A rainfall simulator study of soil erodibility in the Gallatin National Forest, southwest Montana
by Ginger Lee Schmid

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University
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Abstract:
Adequate equations are a necessity for quantitatively predicting soil losses from precipitation events on nonagricultural soils in the Rocky Mountain west. A modified Meeuwig rainfall simulator was used to study sediment yield environments on wildland soils in the Gallatin National Forest of southwest Montana.

Sediment was collected from simulator plots under three different treatments: (1) natural ground cover intact, (2) vegetation and litter removed, and (3) soil surface removed to a depth of 15 cm. Sediment yields from these three treatments on fine textured soils formed on Cretaceous shales were compared to those from coarse textured soils formed on Pre-Cambrian metamorphics. Slope angle; percent of ground area covered by vegetation, litter and rock; and the soil properties of texture, bulk density, organic matter content and water content were measured as possible variables affecting erodibility. These soil and site characteristics were also used to determine if sediment yield prediction equations developed from Meeuwig's (1970,1971) simulator research on high elevation rangeland in the Intermountain west were applicable on forested lands in southwestern Montana.

Soil texture, soil water content, and percent of the soil surface protected by vegetation, litter, and rock were significantly different between soil textures and treatments. No significant differences were found between the fine and coarse textured sediment yields for any one treatment. Significant differences were seen between plot treatments when both textures were considered together. The sediment prediction equations developed by Meeuwig (1970,1971) did not accurately predict the sediment yields collected from this simulator study.

Lack of a significant difference in sediment yields from the two soil texture extremes was probably due to aggregation of clay in the shale soils to form sand sized particles. Significant differences in sediment yield between plot treatments support evidence that disturbance of a soil increases its erodibility. The failure of the Meeuwig equations to predict sediment yields on this study's sites in the Gallatin National Forest does not discredit Meeuwig's work, but rather emphasizes the natural variability involved in mountain soil environments, and the difficulties involved in quantifying soil erodibility in these areas.

A RAINFALL SIMULATOR STUDY OF SOIL ERODIBILITY IN THE GALLATIN NATIONAL FOREST, SOUTHWEST MONTANA

by

Ginger Lee Schmid

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

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Sediment was collected from simulator plots under three different treatments: (1) natural ground cover intact, (2) vegetation and litter removed, and (3) soil surface removed to a depth of 15 cm. Sediment yields from these three treatments on fine textured soils formed on Cretaceous shales were compared to those from coarse textured soils formed on Pre-Cambrian metamorphics. Slope angle; percent of ground area covered by vegetation, litter and rock; and the soil properties of texture, bulk density, organic matter content and water content were measured as possible variables affecting erodibility. These soil and site characteristics were also used to determine if sediment yield prediction equations developed from Meeuwig's (1970,1971) simulator research on high elevation rangeland in the Intermountain west were applicable on forested lands in southwestern Montana.

Soil texture, soil water content, and percent of the soil surface protected by vegetation, litter, and rock were significantly different between soil textures and treatments. No significant differences were found between the fine and coarse textured sediment yields for any one treatment. Significant differences were seen between plot treatments when both textures were considered together. The sediment prediction equations developed by Meeuwig (1970,1971) did not accurately predict the sediment yields collected from this simulator study.

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INTRODUCTION

Erodibility is defined as a soil's susceptibility to erosion. A soil that is highly erodible is highly susceptible to erosion. There are inherent soil characteristics that have been shown to influence a soil's vulnerability to water erosion under certain conditions. These include particle size distribution, aggregation, bulk density, organic matter content and water content (Middleton, 1930; Bryan, 1968; Wischmeier and Mannering, 1969; Hudson, 1981).

The erodibility of agricultural soils in the central and eastern United States has been intensely studied over the past two decades (e.g. Olson and Wischmeier, 1963; Wischmeier and Mannering, 1969; Wischmeier, Johnson, and Cross, 1971; Wischmeier and Smith, 1978; Meyer, 1984). These studies have resulted in the development and use of the Universal Soil Loss Equation (USLE) to predict long term sediment loss due to erosion by rainfall (Wischmeier and Smith, 1978). A K factor for soil erodibility is included in the USLE, and it can be used to quantify the erodibility of soils formed under pedogenic environments similar to those used in the development of the USLE.

Pedogenic environments in the intermountain West are different from those studied in the development of the USLE. As the five factors governing soil formation change, so do the soil characteristics affecting erodibility and the role they play in water erosion environments. When topography and climate change, biological activity

changes and the soil characteristics that control soil erodibility do not play the same roles as corresponding characteristics do in soils east of the Rocky Mountains. The USLE's K factor does not adequately represent soil erodibility in these western environments (Trieste and Gifford, 1980; Trott and Singer, 1983).

Erodibility Studies in the Intermountain West

A considerable amount of work has been done in the western United States on erodibility and related factors of soil erosion by water. Laboratory work in California (André and Anderson, 1961) resulted in a prediction equation that could be used for determining the relative erodibility of a watershed. This equation related a surface-aggregation and a dispersion ratio to parent material type, vegetation type, geographic zone and elevation.

A twenty year, multi-agency field project started in Colorado in 1953 (Schumm and Lusby, 1963) looked at the erosional and hydrological characteristics of grazed and ungrazed areas in small drainage basins developed on shale parent material. Results from the precipitation, runoff, and sediment yield portion of this project gave strong evidence of seasonal changes in the soil characteristics influencing erosion.

Rainfall simulations conducted under winter conditions in the Sierra Nevada Mountains northwest of Reno, Nevada (Haupt, 1967) resulted in restricted field conditions that did not allow a reliable

statistical analysis. Qualitative conclusions indicated that litter and snow cover dissipated raindrop energy and increased infiltration, while exposed rock accelerated overland flow and erosion.

Rainfall simulator studies conducted on high elevation rangeland in Idaho, Montana and Utah (Meeuwig, 1970, 1971a) resulted in regression equations and related nomographs to predict sediment losses in certain erosion environments. These environments were identified by elevation, parent material, soil texture and vegetation type. The equations utilized percent ground cover, slope gradient, soil texture and soil organic matter content in predicting sediment losses. The percent of ground cover intercepting precipitation was the single most important factor in all erosion environments studied, but the magnitude of its role was highly dependent upon the slope gradient.

Meeuwig also conducted rainfall simulator studies in the Carson Range of the Sierra Nevada Mountains (1971b) where he was looking at the effect of location (depth in soil) and continuity of hydrophobic layers on infiltration. These rainfall simulations were conducted on several types of vegetation as well as on bare ground. The most severe hydrophobia and runoff was observed under Western white pine.

The importance of disturbance of the soil surface was investigated on pinyon-juniper sites in southern Utah (Gifford, 1973). Sites that were chained and then seeded to crested wheatgrass had higher runoff and sediment yields under natural precipitation events than the

woodland control sites, even when ground cover on the grass sites increased to 74 percent coverage.

United States Forest Service concerns with the impacts of logging activities on the coarse textured soils of the Idaho Batholith initiated a six year study in the Payette National Forest (Megahan, 1975). Sediment production per unit area of the watershed was 150 times greater after construction of logging roads than it was in undisturbed areas. Eighty-four percent of the sediment from surface erosion measured during the period of study was produced in the first year after construction.

Seasonal variation of soil characteristics was observed in an infiltration study on pinyon-juniper sites in southeastern Utah (Gifford, 1979). Infiltration readings from simulated rainfall on uniform soils exhibited a wide range between minimum and maximum rates. Maximum infiltration occurred in early spring and the minimum rates were observed in late summer. Another rainfall simulator field study (Gifford, 1982) of infiltration in a Big sagebrush community in southern Idaho found that grazing eliminated seasonal variations in infiltration rates. This study also found that plots that had reduced infiltration due to grazing impacts took six years to recover once the animals were removed.

A laboratory study (Dadkhah and Gifford, 1980) evaluated ground cover and trampling rates without the seasonal soil influences. Indoor plot studies under simulated rainfall showed no significant increases

in sediment yield once vegetation covered over 50 percent of the plot area. Increased trampling rates yielded uniform decreases in infiltration up to a 40 percent trampling level of animal impact, after which no significant changes in infiltration were observed.

Over 2000 plot years of data from 189 rainfall simulator field plots on rangeland in three western states and Australia were used to evaluate the use of the USLE on various rangeland conditions (Trieste and Gifford, 1980). USLE predictions did not match sediment yields collected from a majority of the field plots. The failure of the USLE to predict sediment yields under those rangeland circumstances represented by the 189 plots suggested the application of the equation in erosion environments dominated by single storm events to be unreliable. Another rangeland application of the USLE (Johnson, Savabi, and Loomis, 1984) was conducted on rainfall simulator plots in Idaho and Nevada. Predicted yields for tilled field plots were close to measured yields. Predicted yields were considerably higher than yields measured from nontilled-ungrazed plots, while predictions for nontilled-clipped plots were much lower than actual sediment yields.

A field study (Hart and Loomis, 1982) of sediment yields from snowmelt was conducted in the Wasatch Mountains of northern Utah under conditions of deep, continuous snowpack over unfrozen soils. The Rs factor of the USLE designed for predicting sediment losses from thaw and snowmelt greatly over estimated the actual sediment yields. Soil loss seemed to be more dependent upon the rate of snowmelt rather than

the volume of melt runoff. The Rs factor (Wischmeier and Smith, 1978) was adjusted for the nonmountainous, dryland grain areas east of the Cascades in Washington, Oregon and Idaho. This adjustment of the R factor of the USLE required modification of the L and S factors (Wischmeier and Smith, 1978) as well, and all factor modifications were applicable only in the specified agricultural areas (McCool, Wischmeier and Johnson, 1982).

Rainfall simulations were conducted on laboratory plots of two cohesive soils (loam and silty clay loam) over a range of slope gradients from 3-50 percent (Singer and Blackard, 1982). Relative soil erodibility changed as slope angle increased. The S factor as calculated by the USLE did not agree with data from the two soils at the higher slope angles used in this study. This disagreement was thought to indicate slope-erodibility interactions.

Laboratory plots of California range and forest soils were used in rainfall simulations to establish their relative erodibility (Trott and Singer,1983). Results from these plot trials were compared to K factor values estimated from the USLE erodibility nomograph (Wischmeier and Smith, 1978). Results seemed to indicate that the organic matter content is not as important in the erodibility of western mountain soils as it is in the midwestern agricultural soils on which the USLE was developed.

Rainfall simulation on field plots was used to compare the potential sediment production from ten Blue Mountain ecosystems in

northeastern Oregon (Buckhouse and Gaither. 1982). No unusual or severe soil disturbances were present on any of the sites. No differences in sediment production were observed between forest ecosystems. Soil loss from grassland, sagebrush and juniper ecosystems were all significantly higher than those from the forest systems.

A study on alpine soils in Rocky Mountain National Park, Colorado (Summer, 1982) compared field erodibility indices developed from rainfall simulations to laboratory analyses of aggregation, texture, organic carbon and water adsorption properties. Twenty-nine percent of the variance in erodibility was explained through aggregation and texture. This thorough comparison of laboratory and field analysis demonstrated that laboratory analyses are not an adequate method of estimating erodibility indices in alpine environments.

These studies discuss several soil properties that contribute to erodibility in the mountainous West. Many have looked at how these properties differ from those used in USLE factor calculations. Most have recognized the complexity of mountain soil environments. The failure of decades of soil erodibility research in the West to arrive at any single quantifying factor comparable to the USLE's K factor is not due to inadequate or inappropriate research, but rather it reflects the heterogeneity of the soils and of water erosion environments and processes in mountainous areas.

Thesis Objectives

This thesis study addressed the quantification of soil erodibility in the Gallatin National Forest (GNF), south of Bozeman, Montana. The GNF is a multi-management area with watersheds, timber, range, wildlife and recreation being the major uses. The sites for this study were located within two watersheds of the city of Bozeman, and were within areas of timber harvesting. The study had two major objectives:

1. To measure and compare sediment yields from rainfall simulations on two contrasting parent materials commonly occurring in the Gallatin National Forest.
2. To determine if any previous erodibility work in the intermountain West could provide sediment prediction tools applicable to water erosion environments in the Gallatin National Forest.

The first objective provided a basis on which to observe soil and site characteristics thought to influence erosion and soil erodibility. The sediment yield measurements provided the values to test the applicability of predictive models previously developed in high elevation watersheds. The second objective was pursued to determine if a usable soil erodibility prediction tool had already been developed.

Site Details

High elevation, steep, forested slopes were the site characteristics desired to represent soil erosion environments under management in the Gallatin National Forest. Two shale sites and two crystalline metamorphic sites were selected at elevations of approximately 2100 meters (7000 feet) in the northern portion of the Gallatin National Forest (Figure 1). The fine textured sites were located on late Jurassic and Cretaceous shales in the Bozeman Creek Drainage. The coarse textured sites were on PreCambrian crystalline metamorphics in the Hodgman Creek Drainage.

Three of the sites had north to northwest aspects, 35 to 45 percent slopes and were forested (Table 1). Steep shale slopes are not commonly forested in this portion of the GNF, so the fourth site chosen was a meadow area on shale slopes of 15 percent with a southwest aspect. Soil textures closely reflected their parent materials. The two shale sites were predominantly clays, silty clays, and clay loams. The crystalline sites were loamy sands and sandy loams.

Three rainfall simulator plots were located at each of the four sites, providing a total of 12 simulator plots, six plots on each parent material. Microenvironments were avoided by locating plots so they were as representative of the site location as possible in terms of slope, aspect and vegetation. Large tree roots, boulders

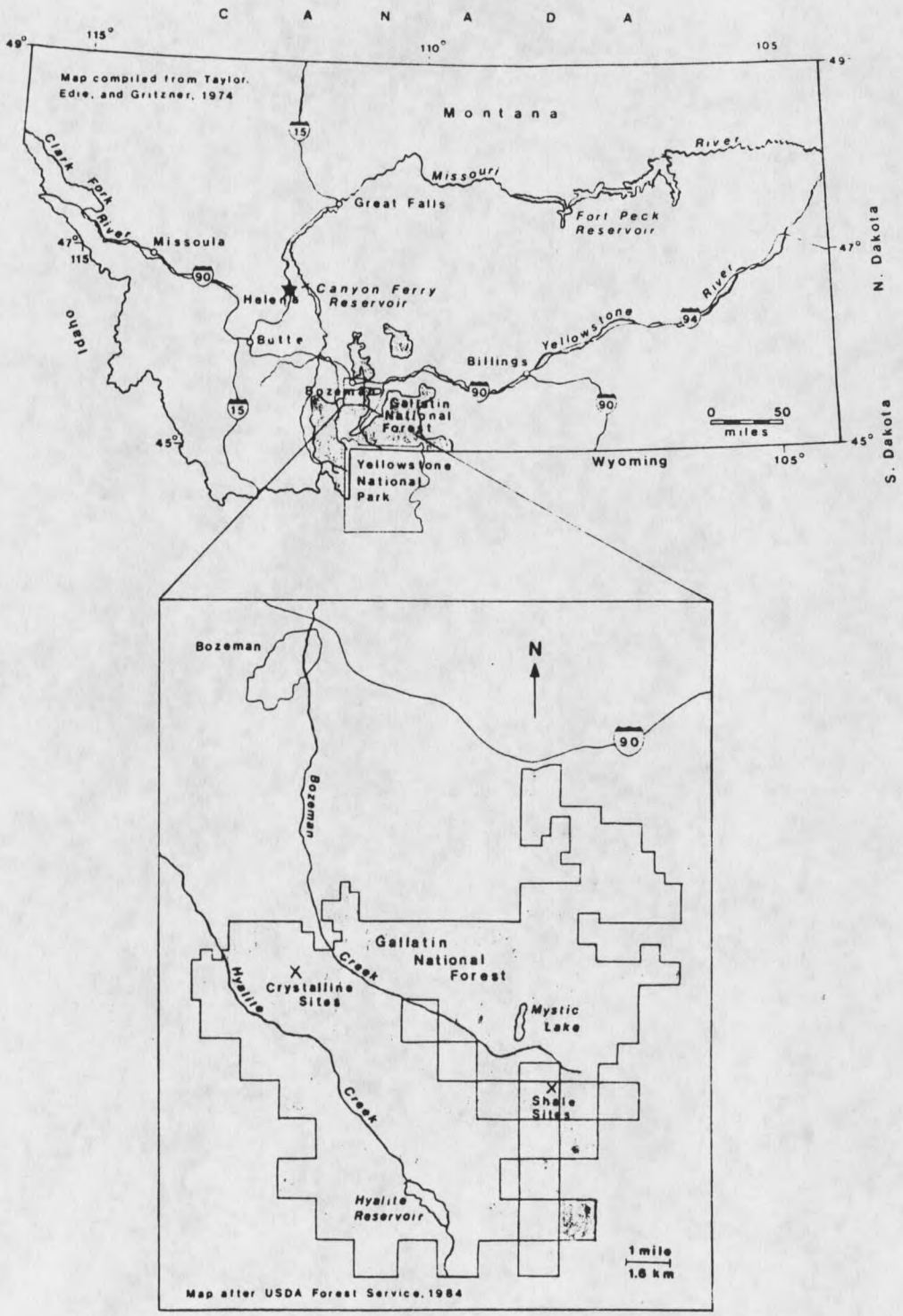


Figure 1. Location of study sites.

	M12	VSH	MER	MLP *
Location	NE 1/4, Sec 6 R7E, T4S	NE 1/4, Sec 31 R7E, T3S	NE 1/4, Sec 24 R5E, T3S	NE 1/4, Sec 24 R5E, T3S
Parent Material	Shale	Shale	Crystalline	Crystalline
Aspect	N	SW	N	NW
Slope	35%	15%	35%	45%
Elevation	2280 m (7600 ft)	2100 m (7000 ft)	2100 m (7000 ft)	2100 m (7000 ft)
Vegetation	Lodgepole Pine (*Pinus contorta*) Whitebark Pine (*Pinus albicaulis*) Subalpine Fir (*Abies lasiocarpa*)	Timothy (*Phelum pretense*) Western Yarrow (*Achillea millefolium*) [Douglas Fir (*Pseudotsuga menziesii*) adjacent]	Lodgepole Pine (*Pinus contorta*) Blue Huckleberry (*Vaccinium globulare*) Arrowleaf Balsamroot (*Balsamorhiza sagittata*)	Lodgepole Pine (*Pinus contorta*) Pinegrass (*Calamagrostis rubescens*)
Soil Textures	clay and silty clay	clay loam and silty clay	loamy sand	loamy sand and sandy loam

Table 1. Site characteristics, Gallatin National Forest, southwest Montana. *See Appendix A for explanation of site location acronyms.

and animal burrows were avoided because of their possible effects on data and also because of limitations with the simulator design.

