A	ton / acre	2.242	metric ton / hectare	t / ha
Soil loss, A	ton / acre	0.2242	kilogram / meter²	kg / m²

[a] Hour and year are written in U.S. customary units as hr and yr and in SI units as h and y. The difference is helpful for distinguishing between U.S. customary and SI units.
[b] The prefix mega (M) has a multiplication factor of 1×10^6.
[c] To convert ft-tonf to megajoule, multiply by 2.712×10^{-3}. To convert acre to hectare, multiply by 0.4071.
[d] This notation, "hundreds of," means numerical values should be multiplied by 100 to obtain true numerical values in given units. For example, R = 125 (hundreds of ft-ton-in/acre-hr) = 12,500 ft-tonf-in/acre-hr. The converse is true for "hundreds of" in the denominator of a fraction.
[e] Erosivity, EI or R, can be converted from a value in U.S. customary units to a value in units of Newton/hour (N/h) by multiplying by 1.702.
[f] Soil erodibility, K, can be converted from a value in U.S. customary units to a value in units of metric ton·hectare/Newton·hour (t·h/ha·N) by multiplying by 1.317.

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