Each of the 12 plots received three rainfall simulation runs with each run conducted on a different level of plot disturbance. The first simulator run was done on an undisturbed plot. The second run was done with the vegetation clipped and removed along with any litter layer present. The bare soil surface was not disturbed for this treatment. The final simulator run was done after the soil surface had been removed to a depth of approximately 15 centimeters (6 inches). Sediment eroded from the plot was collected for each run.

Soil samples were collected from each plot for analysis of soil water content, organic matter content, bulk density and particle size distribution. Additional plot characteristics measured were percent of ground cover and dry weight of litter removed.

METHODS AND EQUIPMENT

Rainfall Simulator

A rainfall simulator was used to monitor erosion because natural storm events are too unreliable and storm characteristics tend to be inconsistent between different locations. Even with reliable storm occurrences it can take years to collect the amount of data obtainable from a single season of rainfall simulator applications (Meyer, 1965; Hudson, 1981).

Erosion studies done with portable rainfall simulators are limited to looking at only the interrill stage of erosion (Gifford, 1986). Transport and deposition of detached particles are limited by the small plot sizes associated with portable machines, and the more advanced stages of rill and gully erosion are not attained.

The interrill stage of erosion is dominated by drop impact (Hudson, 1981; Meyer, 1985), where the drop impact is responsible for both soil particle detachment and transport (Quansah, 1981; Kneale, 1982). The major factors affecting erosion rates under drop impact are soil type, precipitation intensity and soil surface coverage (Meyer, 1985). Precipitation intensity and soil surface coverage are directly measurable. The soil variable in interrill erosion can be equated with soil erodibility. The focus of a rainfall simulator study on interrill erosion is then a focus on soil erodibility.

The erosive energy of rainfall is usually calculated in terms of kinetic energy ($KE = 1/2\ M\ V^2$) rather than strictly in terms of intensity (Wischmeier et al, 1958; Hudson, 1981; Quansah, 1981). The velocity term used in calculating kinetic energy reflects storm intensity. Storms of different intensities have different distributions of raindrop sizes (Laws and Parsons, 1943). The size of a water drop influences the velocity with which that drop will fall (Laws, 1941; Gunn and Kinzer, 1949; Best, 1950), so intensity is reflected in kinetic energy calculations through the influence of drop size on velocity.

Terminal velocity is not readily attainable in the field with many portable rainfall simulators (Young, 1979; Hudson, 1981). Calculations of kinetic energy can be used to compare the energy of a natural storm to that of a simulated rainfall event (Gifford, 1979). Simulated drop size and fall height must be known in order to estimate impact velocity for the simulated precipitation.

The rainfall simulator used in this study was a modified Meeuwig drip-type simulator (Meeuwig, 1971b) (Figure 2) with a drop fall height of 155 cm (62 inches). The approximate waterdrop diameter at a simulated intensity of 127 mm (5 inches) per hour was 2.8 mm (0.11 inches) (Gifford, 1986; Appendix B). Impact velocity for a 2.8 mm waterdrop falling 155 cm is approximately 470 centimeters (15 ft) per second (Laws, 1941). Terminal velocity (impact velocity) of this size

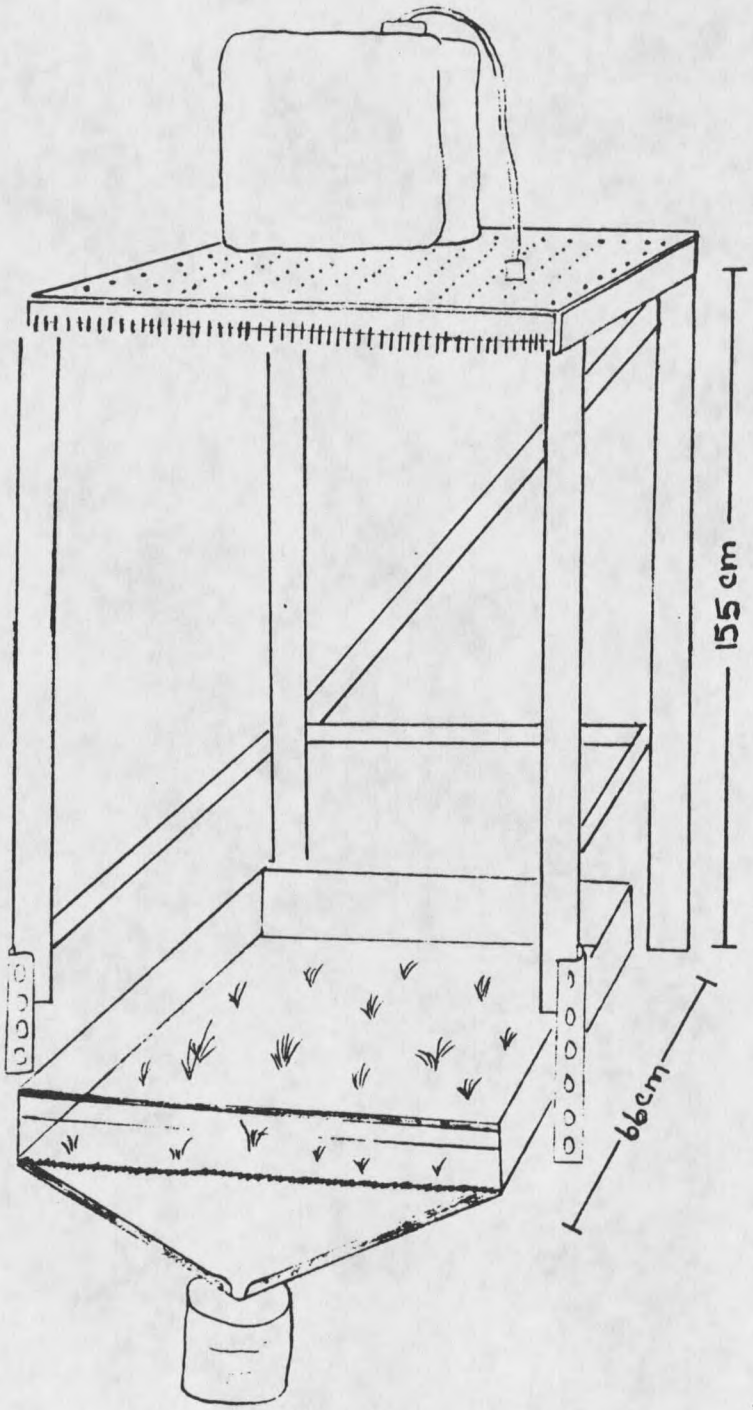


Figure 2. Sketch of rainfall simulator.

drop in a natural storm is 780 centimeters (26 ft) per second (Gunn and Kinzer, 1949).

For this study, the simulated rainfall events had a kinetic energy that was roughly one-third that of equal intensity natural storm events. The 2.8 mm diameter drop was approximately equal to the average drop size for a natural storm with an intensity of 127 mm per hour (Laws and Parsons, 1943; Hudson, 1981). It is then a reasonable assumption that the mass of waterdrops for the simulated events in this study at 127 mm per hour was approximately equal to the mass of a natural storm of the same intensity. The comparison of kinetic energy between the simulated events and natural storms then becomes a ratio of drop impact velocities (V^2[simulated] ÷ V^2[natural]) (Appendix B).

The modified Meeuwig (1971b) simulator used in this study had a 61 cm by 61 cm by 2.5 cm (24 by 24 by 1 inch) plexiglass water chamber with approximately 500 drip needles made from hypodermic tubing. This water chamber was rotated horizontally by an electric motor to prevent the waterdrops from falling repeatedly in the same position on the plot below. The frame holding the water chamber was adjustable allowing the water chamber to be leveled over any slope angle.

An 18.9 liter (5 gallon) reservoir was elevated 20 cm (7.9 inches) above the water chamber. This height maintained a relatively constant head on the water in the chamber, and supplied enough water to the chamber to conduct a 30 minute simulator run at a constant intensity of 127 mm per hour. Distilled water was used for all simulator runs to

ensure a known water quality that would not clog the drip needles and would prevent any undesirable chemical reactions with the soil particles in the plots.

A 66 cm by 66 cm (26 by 26 inches) plot frame was pounded 2 to 5 cm (0.75 to 2 inches) into the soil to reduce lateral movement of water out of the plot. The down slope side of the plot frame was open to allow movement of water runoff and detached sediment onto a collection tray which funneled the water and eroded sediment into a collection can. The plot frame was made larger than the water chamber to accommodate the area covered by the horizontal rotation of the chamber.

The plot edge of the collection tray had a 1.27 cm (0.5 inches) flange that was inserted into the soil until the tray was level with the soil surface inside the plot frame. Dry, powdered bentonite was used to seal the tray edge to the plot. This prevented water and detached sediment from flowing under the tray instead of into the collection can. The surface of the bentonite became fairly smooth when it became wet, so movement of water and sediment from the plot to the tray was negligibly interrupted.

The first 30 minute simulator run, or litter run, was conducted without any disturbance to the plot surface. All vegetation and litter on the soil surface were left undisturbed. A 2.54 cm by 5 cm (1 by 2 inches) rectangular microplot sampler (Morris, 1973) was used to record the percent of soil surface covered by litter, vegetation, or

moss. The rectangle was placed and percent basal cover was recorded at ten equally spaced locations across the diagonal of each plot. These ten readings were averaged to determine the percent of ground cover for each litter run.

The second simulator run, or bare run, was done immediately after the litter run was completed. The plot frame and collection tray were left in place, but all vegetation was clipped and removed along with all litter. All vegetation and litter removed from each plot was taken back to the laboratory and air-dried to a constant weight.

The soil surface itself was undisturbed and bare except for any roots and rocks that were present. Visual estimates were made throughout the 30 minute period of how much of the exposed plot surface was covered by roots and rocks along with their approximate sizes.

The final 30 minute simulator run, the subsurface run, required removal of the plot frame and collection tray. Immediately after completion of the bare run, the plot was dug out to a depth of approximately 15 cm (6 inches), which was below the soil A horizon at all plot locations. The plot frame and collection tray were then reinstalled at the new soil surface level, and the soil surface inside the plot frame was gently smoothed to remove any artificial sediment storage areas. Visual estimates of rock and root size and coverage were again recorded throughout the 30 minute run.

Eroded sediment and water runoff were collected for each of the 30 minute simulator runs. The sediment did not settle out of all samples

after 24 hours, so each sample was flocculated with enough $CaCl_2$ to approximate a 0.01 molar solution and then allowed to settle for another 24 hours. Most of the water could then be siphoned from the settled sediment. The remaining water-sediment slurry was oven-dried to a constant weight before a final weighing of the amount of sediment eroded from each plot.

Soil Samples

Water Content

Soil samples were taken from the soil surface adjacent to each plot prior to the litter runs to determine soil water content. These samples were taken from the area where the collection tray and can were installed in order to get as close to the plot as possible without disturbing the plot surface. Sampling depth averaged 2.5 cm (1 inch) with a maximum depth of 5 cm (2 inches). Any litter on the soil surface was not incorporated into these samples, so the sampling reflected the soil water content, not necessarily the water content of the drop impact surface.

Samples to determine the soil water content of the bare runs were taken after the vegetation and litter were removed. These samples were taken from the soil surface directly outside the plot frame where rotation of the water chamber had rained on areas outside the plot frame.

Thick litter layers on some plots prevented the litter run water from reaching or significantly wetting the soil surface. This was suggested by the lack of eroded sediment from the litter run and was visually obvious when the litter layer was removed and the soil surface exposed for the bare run. In these cases, no additional sample was taken for the bare run soil water content. That sample taken prior to the litter run represented the soil water content for both the litter and bare runs on that plot.

Soil water content samples were taken at similar depths and locations to those of the litter run when the new soil surface level was exposed for the subsurface runs on each plot.

All soil water content samples were returned to the laboratory as soon as possible. They were then weighed wet, oven-dried to a constant weight, and reweighed to determine percent water content on a weight basis.

Organic Matter

Each plot was sampled twice for organic matter determinations. One soil sample was taken from the 0 to 2.5 cm (0 to 1 inch) depth and the second at a depth of 2.5 to 5.0 cm (1 to 2 inches). These soil samples were kept as cold as was practical and were returned to the laboratory as soon as possible where they were oven dried to a constant weight. The samples were then sieved to remove coarse fragments and the fine fraction was ground in a Dynacrush soil grinder. The ground samples were then analyzed by a modified Walkley-Black method according to

procedures defined by Sims and Haby (1971). This organic matter content determination was done on a Spectronic 20 colorimeter.

Bulk Density

Soil samples were taken by the core method (Blake, 1965) from each plot at a 0 to 10 cm (0 to 4 inch) depth for measurement of bulk density. These samples were taken by pounding a 7.5 cm (3 inch) diameter sampling can into the side of each plot after it had been excavated to the subsurface level. The bulk density samples were weighed wet, oven dried to a constant weight, reweighed, and then sieved to remove all coarse fragments greater than 2 mm (0.08 inches) in diameter and all roots.

The roots and rocks were weighed separately in order to determine their respective volumes within the soil sample. Coarse fragment volumes were calculated using the standard 2.65 grams per cm^3 density and root volumes were calculated using a density of 0.5 grams per cm^3. Subtracting these volumes from the total sample allowed a calculation of the soil fine fraction bulk density.

Particle Size Distribution

Surface and subsurface level soil samples for particle size distribution were taken at each plot. The samples were oven dried and them sieved to remove all coarse fragments greater than 2 mm in diameter. The shale samples were wet sieved to prevent shale coarse fragments from being broken into pieces smaller than 2 mm by grinding

in a mortar and pestle. These samples then had to be re-dried before the final hydrometer analysis.

The hydrometer analysis was done according to the American Society of Agronomy (ASA) standard methods (Day, 1965) with two exceptions:

1. Samples mixed with Calgon were allowed to soak overnight rather than ten minutes, and were agitated for two minutes rather than five. The high clay content of some samples required the longer soaking time for adequate dispersion. The longer period of dispersion required a shorter agitation time, which also was less abrasive on sand-sized particles (Bouyoucos, 1962).

2. Sample sizes of 50 grams were used for the shale soils, and samples of up to 100 grams were used for the high sand samples. The extreme range of particle sizes present in the soils required larger sample sizes (Bouyoucos, 1962; Gee and Bauder, 1986).

Hydrometer readings on all samples were taken at the following time intervals:

40 seconds
60 seconds
3 minutes
10 minutes
30 minutes
60 minutes
90 minutes
2 hours
4 hours
12 hours
24 hours

All hydrometer samples for the crystalline sites were re-agitated and the 40 and 60 second readings taken a total of three times. The three readings were then averaged for each sample. These readings were the most susceptible to error because of how rapidly sand sized particles settle and how quickly the readings must be taken. The averaged reading should have yielded a more accurate representation of the high sand content of these samples.

After completion of the hydrometer readings, all samples were wet sieved, redried, and reweighed to determine distribution of very coarse, coarse, medium, fine, and very fine sand sizes particles. Sieve sizes used corresponded to particle diameters of:

1.00 to 2.00 mm	(0.039 to 0.079 inches)
0.50 to 1.00 mm	(0.020 to 0.039 inches)
0.25 to 0.50 mm	(0.010 to 0.020 inches)
0.10 to 0.25 mm	(0.004 to 0.010 inches)
0.05 to 0.10 mm	(0.002 to 0.004 inches)

Site Observations

Slope and aspect measurements were taken at each site using a clinometer and compass. Site elevations were estimated using USGS topographic and geologic maps. Dominant vegetation was also identified at each site. Soil pits were dug at each site and characterized with standard Soil Survey (1975) observations (Appendix C).

Predicted Sediment Yields

The erosion environment regression equations developed by Meeuwig (1970, 1971a) seemed more applicable to this study's site environments than any other works published on interrill erosion in the intermountain West. Study site characteristics were matched with those differentiating Meeuwig's erosion environments (1970).

The shale study sites most closely matched those of Meeuwig's on the Vigilante Experimental Range in the Beaverhead National Forest in southwestern Montana. The crystalline study sites were similar to Meeuwig's sites on the Idaho batholith in the Trinity Mountains of the Boise National Forest in southern Idaho (Table 2).

Meeuwig's rainfall simulator studies (1970, 1971a) resulted in separate regression equations for these two study areas. Both equations included the proportion of the soil surface covered by vegetation and litter and both included slope gradient. The equation for the Vigilante Experimental Range also included the organic matter content of the surface 5 centimeters (2 inches) of soil, while the Trinity Mountains equation included the organic matter content of only the surface 2.5 centimeters (1 inch) (Table 3).

These two regression equations were used to calculate amounts of predicted sediment yields expected under simulator condition like those used by Meeuwig. These predicted sediment yields were then compared to the actual sediment yields obtained during the study. This

comparison was done to determine if Meeuwig's erosion prediction equations would be applicable in the erosion environments of the Gallatin National Forest. Differences between Meeuwig's studies and simulator conditions in this study were considered in the interpretation of this comparison.

Statistical Methods

All data for comparison of the shale sites to the crystalline sites were analyzed using a two independent sample t-test for equality of means. All t-tests were conducted at two alpha levels, 0.01 and 0.05 and P-values were determined(Neter and Wasserman, 1974; Dixon and Massey, 1983; Quimby, 1987).

The three way comparison of sediment yields from the three treatments (sediment yields from both textures were combined and then compared across the three treatments) was analyzed using a one way analysis of variance, also at alpha levels of 0.01 and 0.05 (Neter and Wasserman, 1974; Dixon and Massey, 1983; Quimby, 1987).

The multiple comparison of the combined sediment yields was done between specific pairs of treatments using Tukey's multiple range test and a 95 percent family confidence coefficient (Neter and Wasserman, 1974; Dixon and Massey, 1983; Quimby, 1987).

Site Location	Elevation (meters)	Parent Material	Soil Textures	Vegetation
Vigilante Experimental Range and Monument Ridge Gravelly Range Beaverhead National Forest southwestern Montana	2100 to 2850	red shales siltstone, shales glacial till	silt loam and silty clay loam	Idaho fescue native forbs seeded grasses
Trinity Mountains Boise National Forest southern Idaho	2100	granite (Idaho Batholith)	sandy loam and loamy sand	openings in coniferous forests

Table 2. Characteristics of Meeuwig (1970) sites most similar to Gallatin National Forest study locations.

Shale Sites Vigilantle Experimental Range (Beaverhead National Forest)	Crystalline Sites Trinity Mountains (Boise National Forest)
$Y = 1.563 - 0.629A - 1.86AA - 26.0F + 13.2FF + 0.0133G$	$Y = -0.666 + 1.71A - 1.82AA + 8.60E - 18.0AE + 0.0235G$
Y = logarithm of weight of sediment collected from erosion plots	Y = logarithm of weight of sediment collected from erosion plots
A = proportion of soil surface covered by vegetation and litter	A = proportion of soil surface covered by vegetation and litter
F = organic matter content of surface 5.0 cm of soil	E = organic matter content of surface 2.5 cm of soil
G = slope gradient in percent	G = slope gradient in percent

Table 3. Meeuwig (1970) sediment yield prediction equations for sites similar to Gallatin National Forest study locations.

RESULTS

Soil Samples

Particle Size Distribution

The hydrometer analysis illustrated the distinct difference in soil textures between the soils developed on the shale parent materials and those formed on the crystalline metamorphics.

Sand contents (particles 0.05 to 2 mm in diameter) for the surface and subsurface soil levels ranged from 0 to 33 percent by weight for the shale plots and from 70 to 82 percent for the crystalline plots (Figure 3; Appendix D). The shale plots had from 25 to 68 percent clay sized particles (less than 0.002 mm diameter) while the crystalline plots were only 2 to 5 percent clay in the surface and subsurface horizons (Figure 4; Appendix D). Neither parent material exhibited a distinct change in texture from the surface to the subsurface level.

The fine-coarse contrast was also reflected in the distribution of sand sized particles as determined by wet sieving the hydrometer samples. All the crystalline plots at both the surface and subsurface levels had very little (5% or less) very fine sand (0.05 to 0.10 mm). The majority of the sand sized portion of these plots consisted of comparatively equal amounts of fine to very coarse sand (0.1 to 2.0 mm) (Figure 5; Appendix D, Table 12).

The shale soils did not have as uniform a distribution of particles comprising their sand sized portion (Figure 6; Appendix D).

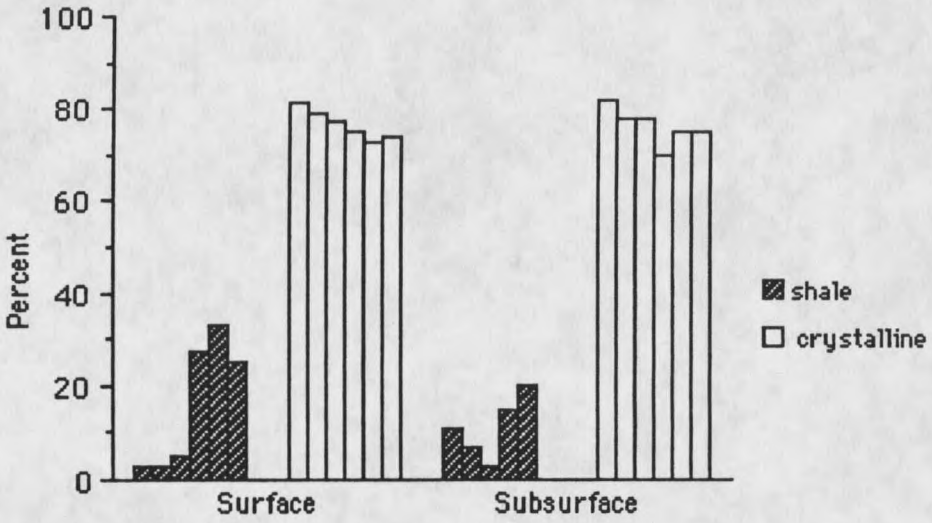


Figure 3. Sand content of the shale and crystalline plots at the surface and subsurface levels.

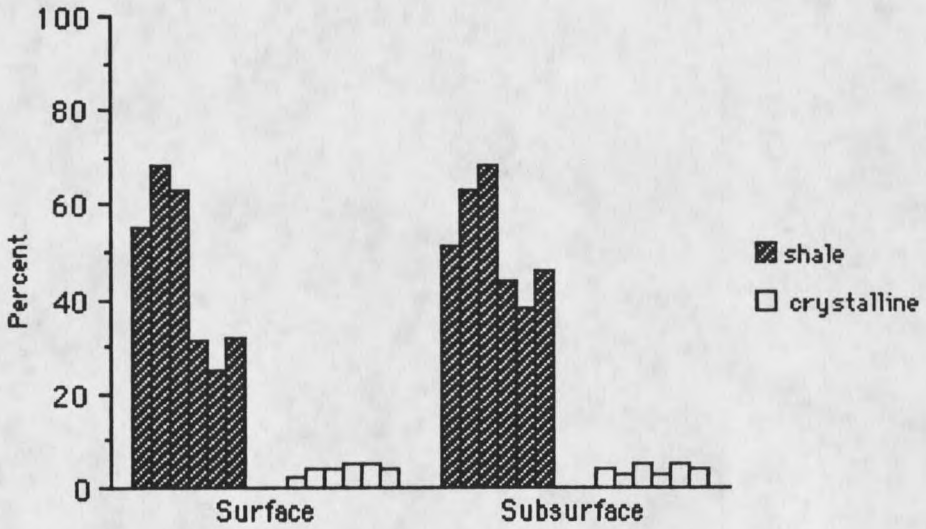


Figure 4. Clay content of the shale and crystalline plots at the surface and subsurface levels.

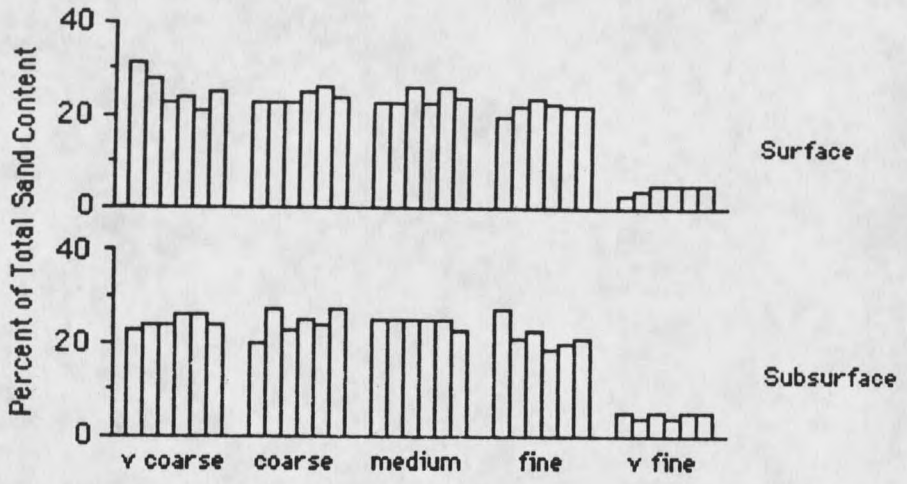


Figure 5. Distribution of sand-sized particles at the surface and subsurface levels of the crystalline plots.

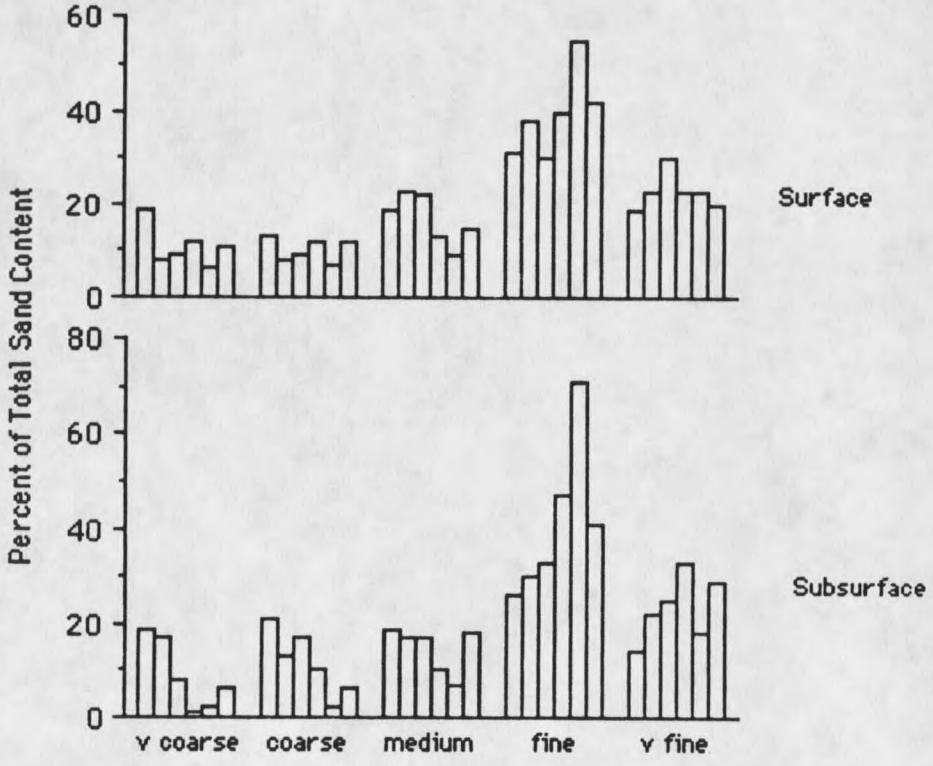


Figure 6. Distribution of sand-sized particles at the surface and subsurface levels of the shale plots.

For the surface and subsurface levels of all shale plots, the largest percentage of sand sized particles were fine sand (0.10 to 0.25 mm). Very fine sand (0.05 to 0.10 mm) represented the next largest portion, followed by medium sand (0.25 to 0.50 mm).

The particle size distribution, especially the distribution of sand sized particles, is a good illustration of the soil variability encountered between the two shale sites, as well as between the plots at each shale site. The opposite is reflected in the very uniform crystalline plots where soil textures varied negligibly between sites and between plots.

Water Content

All sampling was done in September and October of 1986 when natural rainfall and snowfall events occurred frequently. None of the plots were pre-wet due to the relatively high level of natural moisture. The soil water contents, therefore, fit within the natural variation between site locations, natural precipitation levels, and water holding potentials of the two contrasting soil textures.

Shale plot soil water contents were all significantly different from the soil water contents on the crystalline plots for the same simulator treatments (Figure 7; Appendix E, Table 14). Soil water contents tended to vary widely across each texture for a single treatment, but were still significantly different between textures.

For all treatments, the crystalline plots had significantly lower soil water contents than the shale plots. The water holding potential

of the sandy crystalline soils would be expected to be much lower than that of the high clay shale soils (Brady,1984). These sandy soils would, therefore, be expected to have lower soil water contents regardless of local storm amounts as long as site drainage was not restricted. The shale plots had water contents varying from 24.2 to 71.2 percent while the crystalline plots had from 10.2 to 37.5 percent water by weight.

The thick litter layer present on all the crystalline plots allowed little of the litter run simulated rainfall to penetrate to the soil surface, so there were no differences in the surface soil water contents between the litter and bare simulator treatments on the crystalline sites. The plots ranged from 11.5 to 37.5 percent water for these runs.

The shale plots showed a similar relationship between the litter and bare treatment soil water contents. There was more penetration of simulator rainfall through the shale litter layers than was seen on the crystalline plots, so some of the shale bare treatments were run on a slightly higher water content than the litter runs. There were, however, no significant differences between the litter and bare soil water contents on all the shale plots. The shale litter and bare runs ranged from 30.5 to 71.2 percent water by weight.

The litter and bare treatment soil water contents were significantly different from the subsurface soil water contents on both the shale and the crystalline plots (Figure 8; Appendix E, Table

15). This difference between surface and subsurface moisture contents could be reflecting the effect of natural precipitation events being large enough to increase the water content in the surface soil horizons, but not large enough to transmit water throughout the soil profile to the subsurface treatment level. Shale subsurface plots had from 24.2 to 33.3 percent water while the crystalline plots had from 10.2 to 13.8 percent.

Organic Matter

Organic matter contents of the upper five centimeters of the shale soils were not significantly different from those of the same depths in the crystalline soils. All plots on both parent materials had organic matter contents of less than 0.50 percent by weight (Figure 9, Appendix F).

Organic matter contents would be expected to be higher under the meadow sites. Charred roots found at a depth of 34 centimeters indicated that the meadow was forested at one time. It appeared that the meadow vegetation had not been in place long enough to raise the organic matter levels above that of the other forested soils.

Bulk Density

Fine fraction bulk density of the upper 10 centimeters of soil was significantly different between the shale and crystalline plots at the .05 level (Figure 10, Appendix G). The shale derived soils were more dense, ranging from 0.7 to 1.0. The crystalline plot bulk densities

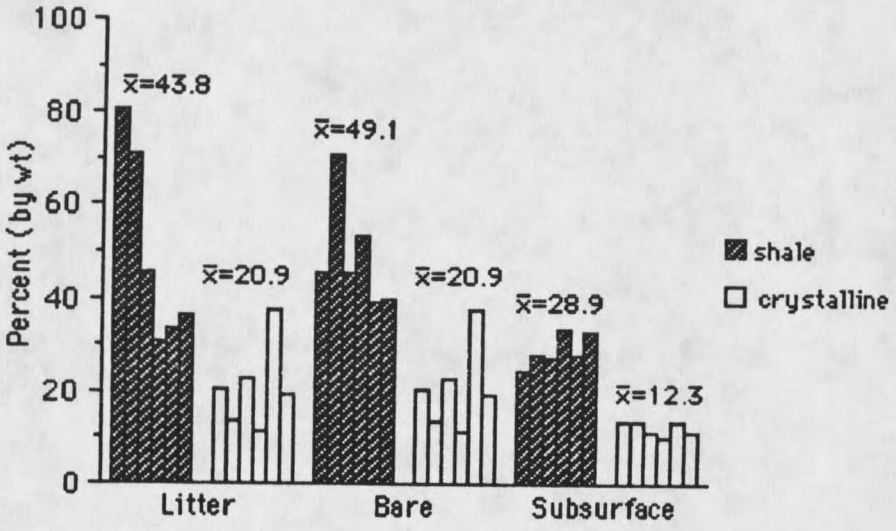


Figure 7. Soil water content prior to each rainfall simulator run on the shale and crystalline plots.

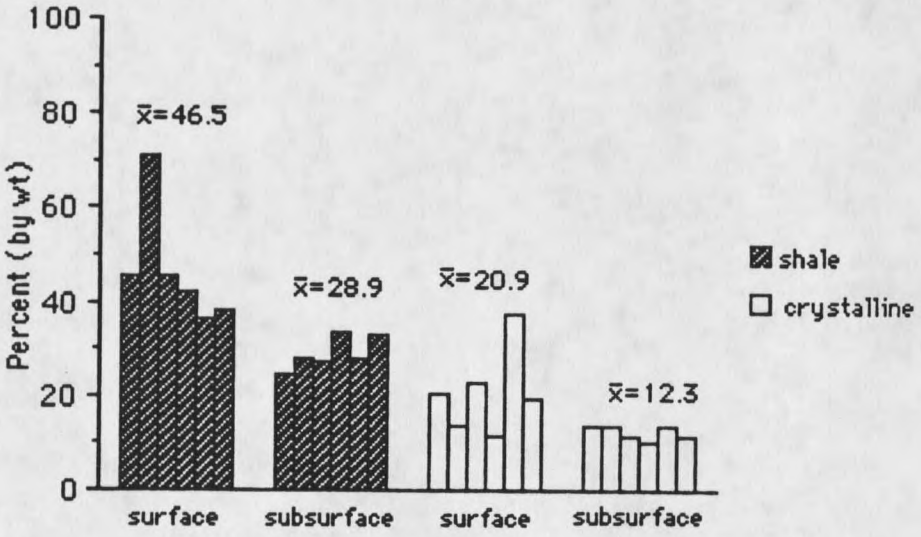


Figure 8. Soil water content prior to rainfall simulator runs at the surface (litter and bare runs) and subsurface levels on the shale and crystalline plots.

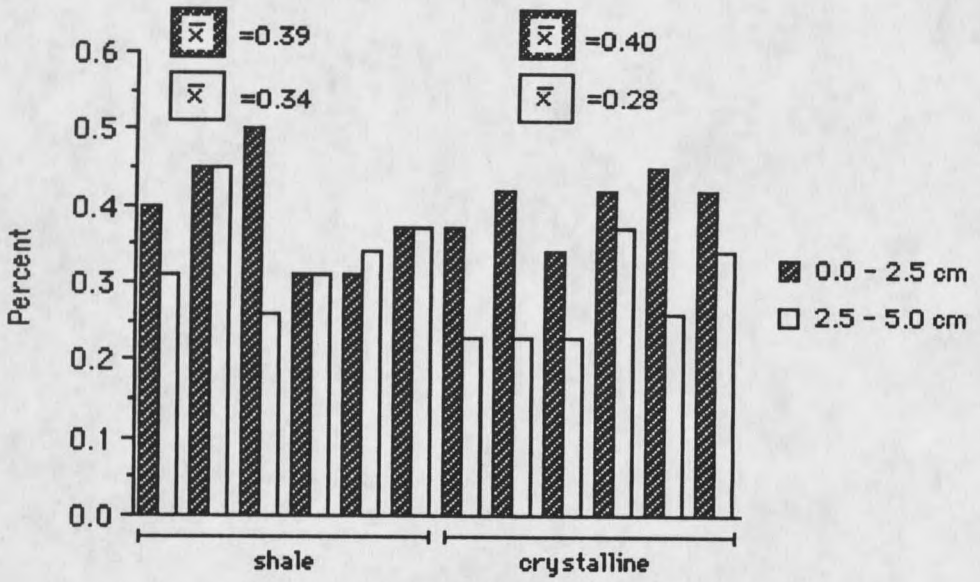


Figure 9. Soil surface organic matter contents on all shale and crystalline plots.

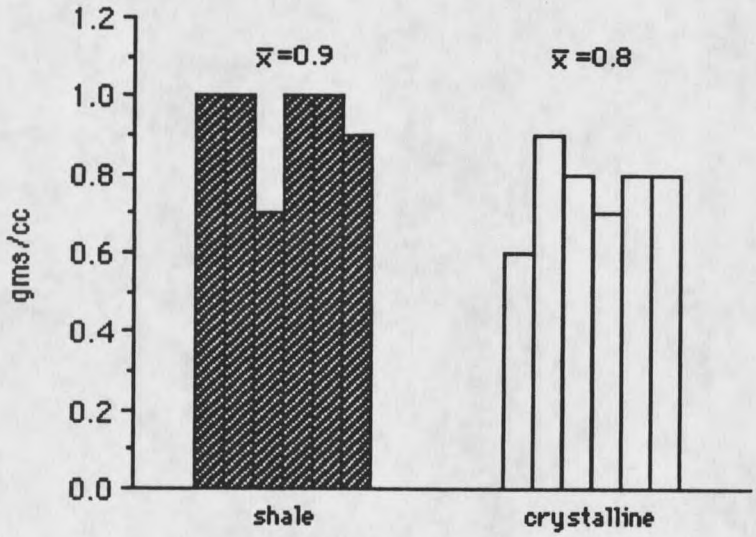


Figure 10. Fine fraction bulk density at 0 to 10 cm on all shale and crystalline plots.

ranged from 0.6 to 0.9. Although statistically different, the actual difference was slight and may not be significant in field applications.

Ground Cover Samples

Percent Ground Cover

The percentage of the soil surface protected by vegetation and litter was significantly different between the shale and the crystalline litter runs at the .05 level (Figure 11; Appendix H, Table 18).

The crystalline sites were very similar, with all plots having 100 percent coverage of the soil surface. This coverage was composed of approximately 2 cm (0.8 inches) in depth of tree needles and cones with some shrub leaves and mosses. This type of litter layer was fairly uniform over all the crystalline plot surfaces.

Ground cover on the shale plots was much more variable. The forest shale plots had from 68 to 97 percent of the soil surface covered by vegetation and litter. These litter layers were composed of needles and moss similar to those on the crystalline plots, but with less overall coverage. Ground cover on the meadow shale plots was dominated by grasses and ranged from 44 to 84 percent coverage of the soil surface.

Ground cover on the bare runs after the vegetation and litter was removed was not significantly different between the shale and crystalline sites. Root and crown coverage of the soil surface of the

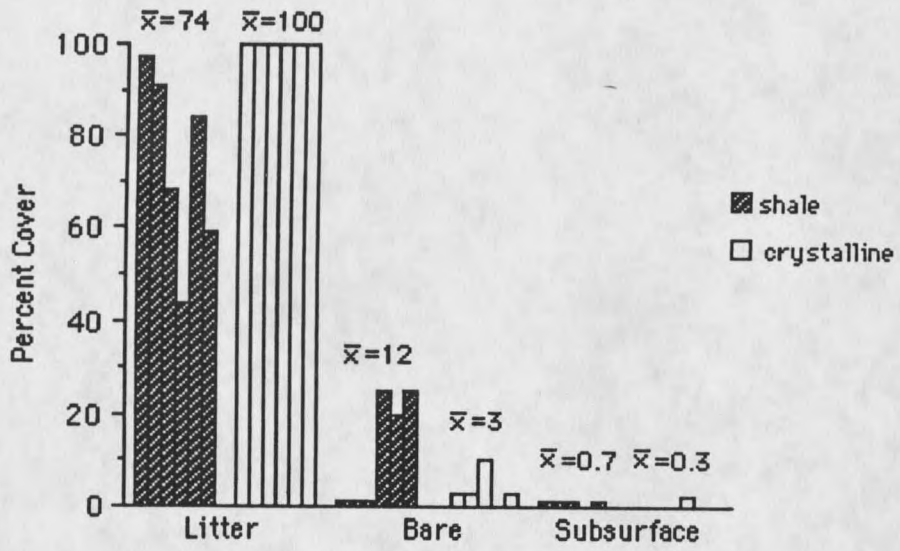


Figure 11. Ground cover during all simulator runs on the shale and crystalline plots expressed as the percentage of the soil surface covered by vegetation and litter only.

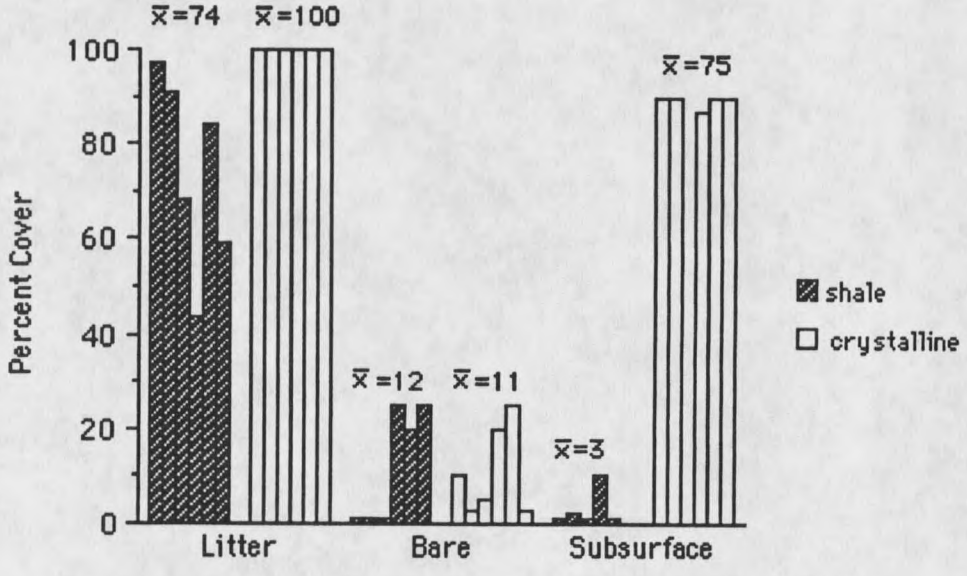


Figure 12. Ground cover during all simulator runs on the shale and crystalline plots expressed as the percentage of the soil surface covered by vegetation, litter and rock.

crystalline plots ranged from 0 to 10 percent, and from 1 to 25 percent of the shale plots (Figure 11; Appendix H).

The grass root crowns on the shale meadow plot did provide greater cover (20-25%) as would be expected from that type of vegetation, while the other forested plots had lower coverage with only single roots present on the soil surface.

The grass root influence did not extend to the subsurface level where all plots had from 0 to 2 percent vegetation cover during the subsurface runs, with no significant difference seen between the shale and crystalline plots (Figure 11; Appendix H, Table 18).

With the shale and crystalline plots combined, there was no significant difference in percent of ground cover between the bare runs and the subsurface runs (Appendix H, Table 19).

When exposed rocks (coarse fragments greater than 1 cm in diameter) were included in ground cover, only the subsurface relationship between the shale and crystalline plots changed. No rocks were visible during the litter runs on any of the plots. The shale plots had no coarse fragments exposed on the soil surface during the bare runs. The crystalline plots had from 10 to 25 percent coverage by rock during the bare runs, but total vegetation, litter, and rock cover was still not significantly different from that on the shale plots.

The percentage of soil surface covered by vegetation, litter, and rock was significantly different between the shale and the crystalline plots for the subsurface runs. The shale plots had from 1 to 10

percent of the subsurface soil surface covered by coarse fragments while the crystalline subsurface plots were covered by 85 to 90 percent rock fragments (Figure 12; Appendix H, Table 21).

Both the crystalline and the shale coarse fragments were dominated by small, angular gravels, often less than 1 cm (0.4 inches) in diameter. Some of the subsurface crystalline plots had exposed coarse fragment up to 8 cm (3.2 inches) in diameter.

The angularity and relatively small size of the coarse fragments on both parent materials is characteristic of surface horizons of young soils formed in place. The dominance of rock fragments on the crystalline plots is consistent with the resistant properties of the crystalline metamorphic parent material. The zero percent rock cover reading on one of the crystalline subsurface plots most likely represents a missing reading rather than no rock fragments exposed at the soil surface (Appendix H).

Litter Weights

Air dry weights of the litter collected from the plots ranged from 748 to 1941 grams (1.7 to 4.3 pounds) per crystalline plot, and from 195 to 1642 grams (0.4 to 3.6 pounds) per plot on the shale sites (Figure 13; Appendix I, Table 22). Statistically, these weights were significantly different between the shale and crystalline plots at the .05 level (Appendix I, Table 22).

Dry litter weight is another expression of the amount of ground cover, and to some extent, the type of cover. The shale meadow plots would be expected to have a different dry litter weight than the forested plots on both parent materials because they had a lower percentage of vegetation and litter cover and also a different composition. The forested shale sites had a vegetation and litter composition very similar to that of the forested crystalline plots, but with less overall coverage.

When the three nonforested shale plots were removed from the statistical analysis, there was no difference in litter weights between the forested shale and crystalline plots (Appendix I). A similar statistical analysis of percent ground cover showed a significant

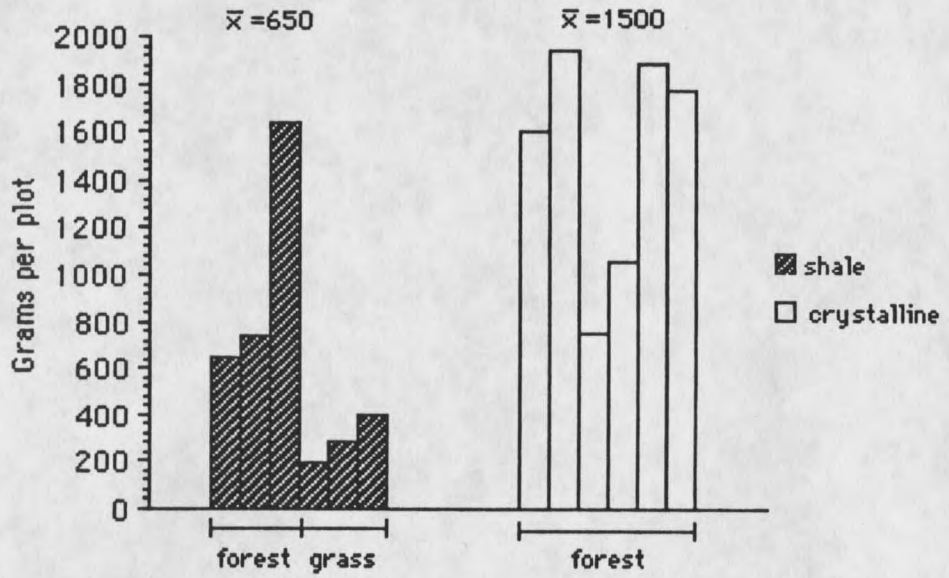


Figure 13. Air dry weight of ground cover removed from all shale and crystalline plots after the simulator litter runs (plot size was 66 cm by 66 cm).

difference between the forested shale plots and the crystalline plots at the .05 level (Appendix I, Table 23). This would indicate that the visual contrast between the ground cover on the forested shale plots was essentially not much different from that on the forested crystalline plots.

Sediment Yields

Grams of eroded sediment collected during the litter runs ranged from zero to 10.9 grams (0 to 0.4 ounces) per shale plot and from 2.4 to 8.2 grams (0.08 to 0.3 ounces) per crystalline plot (Figure 14; Appendix J, Table 25). There was no significant difference between the sediment yields from the shale litter run plots and those from the crystalline litter run plots.

The bare runs yielded 16.7 to 96.7 grams (0.6 to 3.4 ounces) of sediment eroded from the shale plots and 13.3 to 34.2 grams (0.5 to 1.2 ounces) per plot from the crystalline plots (Figure 14; Appendix J, Table 25). There was no significant difference between the sediment yields from the shale bare run plots and those from the crystalline bare run plots.

Subsurface runs on the shale plots had a sediment yield range of 26.4 to 324.3 grams (0.9 to 11.4 ounces) of eroded sediment. Sediment collected from the subsurface crystalline plots ranged from 70.3 to 214.4 grams (2.5 to 7.6 ounces) per plot (Figure 14; Appendix J, Table 25). There was no significant difference between the sediment yields

from the shale subsurface plots and those from the crystalline subsurface plots.

With no significant difference between parent materials, sediment yields from the shale and crystalline sites were combined to test for differences in sediment yields between treatments. There were differences between sediment yields from the subsurface plots and those of the bare and litter plots. There was no difference between sediment yields from the litter plots and sediment yields from the bare plots (Figure 15; Appendix J, Table 26).

Predicted Sediment Yields

All plots from both parent materials were combined to determine if the Meeuwig (1970) regression equations would adequately predict the sediment yields measured in this study. The predicted sediment yields were not significantly different from the sediment yields measured on the litter or on the bare runs (Figure 16, Appendix K, Table 33). The predicted sediment yields were significantly different at the .05 level from the measured amounts on the subsurface runs (Figure 17, Appendix K, Table 33). In all cases, even where not statistically different, the predicted yields were considerably higher than the actual sediment amounts collected.

Sediment yields measured on each parent material were compared to the predicted yields to determine if the Meeuwig equations fit one parent material environment better than the other. The actual shale

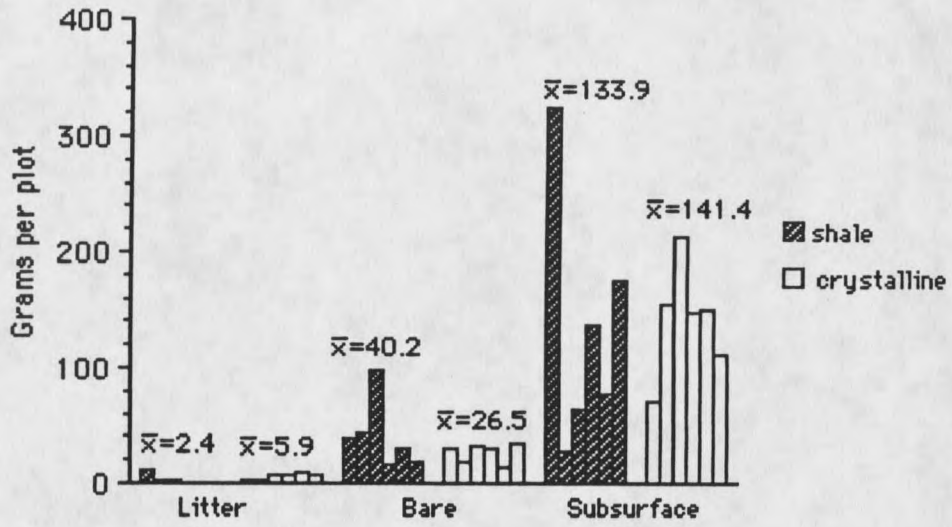


Figure 14. Oven-dry weight of eroded sediment collected from all shale and crystalline plots after each simulator run (plot size was 66 cm by 6 cm).

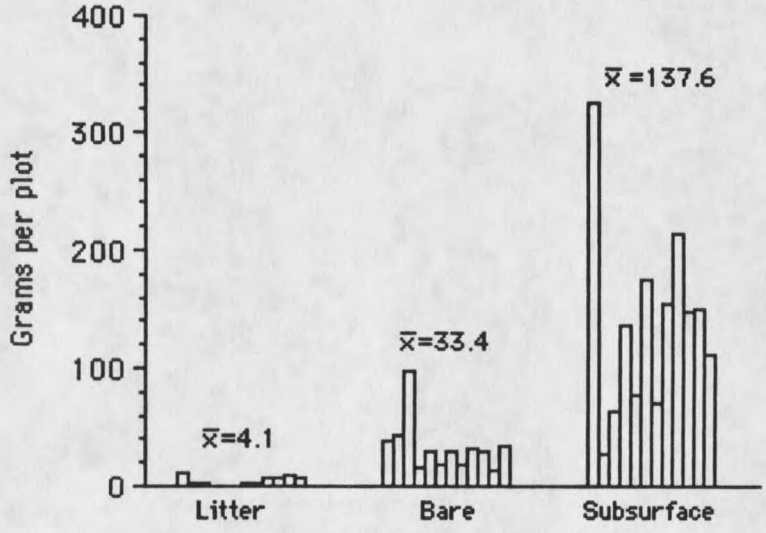


Figure 15. Oven-dry weight of eroded sediment from all plots collected after each simulator run (plot size was 66 cm by 66 cm).

sediment yields were still not significantly different from the predicted yields on the litter runs (Figure 18, Appendix K, Table 34). There were, however, significant differences at the .01 level between the predicted sediment yields and the sediment measured on both the bare and the subsurface runs (Figure 18, Appendix K, Table 34). Again, the predicted sediment yields were much higher than the actual sediment yields measured.

The crystalline plots showed a significant difference at the .01 level on both the litter and the bare runs between the predicted and actual sediment yields (Figure 19, Appendix K, Table 35). The predicted yields were again higher, but not by nearly as large a margin for these two crystalline treatments. The subsurface runs on the crystalline plots were not significantly different between the predicted and measured sediment yields.

Consult Tables 4 and 5 for a summary of the statistical results presented in this section.

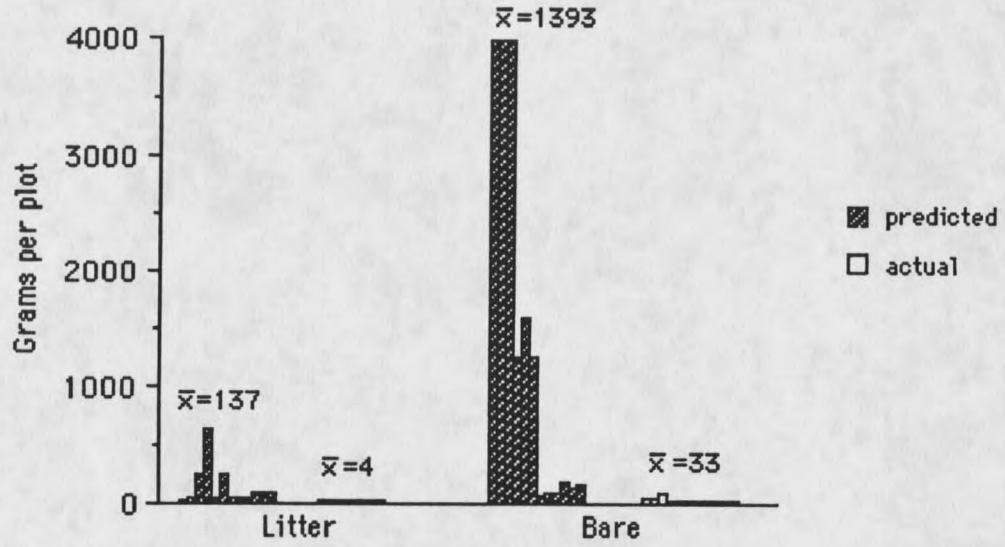


Figure 16. Predicted and actual eroded sediment yields on all plots from the surface simulator runs (plot size was 66 cm by 66 cm).

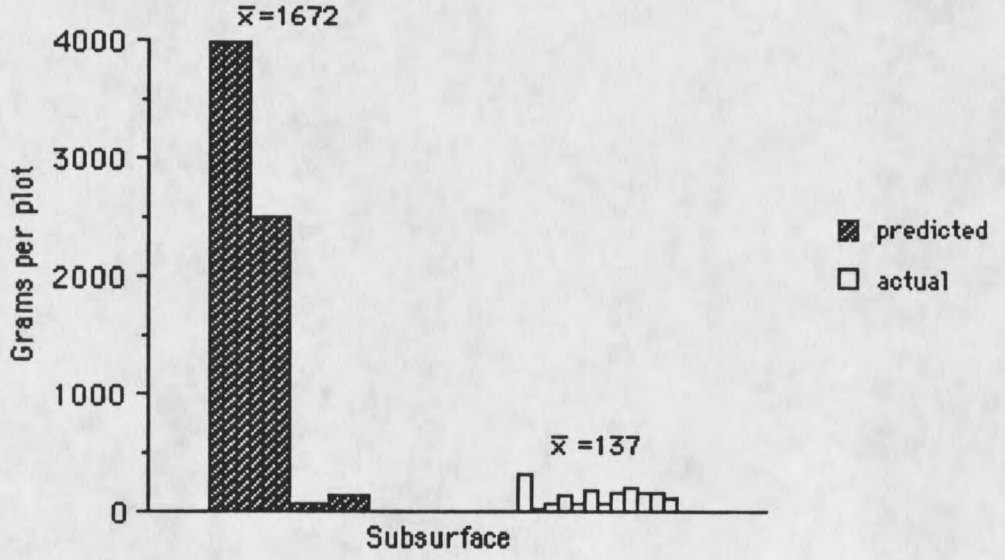


Figure 17. Predicted and actual eroded sediment yields on all plots from the subsurface simulator runs (plot size was 66 cm by 66 cm).

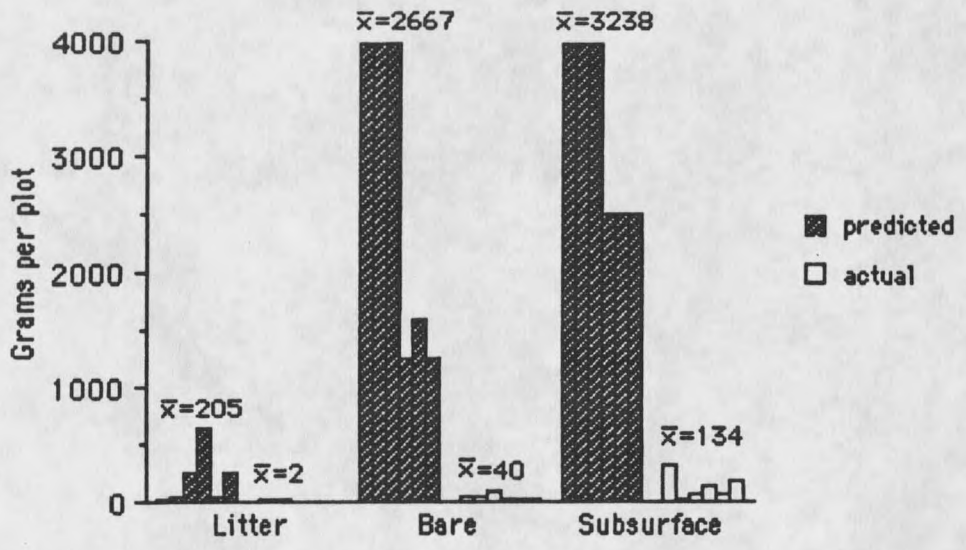


Figure 18. Predicted and actual eroded sediment yields on all shale plots from each simulator run (plot size was 66 cm by 66 cm).

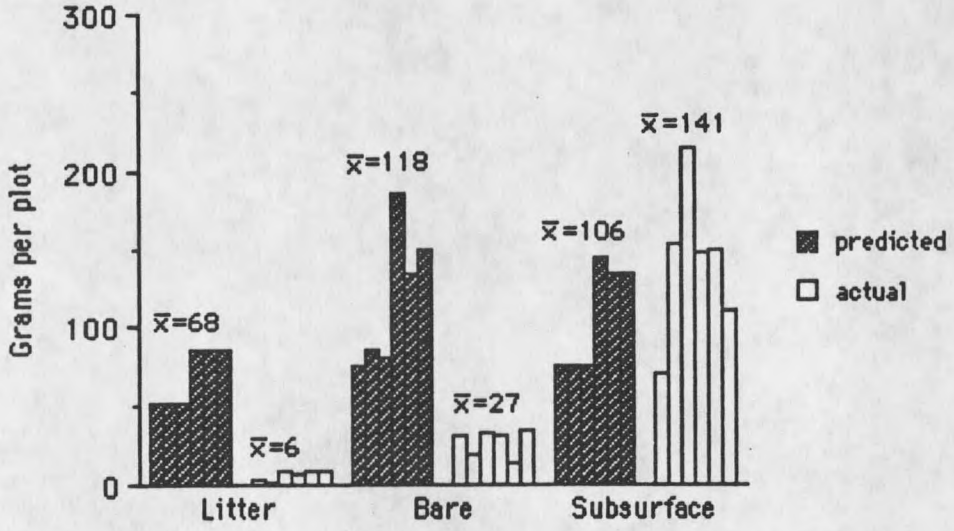


Figure 19. Predicted and actual eroded sediment yields on all cyrstalline plots from each simulator run (plot size was 66 cm by 66 cm).

Data Analyzed	Method	Results		
		.01	.05	.10
Soil Water Content				
sh lit *vs.* crys lit	2 ind smpl t-test	sd	sd	sd
sh bare *vs.* crys bare	2 ind smpl t-test	sd	sd	sd
sh sub *vs.* crys sub	2 ind smpl t-test	sd	sd	sd
sh lit *vs.* sh bare	2 ind smpl t-test	nsd	nsd	nsd
sh bare *vs.* sh sub	2 ind smpl t-test	sd	sd	sd
crys bare *vs.* crys sub	2 ind smpl t-test	nsd	sd	sd
Organic Matter Content				
(0 – 2.5 cm & 2.5 – 5.0 cm)				
sh *vs.* crys	2 ind smpl t-test	nsd	nsd	nsd
Bulk Density				
(0 – 10 cm)				
sh *vs.* crys (fine fraction)	2 ind smpl t-test	nsd	sd	sd
sh *vs.* crys (coarse frag incl)	2 ind smpl t-test	nsd	nsd	nsd
Percent Ground Cover				
(vegetation and litter)				
sh lit *vs.* crys lit	2 ind smpl t-test	nsd	sd	sd
sh bare *vs.* crys bare	2 ind smpl t-test	nsd	nsd	nsd
sh sub *vs.* crys sub	2 ind smpl t-test	nsd	nsd	nsd
forested sh lit *vs.* crys lit	2 ind smpl t-test	nsd	sd	sd
(vegetation and litter; shale and crystalline combined)				
bare *vs.* sub	2 ind smpl t-test	nsd	nsd	nsd
lit *vs.* bare	2 ind smpl t-test	sd	NA	NA
lit *vs.* sub	2 ind smpl t-test	sd	NA	NA
(vegetation, litter, and rock)				
sh lit *vs.* crys lit	2 ind smpl t-test	nsd	sd	sd
sh bare *vs.* crys bare	2 ind smpl t-test	nsd	nsd	nsd
sh sub *vs.* crys sub	2 ind smpl t-test	sd	sd	sd
Air Dry Weight of Litter Removed				
sh *vs.* crys	2 ind smpl t-test	nsd	sd	sd
forested sh *vs.* crys	2 ind smpl t-test	nsd	nsd	nsd

Table 4. Summary of soil property and ground cover statistics.

Data Analyzed	Method	Results		
		.01	.05	.10
Actual Sediment Yields				
sh lit *vs.* crys lit	2 ind smpl t-test	nsd	nsd	nsd
sh bare *vs.* crys bare	2 ind smpl t-test	nsd	nsd	nsd
sh sub *vs.* crys sub	2 ind smpl t-test	nsd	nsd	nsd
(shale & crystalline combined)				
lit *vs.* bare *vs.* sub	1-way ANOVA	sd	sd	--
lit *vs.* bare	Tukey (95%)	not different		
lit *vs.* sub	Tukey (95%)	different		
bare *vs.* sub	Tukey (95%)	different		
Predicted Sediment Yields				
(shale & crystalline combined)				
predicted lit *vs.* actual lit	2 ind smpl t-test	nsd	nsd	sd
predicted bare *vs.* actual bare	2 ind smpl t-test	nsd	nsd	sd
predicted sub *vs.* actual sub	2 ind smpl t-test	nsd	sd	sd
(shale sites only)				
predicted lit *vs.* actual lit	2 ind smpl t-test	nsd	nsd	sd
predicted bare *vs.* actual bare	2 ind smpl t-test	sd	sd	sd
predicted sub *vs.* actual sub	2 ind smpl t-test	sd	sd	sd
(crystalline sites only)				
predicted lit *vs.* actual lit	2 ind smpl t-test	sd	sd	sd
predicted bare *vs.* actual bare	2 ind smpl t-test	sd	sd	sd
predicted sub *vs.* actual sub	2 ind smpl t-test	nsd	nsd	nsd

Table 5. Summary of actual and predicted sediment yield statistics.

SUMMARY AND DISCUSSION

Sediment Yields

Parent Material Differences

The shale soils reflected the fine texture of their parent materials with high percentages of silt and clay sized particles and relatively low sand sized contents (clay, silty clay, and clay loam textures). The crystalline soils had almost no clay sized particles and very high sand contents (sandy loam and loamy sand textures) (Figures 3 and 4).

Organic matter was not significantly different between soil textures (Appendix F). Fine fraction bulk density was slightly higher on the shale sites (Appendix G). Ground cover of vegetation and litter was significantly different on the litter runs only. Rock cover was significantly greater on the crystalline subsurface plots (Appendix H). Water contents were significantly lower on the crystalline plots (Appendix E). There was no significant difference in sediment yields from the contrasting soil textures under the interrill erosion conditions produced by simulated rainfall (Appendix J). With the stark differences in texture, why were there no differences in sediment yields?

Characteristics of Splash Detachment and Transport

Numerous studies have looked at the textural characteristics of soils under natural and simulated rainfall in both field and

laboratory situations. Some of the earliest work was done with chaparral forested mountain soils in California under both natural and simulated rainfall. This study concluded that fine textured soils yielded greater amounts of sediment than coarser textured soils under natural litter conditions and from burned, bare surfaces (Lowdermilk, 1930). In contrast, work with samples of agricultural soils removed from the field and then subjected to natural rainfall gave three times as much raindrop splash yield from very fine sand than from a silt loam texture soil (Free, 1960).

Simulated rainfall on prepared samples of moorland soils in England resulted in a series of detachment and interrill transport where silt loam > loamy sand > silty clay loam > loam > clay loam (Bryan, 1969). A more recent study in England using prepared samples under simulated rainfall resulted in two separate textural series for detachability and transport under interrill erosion conditions. The series for detachment by drop impact was graded sand > sand (soil) > clay (soil) > clay loam (soil). The transport series was somewhat similar with graded sand > clay (soil) > sand (soil) > clay loam (soil) (Quansah, 1981).

A study using simulated rainfall on samples of agricultural soils in the U.S. concluded that the amount of soil detached by waterdrop impact decreased as clay content increased (Bubenzer and Jones, 1971). Simulated rainfall on both field plots and samples of medium textured

Corn Belt soils showed the most erodible to be soils high in silt, low in clay, and low in organic matter (Wischmeier and Mannering, 1969).

What the results of these studies are suggesting is perhaps more clear in studies that have looked at the textural composition of the detached sediment. A study using simulated rainfall on prepared samples of soils from granitic and limestone parent materials concluded that water stable aggregates and nonaggregated particles of equal size behaved the same under waterdrop impact and that sand sized particles or aggregates were the most susceptible to detachment (Farmer and Van Haveren, 1971).

Another study using prepared samples under simulated rainfall found that the percentage of clay sized particles in the splashed sediment collected (undispersed) was much lower than the percentage of clay sized particles in the original soil (dispersed analysis) (Gabriels and Moldenhauer, 1978).

In summarizing the studies described above and many more not cited here, the mechanics of waterdrop impact should be considered. As a waterdrop strikes a fine textured soil surface, any unstable aggregates will be broken down. The smallest particles are dislodged and deposited in the surface pores, in some cases eventually sealing the soil surface (Lowdermilk, 1930; Bryan, 1969; Gabriels and Moldenhauer, 1978). The larger (up to sand sized), more stable aggregates are detached and transported (Meyer et al, 1975; Quansah, 1981). Therefore,

if a high clay soil is not well aggregated, it will not be very erodible. If, however, the clay particles form water stable sand sized aggregates, the soil's potential for erosion increases.

Aggregation is emphasized in many of these soil texture studies. Its role is probably best summarized by viewing the soil textural separates as not being that important by themselves, but rather important for the role they play in aggregation (Summer, 1982). If a fine textured, high clay soil is not well aggregated, it will act as individual clay particles under drop impact. They will be dislodged and deposited in the surface pores, sealing the soil surface so that little interrill erosion will occur. If, however, it is composed of sand sized water stable aggregates, they will be detached and transported as sand sized particles.

A coarse textured soil does not contain the finer textural separates and is much less cohesive than a fine textured soil. Raindrop impact is able to detach the large, noncohesive particles. Once detached, sand particles and sand sized aggregates are transported as equals (Farmer and Van Haveren, 1971; Quansah, 1981; Meyer, 1985). Most of the breakdown of aggregates occurs at the time of drop impact, so most aggregates that are detached are unlikely to be broken down much farther during transport (Gabriels and Moldenhauer, 1978; Meyer, 1985).

It is important to mention that in this study and the ones mentioned above, all discussion of detachment and transport is in an

interrill environment only. In the interrill erosion environment, runoff or overland flow acts as a transporting agent only. This thin film runoff does not have sufficient energy for any further detachment (Bryan, 1969; Meyer et al, 1975). Therefore, the eroded sediment is a result of drop detachment only, and its subsequent transport is by drop impact and/or shallow overland flow.

Discussion

These physical mechanisms of particle detachment operate regardless of the pedogenic environment. The soil forming environment does, however, influence the soil characteristics that control cohesion and aggregation.

In this study, water contents were significantly lower on the coarse textured crystalline plots (Appendix E). Lower water contents mean weaker cohesive forces between soil particles. This could have made the crystalline plots more erodible than if they had been at higher soil water contents. If water content alone had been controlling the sediment yields, the crystalline plots would have had larger sediment yields than the more cohesive shale plots.

Soil organic matter also plays a role in binding or aggregating soil particles. In this study, organic matter contents were so low (<0.5%) in both soil textures (Appendix F), that they would have had a limited role in aggregation. Considering only organic matter, high sediment yields would have been expected from both parent materials.

With low organic matter supplies for glues, the shale sites would have been expected to be poorly aggregated soils whose surface would seal over yielding small amount of sediment under interrill erosion. The crystalline sites had nearly cohesionless particles that would have been readily detachable under waterdrop impact. Sediment yields from these coarse textured plots would have depended upon transport of the detached sand sized particles.

Once detached, sand sized particles are harder to transport than clay sized particles. It is possible that more sand sized crystalline soil particles were detached than clay or silt sized shale soil particles, but that fewer of the sand sized particles were transported. Then, although fewer shale soil particles were detached, sediment yields could have been approximately equal if more of the shale soil particles were transported.

Consider, however, the roughness of the soil surface under natural field conditions. Fine fraction bulk densities were fairly low for both parent materials (0.7-1.0 shale plots; 0.6-0.9 crystalline plots). This indicates that both soil textures were present in a relatively loosened or fluffy condition. With numerous surface pores, it seems unlikely that transport of clay or silt sized particles would be greater than that of sand sized particles because the finer particles would tend to become lodged in the soil pores. Even if both size particles were deposited in the surface pores, there would not have been enough repeated dislodging of the small sized particles to

keep the amount transported greater than that of sand sized particles in motion.

Another potential explanation of the similar sediment yields is that it was not necessarily the dominant textural separate that was eroding from each parent material. That is, perhaps the shale plots were predominantly yielding their sand fraction or the crystalline plots were losing their finer fraction to the point that the two parent materials were yielding similar amounts of sediment.

A particle size distribution analysis of a dispersed sample of the eroded sediment would have indicated whether the distribution of size fractions was similar to the original soil or not. Because the sediment yield samples had been flocculated for greater ease in decanting and drying, a hydrometer analysis would have been very difficult to do.

Visual inspections of the sediment yields as they were coming off the plots and after they were dry showed the shale plot sediment yields to be distinctly different from those off the crystalline plots. Wet sieving of a selected sampling of the sediment yields indicated that the majority of soil eroded from the shale plots was composed of silt to clay sized particles. The crystalline eroded sediments were approximately half sand sized particles (Appendix L). This relates to the plot soil textures that were approximately 80 percent sand sized particles. The numbers should not be interpreted number-to-number, since the hydrometer analysis splits silt and sand

sized particles at .05 mm and the wet sieving was done at .063 mm. This is a very small portion (.05 to .063 mm) of the particle size distribution, but could be very significant if one is looking at the silt and very fine sand fractions.

The most likely explanation of similar sediment yields from the contrasting textures appears to be that the fine textured soils were responding to the interrill erosion in a manner similar to that of the coarse textured soils. These conditions of similarity would have been met if the shale soils were aggregated into sand sized water stable aggregates.

The sediment yields were not analyzed for aggregate size in suspension. Once they were flocculated for decanting and drying, this type of measurement was no longer possible. Despite the failure to collect these data, the aggregation of the shale soils is still the most plausible explanation of the equivalent sediment yields.

An investigation of clay mineralogy might help to explain the aggregation given the other environmental conditions discussed earlier. Work done on prepared samples of northern California upland soils under simulated precipitation found soil loss to be correlated with clay mineralogy (Trott and Singer, 1983). Two other studies using western mountain soils found soil loss to be related to parent material (André and Anderson, 1961; Willen, 1965). It is possible that this geology influence could be extrapolated to a texture related clay mineralogy influence.

Treatment Differences

With no differences in sediment yields between the parent materials, they were combined to determine if there were any differences in sediment yields from the different soil surface treatments. This pairwise comparison showed that there was no difference in sediment yields from the litter and the bare soil surface treatments. There were differences, however, between the subsurface sediment yields and those from the litter and the bare runs (Appendix J).

R.B. Bryan, in his work on the moorland region soils in England (1969), noted that he found no great difference in erodibility between surface horizons developed on different parent materials but under similar vegetation. He did, however, find differences in erodibility between A and B horizons with the B horizons being more erodible than the A horizons. He had limited sampling and analyses of C horizons, but his data indicated that the C horizons were even more erodible than the B horizons. His results indicate that even when surface horizons are not protected by ground cover, subsurface horizons are more erodible.

The results of this study support the hypothesis that changes in erodibility are not always closely tied to ground cover. In this case, there was a dramatic change in ground cover when the litter layer was removed and the bare soil surface exposed. But yet there was no difference between the sediment yields from the litter runs and those from the bare runs. Where there was no difference in vegetation and

litter cover between the bare and subsurface runs, there was a difference in sediment yields (Figures 11 and 15).

The higher erodibility of the subsurface plots in this study is probably due to changes in more than one variable that influenced soil stability.

Although there was no statistical difference in ground cover between the bare and subsurface horizons, there was a loss of root penetration. Roots do not constitute a high percentage of ground cover, so they did not show up in the statistical analysis. They do, however, play a role in stabilizing a soil horizon. Roots physically aid in aggregation and provide living organisms that help to stabilize aggregates (Brady, 1984). The presence of root mycorrhizae in the surface horizon during the bare and litter runs may have helped to stabilize the soil at the particle size level.

Along with the decrease in roots with depth, would have come a decrease in microbial populations. The role of these microrganisms was not investigated, but it was more than likely one of interaction with that of the plant roots. With this interaction, their populations would have been diminished in the more erodible subsurface horizons.

As discussed earlier, the fine fraction bulk densities of the surface horizons were relatively low (Figure 10). No comparable measurements were taken at the subsurface level. These bulk densities could have been artificially low due to the excavation disturbance. This

disturbed state would have added to the erodibility of the subsurface horizon because of easier particle detachment in the loosened state.

Predicted Sediment Yields

Considering both soil textures together, predicted sediment yield calculations (Meeuwig, 1970) were numerically higher than the measured yields, but were not statistically different for the litter and bare soil treatments. Subsurface predictions for both textures combined were significantly higher than the measured yields (Appendix K).

Predictions for the shale plots only were significantly different from the measured sediment yields for both the bare and subsurface treatments. Predictions for the crystalline plots were significantly different from the measured yields for the litter and bare treatments (Appendix L).

Of all the predicted sediment yields compared to the actual yields, the only comparison that was numerically "close" and statistically not different were the subsurface runs on the crystalline textures. All other predictions of eroded sediment using the regression equations developed by R.O. Meeuwig on high elevation rangeland in the intermountain West (1970), were consistently 10 to 100 times greater than the actual measured sediment yields.

It should be emphasized here that for all the statistical analyses of predicted versus actual sediment yields, except the crystalline subsurface plots, the F test for equality of variances was rejected by

a fairly large margin (Appendix K). The subsequent t test for equality of means can usually be considered to be fairly robust, despite the inequality of variances (Quimby, 1987).

With this in mind, the question is whether a potential 10 to 100 fold difference in the prediction of sediment yields provides a viable management tool, or is this difference pointing out some erosional differences between the regression equations and the environments they were applied in? In partial answer to this question, the following discussion will address some of the factors that must be considered when interpreting and applying rainfall simulator data.

Meeuwig (1970) states in the publication of his simulator work and the resulting regression equations that the equations should be used for estimation in other areas only if the study areas closely resemble those used in his study. And, that the uncertainty of the estimate increases with increased differences between the areas of equation application and equation development.

This study matched the sites as closely as possible to the areas described by Meeuwig (1970) (Tables 1 and 2). Vegetation on both parent materials was slightly different from that in Meeuwig's study. Even more important, however, is the differences in parent material mineralogy. The most significant differences in mineralogy would, no doubt, have been with the clay mineralogy of the fine textured sites.

Differences in the rainfall simulators must also be addressed. This study used a simulator that Meeuwig developed for research he did after developing the prediction equations used here (1971b). As discussed in the methods section of this paper, it operated at a kinetic energy that was approximately 33 percent of natural rainfall. The Dortignac (1951) style simulator used by Meeuwig in development of his prediction equations operated at approximately 43 percent of natural storm kinetic energy (Gifford, 1979). This 10 percent difference in kinetic energy makes comparison of their sediment yields questionable, but probably does not totally account for the 10 to 100 fold difference between the predicted yields and the actual sediment yields.

The predicted sediment yields and those actually measured are both representative of small interrill erosion plots. Direct extrapolations of either set of numbers to larger size areas is difficult (Young, 1979). Any direct application to non-interrill environments would be totally invalid. And, both sets of numbers were generated at kinetic energies below that of natural rainfall.

CONCLUSIONS

With simulated precipitation at kinetic energies well below that of natural storms, small plot sizes that are not readily extrapolated to real world erosional areas, and measurements of interrill erosion only, what did this study accomplish?

This study provided an assessment of the basis of soil erodibility in the Gallatin National Forest. With no previous erodibility work conducted in the high elevation erosion environments of the Gallatin National Forest, this base study was needed to establish which variables should be investigated in more detail when attempting to quantify soil erodibility.

The comparison of two contrasting soil textures identified soil variable questions that should be addressed in any further study of soil erodibility in the Gallatin National Forest. A short list of these soil variables includes the role of very fine sand and silt sized particles in the erodibility of coarse textured soils and the clay mineralogy and the degree and stability of soil aggregation in finer textured soils. Many soil environment variables also appeared to play roles in the erodibility measured, including roots, mycorrhizae, and to some extent, microbial populations.

The results of this study emphasized the role of soil surface disturbance in erosion. These results have immediate management

implications in a multi-use forest setting. Road construction, logging, mining, hiking, packing, grazing, and off-road vehicles are all managed uses that contribute to soil disturbance in varying degrees. Water quality is a prime concern for fish populations and watershed management. In a management sense, it must be re-emphasized that this study looked at interrill erosion only. It did not address rill or gully erosion, or the inherent geologic instability of shale formations.

This study indicates the need to study the implications of the dynamic characteristics of soil erodibility, i.e. bulk density, water content, and microbial activity, all which change throughout the year. How much the seasonality of these soil variables affects erodibility needs to be clarified.

Another question raised by this study is, what are valid alpha levels for statistical analyses? The discussions of statistical significance in this paper used the standard .01 and .05 levels. With high natural variability in the soil and other field variables, perhaps levels of .1 and even higher are more appropriate for the environments under study.

A more thorough investigation of P levels for the various variables measured in this study could provide further clues into the roles and interactions that these soil characteristics have in erodibility. Perhaps a .2 level of difference in sediment yields is significant in comparing the erosion of litter covered plots on

contrasting soil textures. A .4 level of difference could be significant for bare exposed surfaces.

The level of statistical analysis somewhat depends on the level of application of the results. A similar level of applicability is seen with the rainfall simulation data. The prediction equations used in this study along with the actual measured yields should not be extrapolated to generate numbers for sediment loss on a slope or watershed basis. They could, however, be looked at for general comparisons of soil erodibility under similar conditions.

Erodibility is a complex soils characteristic which is not readily predictable in many soil environments. The better its influencing factors are understood, however, the more accurately its role in erosion can be managed. This study has provided a basis on which further investigations of soil erodibility in the Gallatin National Forest could be built. It is hoped that this study has raised some significant questions that can eventually bring us closer to understanding erodibility in mountain soil environments.

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APPENDICES

APPENDIX A

SITE NAME ACRONYMS

Acronym	Explanation
M12	Mile 12 shale site (forested) located near the Mile 12 marker on the Mystic Lake–Bozeman Creek Forest Service Access Road
VSH	Volcanic SHale site (meadow) located adjacent to Tertiary volcanic landslide on the Mystic Lake–Bozeman Creek Forest Service Access Road
MER	Moser End of Road crystalline site located at the end of the Moser Creek Jump Off Forest Service Access Road
MLP	Moser LodgePole crystalline site located near end of the Moser Creek Jump Off Forest Service Access Road, distinguished from MER by the predominance of Lodgepole pine (*Pinus contorta*)

Table 6. Explanation of site name acronyms.

APPENDIX B

SIMULATOR CHARACTERISTICS

Determination of Water Drop Size

Two samplings of 100 water drops taken at different stages from two separate 127 mm per hour simulated events (each conducted for one-half hour only) were collected in a ten milliliter graduated cylinder. The volume was noted for each sample and calculations for average drop size were done as shown below.

These calculations assume that the drops collected in each sampling were approximately the same size, as they should be if the simulator was running correctly. The fact that both 100 drop samples, taken from two different events and at different stages in each event (e.g. not both in the first ten minutes of the 30 minute simulator run), had equal volumes supports this assumption.

These calculations of average drop size also agree with the 2.5 to 2.9 mm average range given by G.F. Gifford (1986) from his studies done with the same model simulator.

Sample	Number of Drops	Volume of Sample
1	100	1.2 ml
2	100	1.2 ml

$$100 \text{ drops} = 1.2 \text{ ml } H_2O = 1.2 \text{ cm}^3$$

$$\text{Each drop} = 1.2 \times 10^{-2} \text{ cm}^3$$

$$\text{Volume of a sphere} = 2(2/3\ \pi\ r^3) = 4/3\ \pi\ r^3$$

$$1.2 \times 10^{-2} \text{ cm}^3 = 4/3\ \pi\ r^3$$

$$r^3 = 0.0029 \text{ cm}^3$$

$$r = 0.14 \text{ cm}$$

$$\text{diameter} = 0.28 \text{ cm} = 2.8 \text{ mm}$$

Kinetic Energy of Simulated Rainfall

The following calculations for the determination of simulated rainfall kinetic energy relative to that of a natural storm were done in the manner of information given by G.F. Gifford (1979).

The kinetic energy (KE) of an object is defined as: KE = (Mass)(Velocity)^2. When considering rainfall, the mass is that of the falling waterdrops and the velocity is their impact velocity. To determine the relative KE of a simulated storm, the following equation is solved:

$$\text{Relative KE of simulated storm} = \text{KE of simulated rainfall} \div \text{KE of natural storm} = M_s V_s^2 \div M_n V_n^2.$$

The mass of the simulated rainfall in this study (waterdrop diameter of 2.8 mm) is approximately equal to that of a natural storm of equal intensity (127mm per hour). The relative KE of the simulated storm than becomes:

$$\text{Relative KE} = V_s^2 \div V_n^2.$$

The impact velocity for the simulated waterdrops in this study was approximately 470 cm per second (Laws, 1941), while natural raindrops usually reach a terminal velocity of 780 cm per second. The relative kinetic energy of the simulated rainfall than becomes:

$$\text{Relative KE} = (470)^2 \div (780)^2$$

$$= 0.363 = 36\%.$$

APPENDIX C

SOIL PROFILE DESCRIPTIONS

Area: Bozeman Creek Drainage, Gallatin National Forest; Study Site M12

Location: NE1/4, Sec 6, R7E, T4S, Montana

Physiographic position: steep ridge; 2280 m elevation; 35% slope; N aspect

Parent material: Jurassic shales

Vegetation: lodgepole pine, white bark pine, subalpine fir, grouse whortleberry, prince's plume, service berry

Notes: (9/5/86) 50° F air temp; 45° F 50 cm soil temp

Depth (cm)	Horizon	Color (moist)	Texture	Structure	Consistency	Roots	Coarse Frags.	pH (rxn)
2.5 - 0	O	(Needles and Cones)						
0 - 6	A	2.5YR 5\4	l-cl 35 % s 25% c	mod fine gran	sh fr ss,sp	common med & fine	none	4.5 (-)
6 - 23	Bw	2.5 YR 3\4	cl 30% s 38% c	strong vf ang blocky	sh fr s,p	many coarse	5% angular	4.5 (-)
23+	C	--	--	--	--	--	75% angular	4.5 (-)

Table 7. Soil profile description study site M12.

Area: Bozeman Creek Drainage, Gallatin National Forest; Study Site VSH

Location: NE 1/4, Sec 31, R7E, T3S, Montana

Physiographic position: gentle slope, adjacent to Tertiary volcanic landslide; 2100 m elevation; 15% slope; SW aspect

Parent material: Cretaceous shales

Vegetation: timothy, yarrow, strawberry, thistle, praire coneflower, and clover

Notes: (10/9/86) Douglas-fir and lodgepole pine in surrounding forest; some young D-fir (4-5 ft tall) invading meadow; red, green, and yellow streaks throughout profile from 18 cm down, due to rock weathering; charcoaled roots to a 34 cm depth; 60° F air temp; 40° F 50 cm soil temp

Depth (cm)	Horizon	Color (moist)	Texture	Structure	Consistency	Roots	Coarse Fragments	pH (rxn)
0 - 18	A	10 YR 3\2	cl 35% c	mod fine granular	sh fr ss, sp	many fine & v fine	none	7.0 (-)
18 - 34	Bt	10 YR 3\3	c 42% c	--	--	many fine & v fine	10% angular cobbles & smaller	7.0 (-)
34 +	C	10 YR 4\3	c 40% c	--	--	common v fine	mixed lithology (ss,volc, & shale)	8.0 (-)

Table 8. Soil profile description study site VSH.

Area: Hodgman Creek Drainage, Gallatin National Forest; Study Site MER

Location: NE 1/4, Sec 24, R5E, T3S, Montana

Physiographic position: moderately steep slope; 2100 m elevation; 35% slope; N aspect

Parent material: Precambrian crystalline metamorphics

Vegetation: lodgepole pine, arrowleaf balsamroot, glacier lily, and blue huckleberry

Notes: (10/13/86) nearly continuous whitish-gray layer under litter layer on top of mineral horiz, probably fungus; 42° F air temp; (soil thermometer at 50 cm still in ground)

Depth (cm)	Horizon	Color (moist)	Texture	Structure	Consistency	Roots	Coarse Frags.	pH (rxn)
6 - 0	O	(moss, needles, & cones)						
0 - 3	A	10 YR 3\3	ls	single grain	lo lo so, po	many f & vf common med	30% angular < 2 cm	5.5 (-)
3 - 28	Bw	7.5 YR 4\4	ls	single grain	lo lo so, po	commom fine & med	45% angular up to 15 cm	6.0 (-)
28 +	C	7.5 YR 4\4	ls	--	--	commom fine & med	60% angular cobbles & smaller	6.5 (-)

Table 9. Soil profile description study site MER.

Area: Hodgman Creek Drainage, Gallatin National Forest; Study Site MLP

Location: NE 1/4, Sec 24, R5E, T3S, Montana

Physiographic position: steep slope; 2100 m elevation; 45% slope; NW aspect

Parent material: Precambrian crystalline metamorphics

Vegetation: lodgepole pine, pine grass, prince's plume, mosses

Notes: (10/17/86) some slight pistol butting of lodgepole, but not dominant; black & orange streaking of profile below 46 cm (5YR\4\4), probably decomposed bedrock; 40° F air temp; 39° F 50 cm soil temp

Depth (cm)	Horizon	Color (moist)	Texture	Structure	Consistency	Roots	Coarse Frags.	pH (rxn)
5 - 0	O	(needles, mosses, & cones)						
0 - 24.5	A	5 YR 4\2	ls	single grain	lo lo so, po	many fine & v fine c med few lrg	10% angular up to 10 cm	6.5 (-)
24.5-46	Bw	5 YR 4\4	ls	single grain	lo lo so, po	many fine & v fine c med few lrg	50% angular up to 8 cm	6.0 (-)
46 +	C	5 YR 4\2	ls	single grain	lo lo so, po	common f & vf	65% angular up to 8 cm	5.5 (-)

Table 10. Soil profile description study site MLP.

APPENDIX D

PARTICLE SIZE DISTRIBUTION

		percent sand (.05-2.0 mm)	percent silt (.05-.002 mm)	percent clay (< .002 mm)
M12 Surface	1	3	42	55
	2	3	29	68
	3	5	32	63
M12 Sub	1	11	38	51
	2	7	30	63
	3	3	29	68
VSH Surface	1	27	42	31
	2	33	42	25
	3	25	43	32
VSH Sub	1	15	41	44
	2	20	42	38
	3	0	54	46
MER Surface	1	81	17	2
	2	79	17	4
	3	77	19	4
MER Sub	1	82	14	4
	2	78	19	3
	3	78	17	5
MLP Surface	1	75	20	5
	2	73	22	5
	3	74	22	4
MLP Sub	1	70	27	3
	2	75	20	5
	3	75	21	4

Table 11. Particle size distribution.

		% v coarse	% coarse	% medium	% fine	% v fine
M12 Surface	1	19	13	19	31	19
	2	8	8	23	38	23
	3	9	9	22	30	30
M12 Sub	1	19	21	19	26	14
	2	17	13	17	30	22
	3	8	17	17	33	25
VSH Surface	1	12	12	13	40	23
	2	6	7	9	55	23
	3	11	12	15	42	20
VSH Sub	1	1	10	10	47	33
	2	2	2	7	71	18
	3	6	6	18	41	29
MER Surface	1	31	23	23	20	3
	2	28	23	23	22	4
	3	23	23	26	24	5
MER Sub	1	23	20	25	27	5
	2	24	27	25	21	4
	3	24	23	25	23	5
MLP Surface	1	24	25	23	23	5
	2	21	26	26	22	5
	3	25	24	24	22	5
MLP Sub	1	26	25	25	19	4
	2	26	24	25	20	5
	3	24	27	23	21	5

Table 12. Sieved sand as percent of total sand content.

M12 Surface	1	silty clay
	2	clay
	3	clay
M12 Sub	1	clay to silty clay
	2	clay
	3	clay
VSH Surface	1	clay loam
	2	loam
	3	clay loam
VSH Sub	1	silty clay to clay
	2	clay loam to silty clay loam
	3	silty clay
MER Surface	1	loamy sand
	2	loamy sand
	3	loamy sand
MER Sub	1	loamy sand
	2	loamy sand
	3	loamy sand
MLP Surface	1	loamy sand to sandy loam
	2	sandy loam to loamy sand
	3	loamy sand to sandy loam
MLP Sub	1	sandy loam to loamy sand
	2	loamy sand to sandy loam
	3	loamy sand to sandy loam

Table 13. Soil textural class.

APPENDIX E

SOIL WATER CONTENT DATA

AND

STATISTICAL ANALYSIS

	shale-litter	crys-litter	shale-bare	crys-bare	shale-sub	crys-sub
Soil Water	45.6	20.7	45.6	20.7	24.2	13.5
Content	71.2	13.7	71.2	13.7	28.1	13.8
(percent)	45.7	23.0	45.7	23.0	27.2	11.6
	30.5	11.5	53.6	11.5	33.3	10.2
	33.3	37.5	39.0	37.5	27.6	13.4
	36.3	19.2	39.7	19.2	32.7	11.5
min	30.5	11.5	39.0	11.5	24.2	10.2
max	71.2	37.5	71.2	37.5	33.3	13.8
range	40.7	26.0	32.2	26.0	9.1	3.6
mean	43.8	20.9	49.1	20.9	28.9	12.3
median	40.9	20.0	45.7	20.0	27.9	12.5
st dev	14.8	9.2	12.0	9.2	3.5	1.4
variance	220.2	84.6	144.6	84.6	12.2	2.1
Ho = var						
F obs	2.6		1.71		5.81	
(.01) F table	14.9	do not reject	14.9	do not reject	14.9	do not reject
(.05) F table	7.15	do not reject	7.15	do not reject	7.15	do not reject
Ho = means						
Est	22.8		28.2		16.5	
SE(Est)	7.1		6.2		1.5	
t obs (10df)	3.204		4.563		10.697	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	0.2	reject	8.6	reject	11.6	reject
	45.4		47.8		21.4	
95% CI	7.0	reject	14.4	reject	13.1	reject
	38.7		42.0		20.0	
P	.001< P< .01	reject (.01, .05)	.001<P<.01	reject (.01, .05)	P< .001	reject (.01, .05)

Table 14. Soil water content prior to each rainfall simulator run on the shale and crystalline plots for all three plot treatments (litter, bare, subsurface). Statistical analysis compares water content between parent materials for each treatment.

	shale-bare	shale-subsf	crys-bare	crys-subsf	shale-litter	shale-bare
Soil Water	45.6	24.2	20.7	13.5	45.6	45.6
Content	71.2	28.1	13.7	13.8	71.2	71.2
(percent)	45.7	27.2	23.0	11.6	45.7	45.7
	53.6	33.3	11.5	10.2	30.5	53.6
	39.0	27.6	37.5	13.4	33.3	39.0
	39.7	32.7	19.2	11.5	36.3	39.7
min	39.0	24.2	11.5	10.2	30.5	39.0
max	71.2	33.3	37.5	13.8	71.2	71.2
range	32.2	9.1	26.0	3.6	40.7	32.2
mean	49.1	28.9	20.9	12.3	43.8	49.1
median	45.7	27.9	20.0	12.5	40.9	45.7
st dev	12.0	3.5	9.2	1.4	14.8	12.0
variance	144.6	12.2	84.6	2.1	220.2	144.6
Ho = var						
F obs	11.9		40.3		2.6	
(.01) F table	14.9	do not reject	14.9	reject	14.9	do not reject
(.05) F table	7.15	reject	7.15	reject	7.15	do not reject
Ho = means						
Est	20.2		8.6		-5.3	
SE(Est)	5.1		3.8		7.8	
t obs (10df)	3.951		2.262		-0.684	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	4.0	reject	-3.4	do not reject	-30.0	do not reject
	36.4		20.6		19.4	
95% CI	8.8	reject	0.1	reject	-22.7	do not reject
	31.6		17.1		12.0	
P	.001< P<.01	reject (.01, .05)	.02< P< .05	reject (.05)	.5< P< .6	do not reject (.01, .05)

Table 15. Soil water content prior to each simulator run on the shale and crystalline plots for all three plot treatments (litter, bare, subsurface). Statistical analysis compares water content between treatments for each parent material (crys litter = crys bare).

APPENDIX F

ORGANIC MATTER DATA

AND

STATISTICAL ANALYSIS

	sh (0-2.5cm)	crys (0-2.5cm)	sh (2.5-5.0 cm)	crys (2.5-5.0 cm)
Organic	0.40	0.37	0.31	0.23
Matter	0.45	0.42	0.45	0.23
Content	0.50	0.34	0.26	0.23
(percent)	0.31	0.42	0.31	0.37
	0.31	0.45	0.34	0.26
	0.37	0.42	0.37	0.34
min	0.31	0.34	0.26	0.23
max	0.50	0.45	0.45	0.37
range	0.19	0.11	0.19	0.14
mean	0.39	0.40	0.34	0.28
median	0.39	0.42	0.33	0.25
st dev	0.08	0.04	0.07	0.06
variance	0.006	0.002	0.004	0.004
Ho = var				
F obs	3.566		1.085	
(.01) F table	14.9	do not reject	14.9	do not reject
(.05) F table	7.15	do not reject	7.15	do not reject
Ho = means				
Est	-0.01		0.06	
SE(Est)	0.04		0.04	
t obs (10df)	-0.379		1.719	
C .01/2	3.169		3.169	
C .05/2	2.228		2.228	
99% CI	-0.12	do not reject	-0.05	do not reject
	0.10		0.18	
95% CI	-0.09	do not reject	-0.02	do not reject
	0.07		0.15	
P	.7< P< .8	do not reject (.01, .05)	.1< P< .2	do not reject (.01, .05)

Table 16. Organic matter content of soil from each plot at two depths from mineral soil surface. Statistical analysis compares OM content between parent materials at both depths.

APPENDIX G

BULK DENSITY DATA

AND

STATISTICAL ANALYSIS

	shale	crystalline
Fine Fraction	1.0	0.6
Bulk	1.0	0.9
Density	0.7	0.8
(0 to 10 cm)	1.0	0.7
	1.0	0.8
	0.9	0.8
min	0.7	0.6
max	1	0.9
range	0.3	0.3
mean	0.9	0.8
median	1.0	0.8
st dev	0.1	0.1
variance	0.01	0.01
Ho = var		
F obs	1	
(.01) F table	14.9	do not reject
(.05) F table	7.15	do not reject
Ho = means		
Est	0.2	
SE(Est)	0.1	
t obs (10df)	2.565	
C .01/2	3.169	
C .05/2	2.228	
99% CI	-0.04	do not reject
	0.37	
95% CI	0.02	reject
	0.31	
P	.02< P< .05	do not reject (.01)

Table 17. Fine fraction bulk density of the surface 10 cm on all shale and crystalline plots. Statistical analysis compares BD between parent material.

APPENDIX H

GROUND COVER DATA

AND

STATISTICAL ANALYSIS

	shale-litter	crys-litter	shale-bare	crys-bare	shale-sub	crys-sub
Percent	97	100	1	0	1	0
Ground Cover	91	100	1	3	1	0
(vegetation &	68	100	1	3	1	0
litter only)	44	100	25	10	0	2
	84	100	20	0	1	0
	59	100	25	3	0	0
min	44	100	1	0	0	0
max	97	100	25	10	1	2
range	53	0	24	10	1	2
mean	73.8	100.0	12.2	3.2	0.7	0.3
median	76.0	100.0	10.5	3.0	1.0	0.0
st dev	20.4	0.0	12.4	3.7	0.5	0.8
variance	415.8	0.0	153.0	13.4	0.3	0.7
Ho = var						
F obs			11.42		2.33	
(.01) F table		reject	14.9	do not reject	14.9	do not reject
(.05) F table		reject	7.15	reject	7.15	do not reject
Ho = means						
Est	-26.2		9.0		0.3	
SE(Est)	8.3		5.3		0.4	
t obs (10df)	-3.143		1.709		0.845	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	0.2	do not reject	-7.7	do not reject	-0.9	do not reject
	-52.5		25.7		1.6	
95% CI	-7.6	reject	20.7	do not reject	-0.5	do not reject
	-44.7		-2.7		1.2	
P	.01< P< .02	reject (.05)	.1< P< .2	do not reject (.01, .05)	.3< P<.4	do not reject (.01, .05)

Table 18. Percent of ground covered by vegetation and litter only on the shale and crystalline plots for all three plot treatments (litter, bare, subsurface). Statistical analysis compares percent ground cover between parent materials for each treatment.

	bare	subsurface	litter	bare	litter	subsurface
Percent	1	0	97	1	97	0
Ground Cover	1	3	91	1	91	3
(vegetation &	1	3	68	1	68	3
litter only)	25	10	44	25	44	10
All Plots	20	0	84	20	84	0
	25	3	59	25	59	3
	1	0	100	1	100	0
	1	0	100	1	100	0
	1	0	100	1	100	0
	0	2	100	0	100	2
	1	0	100	1	100	0
	0	0	100	0	100	0
min	0	0	44	0	44	0
max	25	10	100	25	100	10
range	25	10	56	25	56	10
mean	6.4	1.8	86.9	6.4	86.9	1.8
median	1.0	0.0	72.0	1.0	72.0	0.0
st dev	10.3	2.9	19.4	10.3	19.4	2.9
variance	105.7	8.6	375.7	105.7	375.7	8.6
Ho = var						
F obs	12.3		3.6		43.7	
(.01) F table	5.38	reject	5.38	do not reject	5.38	reject
(.05) F table	3.50	reject	NA		NA	
Ho = means						
Est	4.7		80.5		85.2	
SE(Est)	3.1		6.3		5.7	
t obs (22df)	1.512		12.709		15.050	
C .01/2	2.819		2.819		2.819	
C .05/2	2.074					
99% CI	13.366	do not reject	98.356	reject	101.119	reject
	-4.033		62.644		69.214	
95% CI	11.067	do not reject				
	-1.734					
P	.01< P< .2	do not reject (.01, .05)	P< .001	reject (.01)	P< .001	reject (.01)

Table 19. Percent of ground covered by vegetation and litter only on all plots. Statistical analysis compares percent of ground cover between treatments.

	forested shale only	all crystalline
Percent Ground Cover (vegetation & litter only)	97	100
	91	100
	68	100
		100
		100
		100
min	68	100
max	97	100
range	29	0
mean	85.3	100.0
median	91.0	100.0
st dev	15.3	0.0
variance	234.3	0.0
Ho = var		
F obs		
(.01) F table		reject
(.05) F table		reject
Ho = means		
Est	-14.7	
SE(Est)	5.8	
t obs (10df)	-2.535	
C .01/2	3.499	
C .05/2	2.365	
99% CI	-34.9	do not reject
	5.6	
95% CI	-28.4	reject
	-1.0	
P	.02< P< .05	reject (.05)

Table 20. Percent of ground covered by vegetation and litter only on all forested plots. Statistical analysis compares percent of ground cover between parent materials on the forested plots.

	shale-litter	crys-litter	shale-bare	crys-bare	shale-sub	crys-sub
Percent	97	100	1	10	1	90
Ground Cover	91	100	1	3	2	90
(vegetation,	68	100	1	5	1	0
litter & rock)	44	100	25	20	10	87
	84	100	20	25	1	90
	59	100	25	3	0	90
min	44	100	1	3	0	0
max	97	100	25	25	10	90
range	53.0	0.0	24.0	22.0	10.0	90.0
mean	73.8	100.0	12.2	11.0	2.5	74.5
median	76.0	100.0	13.0	7.5	1.0	90.0
st dev	20.4	0.0	12.4	9.4	3.7	36.5
variance	415.8	0.0	153.0	88.4	13.9	1333.5
Ho = var						
F obs			1.73		95.9	
(.01) F table		reject	14.9	do not reject	14.9	reject
(.05) F table		reject	7.15	do not reject	7.15	reject
Ho = means						
Est	-26.2		1.2		-72.0	
SE(Est)	8.3		6.3		15.0	
t obs (10df)	-3.143		0.184		-4.805	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	0.2	do not reject	-18.9	do not reject	-24.5	reject
	-52.5		21.3		-119.5	
95% CI	-7.6	reject	-13.0	do not reject	-38.6	reject
	-44.7		15.3		-105.4	
	P .01< P< .02	reject (.05)	.8< P< .9	do not reject (.01, .05)	P< .001	reject (.01, .05)

Table 21. Percent of ground covered by vegetation, litter and rock on the shale and crystalline plots for all three plot treatments (litter, bare, subsurface). Statistical analysis compares percent ground cover between parent materials for each treatment.

APPENDIX I

LITTER WEIGHT DATA

AND

STATISTICAL ANALYSIS

	shale--lbs	crys--lbs	shale--grams	crys--grams
Air dry	1.44	3.53	653.2	1601.2
weight	1.62	4.28	734.8	1941.4
of litter	3.62	1.65	1642.0	748.4
removed	0.43	2.34	195.0	1061.4
(lbs/plot)*	0.62	4.15	281.2	1882.4
(gms/plot)*	0.87	3.90	394.6	1769.0
min	0.43	1.65	195.00	748.40
max	3.62	4.28	1642.00	1941.40
range	3.19	2.63	1447.00	1193.00
mean	1.4	3.3	650.1	1500.6
median	1.2	3.7	523.9	1685.1
st dev	1.2	1.1	529.1	486.0
variance	1.4	1.1	279906.6	236187.3
Ho = var				
F obs	1.27		1.18	
(.01) F table	14.9	do not reject	14.9	do not reject
(.05) F table	7.15	do not reject	7.15	do not reject
Ho = means				
Est	-1.9		-850.5	
SE(Est)	0.6		293.3	
t obs (10df)	-2.900		-2.900	
C .01/2	3.169		3.169	
C .05/2	2.228		2.228	
99% CI	-3.9	reject	-1779.9	do not reject
	0.2		78.9	
95% CI	-3.3	reject	-1503.9	reject
	-0.4		-197.1	
P	.01< P< .02	reject (.05)	.01< P< .02	reject (.05)

* plot size was 66 cm x 66 cm (26 x 26 inches)

Table 22. Air dry weight of ground cover (vegetation and litter) removed from all shale and crystalline plots. Statistical analysis compare dry weights between parent materials.

	forested shale	all crystalline
Air dry weight of litter removed (lbs/plot)*	1.44 1.62 3.62	3.53 4.28 1.65 2.34 4.15 3.90
min	1.44	1.65
max	3.62	4.28
range	2.2	2.6
mean	2.2	3.3
median	1.6	3.7
st dev	1.2	1.1
variance	1.5	1.1
Ho = var		
F obs	1.36	reject
(.01) F table	199.0	
(.05) F table	39.3	
Ho = means		
Est	-1.1	
SE(Est)	0.8	
t obs (10df)	-1.375	
C .01/2	3.499	
C .05/2	2.365	
99% CI	-3.8 1.7	do not reject
95% CI	-2.9 0.8	do not reject
P	.2< P< .3	do not reject (.01, .05)

* plot size was 66 cm x 66 cm (26 x 26 inches)

Table 23. Air dry weight of ground cover (vegetation and litter) removed from forest plots only. Statistical analysis compares dry weights between parent materials.

APPENDIX J

SEDIMENT YIELD DATA

AND

STATISTICAL ANALYSIS

	grams per simulator plot*			pounds per milacre		
	litter	bare	subsurface	litter	bare	subsurface
M12-1	10.9	39.4	324.3	0.218	0.788	6.486
M12-2	1.9	42.7	26.4	0.038	0.854	0.528
M12-3	1.4	96.7	64.0	0.028	1.934	1.280
VSH-1	0.0	16.7	135.4	0.000	0.334	2.708
VSH-2	0.0	28.6	78.1	0.000	0.572	1.562
VSH-3	0.0	17.2	175.0	0.000	0.344	3.500
MER-1	3.4	29.6	70.3	0.068	0.592	1.406
MER-2	2.4	19.2	153.8	0.048	0.384	3.076
MER-3	7.6	32.8	214.4	0.152	0.656	4.288
MLP-1	6.4	29.9	148.3	0.128	0.598	2.966
MLP-2	8.2	13.3	150.2	0.164	0.266	3.004
MLP-3	7.5	34.2	111.4	0.150	0.684	2.228

	logarithm of sed yld (lbs/milacre)			kilograms per hectare		
	litter	bare	subsurface	litter	bare	subsurface
M12-1	-0.66	-0.10	0.81	244.3	883.2	7269.5
M12-2	-1.42	-0.07	-0.28	42.6	957.2	591.8
M12-3	-1.55	0.29	0.11	31.4	2167.6	1434.6
VSH-1	no yield	-0.48	0.43	0.0	374.3	3035.1
VSH-2	no yield	-0.24	0.19	0.0	641.1	1750.7
VSH-3	no yield	-0.46	0.54	0.0	385.6	3922.8
MER-1	-1.17	-0.23	0.15	76.2	663.5	1575.8
MER-2	-1.32	-0.42	0.49	53.8	430.4	3447.6
MER-3	-0.82	-0.18	0.63	170.4	735.2	4806.0
MLP-1	-0.89	-0.22	0.47	143.5	670.2	3324.3
MLP-2	-0.79	-0.58	0.48	183.8	298.1	3366.9
MLP-3	-0.82	-0.16	0.35	168.1	766.6	2497.1

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 24. Actual measured sediment yields (unit conversions).

	shale-litter	crys-litter	shale-bare	crys-bare	shale-sub	crys-sub
Sediment	10.9	3.4	39.4	29.6	324.3	70.3
Yield	1.9	2.4	42.7	19.2	26.4	153.8
(grams per	1.4	7.6	96.7	32.8	64.0	214.4
plot)*	0	6.4	16.7	29.9	135.4	148.3
	0	8.2	28.6	13.3	78.1	150.2
	0	7.5	17.2	34.2	175.0	111.4
min	0	2.4	16.7	13.3	26.4	70.3
max	10.9	8.2	96.7	34.2	324.3	214.4
range	10.9	5.8	80.0	20.9	297.9	144.1
mean	2.4	5.9	40.2	26.5	133.9	141.4
median	0.7	7.0	34.0	29.8	106.8	149.3
st dev	4.3	2.4	29.7	8.3	107.2	48.1
variance	18.2	5.9	883.0	69.5	11499.9	2312.6
Ho = var						
F obs	3.08		12.71		4.97	
(.01) F table	14.9	do not reject	14.9	do not reject	14.9	do not reject
(.05) F table	7.15	do not reject	7.15	reject	7.15	do not reject
Ho = means						
Est	-3.6		13.7		-7.5	
SE(Est)	2.0		12.6		48.0	
t obs (10df)	-1 773		1.089		-0.157	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	-9.9	do not reject	-26.2	do not reject	-159.6	do not reject
	2.8		53.6		144.5	
95% CI	-8.0	do not reject	-14.4	do not reject	-114.4	do not reject
	0.9		41.8		99.4	
P	.1< P< .2	do not reject (.01, .05)	.3< P< .4	do not reject (.01, .05)	.8< P< .9	do not reject (.01, .05)

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 25. Oven-dry weight of eroded sediment collected from all shale and crystalline plots after each simulator run for each treatment (litter, bare, subsurface). Statistical analysis compares sediment yields between parent materials for each treatment.

	litter	bare	subsurface
Sediment	10.9	39.4	324.3
Yield	1.9	42.7	26.4
(grams per	1.4	96.7	64.0
plot)*	0.0	16.7	135.4
All Plots	0.0	28.6	78.1
	0.0	17.2	175.0
	3.4	29.6	70.3
	2.4	19.2	153.8
	7.6	32.8	214.4
	6.4	29.9	148.3
	8.2	13.3	150.2
	7.5	34.2	111.4
mean	4.1	33.4	137.6
mean, all obsv	58.4		
variance	14.4	484.3	6293.9

Ho: all means =				(ANOVA)
(2 df)	MSTr	59093.8		
(33 df)	MSE	2264.2		
	F obs	26.1		
(.01)	F table	5.39	reject	
(.05)	F table	3.32	reject	

Pairwise comparisons of equal means			(Tukey's)
(.05)	q	3.47	
	T	2.45	
	D	47.6	

-18.3 ≤ Bare - Lit ≤ 76.9 not different

85.9 ≤ Sub - Lit ≤ 181.1 different

56.6 ≤ Sub - Bare ≤ 151.8 different

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 26. Oven-dry weight of eroded sediment collected from all shale and crystalline plots after each simulator run for each treatment (litter, bare, subsurface). Statistical analysis compares sediment yields between treatments on all plots.

APPENDIX K

PREDICTED SEDIMENT YIELD DATA

AND

STATISTICAL ANALYSIS

Shale Sites (Vigilante Experimental Range)

$y=1.563 - 0.629A - 1.86AA - 26.0F + 13.2FF + 19.0AF + 0.0133G$

Litter runs	veg&lit cover (A)	AA	OM 0-5cm (F)	FF	AF	%slope (G)
M12-1	0.97	0.9409	0.0035	0.00001225	0.003395	35
M12-2	0.91	0.8281	0.0045	0.00002025	0.004095	35
M12-3	0.68	0.4624	0.0038	0.00001444	0.002584	35
VSH-1	0.44	0.1936	0.0031	0.00000961	0.001364	15
VSH-2	0.84	0.7056	0.0032	0.00001024	0.002688	15
VSH-3	0.59	0.3481	0.0037	0.00001369	0.002183	15

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot*
M12-1	-0.4	0.4	448	20
M12-2	-0.1	0.8	897	40
M12-3	0.7	5.0	5604	250
VSH-1	1.1	12.6	14122	630
VSH-2	-0.1	0.8	897	40
VSH-3	0.7	5.0	5604	250

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 27. Calculation of predicted sediment yields according to Meeuwig, 1970 for litter treatment on the shale plots.

Crystalline Sites (Trinity Mountains)

$y= -0.666 + 1.71A - 1.82AA + 8.60E - 18.0AE + 0.0235G$

Litter runs	veg&lit cover (A)	AA	OM 0-2.5cm (E)	AE	%slope (G)
MER-1	1	1	0.0037	0.0037	35
MER-2	1	1	0.0042	0.0042	35
MER-3	1	1	0.0034	0.0034	35
MLP-1	1	1	0.0042	0.0042	45
MLP-2	1	1	0.0045	0.0045	45
MLP-3	1	1	0.0042	0.0042	45

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot*
MER-1	0.01	1.02	1143	51
MER-2	0.01	1.02	1143	51
MER-3	0.01	1.02	1143	51
MLP-1	0.24	1.7	1905	85
MLP-2	0.24	1.7	1905	85
MLP-3	0.24	1.7	1905	85

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 28. Calculation of predicted sediment yields according to Meeuwig, 1970 for litter treatment on the crystalline plots.

Shale Sites (Vigilante Experimental Range)
y=1.563 - 0.629A - 1.86AA - 26.0F + 13.2FF + 19.0AF + 0.0133G

Bare runs	veg&lit cover (A)	AA	OM 0-5cm (F)	FF	AF	%slope (G)
M12-1	0.01	0.0001	0.0035	0.00001225	0.000035	35
M12-2	0.01	0.0001	0.0045	0.00002025	0.000045	35
M12-3	0.01	0.0001	0.0038	0.00001444	0.000038	35
VSH-1	0.25	0.0625	0.0031	0.00000961	0.000775	15
VSH-2	0.20	0.0400	0.0032	0.00001024	0.000640	15
VSH-3	0.25	0.0625	0.0037	0.00001369	0.000925	15

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot*
M12-1	1.9	79.4	88992	3970
M12-2	1.9	79.4	88992	3970
M12-3	1.9	79.4	88992	3970
VSH-1	1.4	25.1	28132	1255
VSH-2	1.5	31.6	35417	1580
VSH-3	1.4	25.1	28132	1255

* plot size was 66 by 66 cm (26 x 26 inches)

Table 29. Calculation of predicted sediment yields according to Meeuwig, 1970 for bare treatment on the shale plots.

Crystalline Sites (Trinity Mountains)
y= -0.666 + 1.71A - 1.82AA + 8.60E - 18.0AE + 0.0235G

Bare runs	veg&lit cover (A)	AA	OM 0-2.5cm (E)	AE	%slope (G)
MER-1	0.00	0.0000	0.0037	0.0000	35
MER-2	0.03	0.0009	0.0042	0.0001	35
MER-3	0.03	0.0009	0.0034	0.0001	35
MLP-1	0.10	0.0100	0.0042	0.0004	45
MLP-2	0.00	0.0000	0.0045	0.0000	45
MLP-3	0.03	0.0009	0.0042	0.0001	45

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot*
MER-1	0.19	1.5	1681	75
MER-2	0.24	1.7	1905	85
MER-3	0.23	1.6	1793	80
MLP-1	0.57	3.7	4147	185
MLP-2	0.43	2.7	3026	135
MLP-3	0.48	3.0	3362	150

* plot size was 66 by 66 cm (26 x 26 inches)

Table 30. Calculation of predicted sediment yields according to Meeuwig, 1970 for bare treatment on the crystalline plots.

Shale Sites (Vigilante Experimental Range)
y=1.563 - 0.629A - 1.86AA - 26.0F + 13.2FF + 19.0AF + 0.0133G

Subsurface*	veg&lit cover (A)	AA	OM 0-5cm (F)*	FF	AF	%slope (G)
M12-1	0.01	0.0001	0.0035	0.00001225	0.000035	35
M12-2	0.01	0.0001	0.0045	0.00002025	0.000045	35
M12-3	0.01	0.0001	0.0038	0.00001444	0.000038	35
VSH-1	0.00	0.0000	0.0031	0.00000961	0.000000	15
VSH-2	0.01	0.0001	0.0032	0.00001024	0.000032	15
VSH-3	0.00	0.0000	0.0037	0.00001369	0.000000	15

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot **
M12-1	1.9	79.4	88992	3970
M12-2	1.9	79.4	88992	3970
M12-3	1.9	79.4	88992	3970
VSH-1	1.7	50.1	56152	2505
VSH-2	1.7	50.1	56152	2505
VSH-3	1.7	50.1	56152	2505

* subsurface level organic matter contents not available; values used are for depths as noted at original soil surface level; true organic matter contents at the subsurface level would be close to the same, but somewhat lower

** plot size was 66 by 66 cm (26 x 26 inches)

Table 31. Calculation of predicted sediment yields according to Meeuwig, 1970 for subsurface treatment on the shale plots.

Crystalline Sites (Trinity Mountains)
y= -0.666 + 1.71A - 1.82AA + 8.60E - 18.0AE + 0.0235G

Subsurface*	veg&lit cover (A)	AA	OM 0-2.5cm (E)*	AE	%slope (G)
MER-1	0.00	0.0000	0.0037	0.0000	35
MER-2	0.00	0.0000	0.0042	0.0000	35
MER-3	0.00	0.0000	0.0034	0.0000	35
MLP-1	0.02	0.0004	0.0042	0.0001	45
MLP-2	0.00	0.0000	0.0045	0.0000	45
MLP-3	0.00	0.0000	0.0042	0.0000	45

	Logarithm Lbs/milacre (y)	Lbs/milacre	Kg/hectare	Grams/plot **
MER-1	0.19	1.5	1681	75
MER-2	0.19	1.5	1681	75
MER-3	0.19	1.5	1681	75
MLP-1	0.46	2.9	3250	145
MLP-2	0.43	2.7	3026	135
MLP-3	0.43	2.7	3026	135

* subsurface level organic matter contents not available; values used are for depths as noted at original soil surface level; true organic matter contents at the subsurface level would be close to the same, but somewhat lower

** plot size was 66 by 66 cm (26 x 26 inches)

Table 32. Calculation of predicted sediment yields according to Meeuwig, 1970 for subsurface treatment on the crystalline plots.

	predict-litter	actual-litter	predict-bare	actual-bare	predict-sub	actual-sub
Sediment	20	10.9	3970	39	3970	324
Yields	40	1.9	3970	43	3970	26
(grams per	250	1.4	3970	97	3970	64
plot)*	630	0.0	1255	17	2505	135
All Plots	40	0.0	1580	29	2505	78
	250	0.0	1255	17	2505	175
	51	3.4	75	30	75	70
	51	2.4	85	19	75	154
	51	7.6	80	33	75	214
	85	6.4	185	30	145	148
	85	8.2	135	13	135	150
	85	7.5	150	34	135	111
min	20.0	0.0	75.0	13.0	75.0	26.0
max	630.0	10.9	3970.0	97.0	3970.0	324.0
range	610.0	10.9	3895.0	84.0	3895.0	298.0
mean	136.5	4.1	1392.5	33.4	1672.1	137.4
median	68.0	2.9	720.0	31.5	1325.0	141.5
st dev	173.6	3.8	1644.7	22.1	1722.4	79.3
variance	30126.5	14.37	2704970.5	488.4	2966524.8	6292.6
Ho = var						
F obs	2096.5		5537.9		471.4	
(.01) F table	5.38	reject	5.38	reject	5.38	reject
(.05) F table	3.50	reject	3.50	reject	3.50	reject
Ho = means						
Est	132.4		1359.1		1534.7	
SE(Est)	70.9		671.5		703.9	
t obs (22df)	1.867		2.024		2.180	
C .01/2	2.819		2.819		2.819	
C .05/2	2.074		2.074		2.074	
99% CI	-67.4	do not reject	-533.9	do not reject	-449.6	do not reject
	332.2		3252.0		3518.9	
95% CI	-14.6	do not reject	-33.6	do not reject	74.8	reject
	279.4		2751.8		2994.5	
P	.05< P< .1	do not reject (.01, .05)	.05< P< .1	do not reject (.01, .05)	.02< P< .05	reject (.05)

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 33. Predicted and actual eroded sediment yields from all plots for all treatments (litter, bare, subsurface). Statistical analysis compares between predicted and actual sediment yields for all treatments.

	predict-litter	actual-litter	predict-bare	actual-bare	predict-sub	actual-sub
Shale	20	10.90	3970	39	3970	324
Sediment	40	1.90	3970	43	3970	26
Yields	250	1.40	3970	97	3970	64
(grams per	630	0.00	1255	17	2505	135
plot)*	40	0.00	1580	29	2505	78
	250	0.00	1255	17	2505	175
min	20.0	0.0	1255.0	17.0	2505.0	26.0
max	630.0	10.9	3970.0	97.0	3970.0	324.0
range	610.0	10.9	2715.0	80.0	1465.0	298.0
mean	205.0	2.37	2666.7	40.3	3237.5	133.7
median	145.0	0.70	4775.0	34.0	3237.5	106.5
st dev	233.8	4.3	1432.7	29.8	802.4	107.2
variance	54670.0	18.15	2052496.7	887.5	643867.5	11496.3
Ho = var						
F obs	3012.1		2312.7		56.0	
(.01) F table	14.9	reject	14.9	reject	14.9	reject
(.05) F table	7.15	reject	7.15	reject	7.15	reject
Ho = means						
Est	202.6		2626.3		3103.8	
SE(Est)	95.5		585.0		330.5	
t obs (10df)	2.122		4.489		9.391	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	-99.9	do not reject	772.5	reject	2056.5	reject
	505.2		4480.2		4151.2	
95% CI	-10.1	do not reject	1322.9	reject	2367.5	reject
	415.3		3929.7		3840.2	
P	.05< P< .1	do not reject (.01, .05)	.001< P< .01	reject (.01, .05)	P< .001	reject (.01, .05)

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 34. Predicted and actual eroded sediment yields from all shale plots for all treatments (litter, bare, subsurface). Statistical analysis compares between predicted and actual sediment yields for all treatments.

	predict-litter	actual-litter	predict-bare	actual-bare	predict-sub	actual-sub
Crystalline	51	3	75	30	75	70
Sediment	51	2	85	19	75	154
Yields	51	8	80	33	75	214
(grams per	85	6	185	30	145	148
plot)*	85	8	135	13	135	150
	85	8	150	34	135	111
min	51.0	2.40	75.0	13.3	75.0	70.3
max	85.0	8.20	185.0	34.2	145.0	214.4
range	34.0	5.80	110.0	20.9	70.0	144.1
mean	68.0	5.92	118.3	26.5	106.7	141.4
median	68.0	7.00	110.0	30.0	105.0	249.0
st dev	18.6	2.43	45.1	8.3	34.9	48.1
variance	346.8	5.90	2036.7	69.54	1216.7	2312.6
Ho = var						
F obs	58.8		29.3		1.9	
(.01) F table	14.9	reject	14.9	reject	14.9	do not reject
(.05) F table	7.15	reject	7.15	reject	7.15	do not reject
Ho = means						
Est	62.1		91.8		-34.7	
SE(Est)	7.7		18.7		24.3	
t obs (10df)	8.097		4.901		-1.432	
C .01/2	3.169		3.169		3.169	
C .05/2	2.228		2.228		2.228	
99% CI	37.8	reject	32.5	reject	-111.6	do not reject
	86.4		151.2		42.1	
95% CI	45.0	reject	50.1	reject	-88.8	do not reject
	79.2		133.6		19.3	
P	P< .001	reject (.01, .05)	P< .001	reject (.01, .05)	.1< P< .2	do not reject (.01, .05)

* plot size was 66 cm by 66 cm (26 x 26 inches)

Table 35. Predicted and actual eroded sediment yields from all crystalline plots for all treatments (litter, bare, subsurface). Statistical analysis compares between predicted and actual sediment yields for all treatments.

APPENDIX L

SAND CONTENTS OF SEDIMENT YIELDS

	eroded sediment samples			plot samples
	sand wt (gms)	original smpl wt	% sand sieved	hydrom % sand*
Shale plots				
M12 Sub 1	28.7	324.3	9	11
M12 Bare 2	11.2	42.7	**26	3
VSH Sub 1	7.1	135.4	5	15
VSH Sub 3	1.4	175	1	0
Crys Plots				
MER Bare 1	10.8	29.6	36	81
MER Sub 1	24.1	70.3	34	82
MER Sub 2	67.4	153.8	44	78
MER Sub 3	136.2	214.4	64	78
MLP Sub 1	39.0	148.3	26	70
MLP Sub 2	64.2	150.2	43	75
MLP Sub 3	36.4	111.4	33	75

*these are hydrometer measured % sand >.05 mm, sieved samples were for >.063 mm; differences due to the .05 to .063 mm fraction would be most apparent on the high sand crystalline plots

**this particular sediment yield sample was dominated by organic litter; it also contained some visual clay aggregates after sieving; both of these probably affected sieved weight of sand

Table 36. Sieved sand content (>0.063 mm) of selected sediment yield samples.

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