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Evaluation of Some Soil Loss Equations for Predicting Sheet Erosion

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AN EVALUATION OF SOME

EROSION EQUATIONS

by

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of

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Douglas J. Trieste

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ABSTRACT

Evaluation of Some Soil Loss Equations

for Predicting Sheet Erosion

by

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Utah State University, 1977

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The objectives of this study were (a) to apply sediment and associated plot data from various infiltrometer studies to the parameters in the Universal Soil Loss Equation, a modified version of the original Musgrave Equation, and a modified version of the original Universal Soil Loss Equation, and compare the computed results with the measured soil loss, (b) to suggest reasons for any differences between computed and measured soil loss, and (c) to suggest improvements for each equation so that it will give results near the measured soil loss. The data used consisted of 2805 infiltrometer plots collected by previous researchers in a variety of rangeland conditions, both in the western United States and Australia, and included the necessary information needed to compute the factors in each of the above equations. Simple and multiple linear regression techniques were used to make the evaluations by computing the coefficient of determination (R^2), correlation coefficients (r), and to optimize each factor in the equations by placing an exponent on it.

The results showed that the three soil loss prediction equations are not universal, but, for the most part, explain sediment yield with varying degrees of accuracy in different situations with no apparent trends or patterns. However, most individual mine sites and other sites with loosely consolidated soil resembling fallow conditions showed high R^2 values when the computed sediment yield was regressed against measured sediment yield. Little improvement was made in reducing the variability of the equations by placing exponents on each factor indicating that the factors, as determined in each equation, do not explain sediment yield under western rangeland conditions. In summary, the prediction equations are not recommended as "universal" predictors of sheet erosion in western rangelands, but, may be applied in specific situations.

(167 pages)

INTRODUCTION

The Problem

The need to accurately predict erosion in wildlands is important in that it enables a land manager or researcher to assess the magnitude of the problem under specified geographic, land use, and management conditions, and also to guide the selection of management practices for specific sites. There are currently several erosion equations that are being used to fill the above needs. However, these equations were developed from data collected on farmlands east of the Rocky Mountains and little effort has been made in evaluating and adapting them to western wildlands. Thus, no proven erosion prediction equations exist which are "universally" applicable to wildlands, although many attempts have been made to develop erosion prediction equations in specific study areas.

Objectives

The objectives of this study were to:

1. To apply sediment and associated plot data from various infiltrometer studies, to the parameters in the Universal Soil Loss Equation, a modified version of the original Musgrave Equation, and a modified version of the original Universal Soil Loss Equation (as used for predicting erosion during highway construction), and compare the computed results with the measured soil loss.

2. Suggest reasons for any differences between computed and measured soil loss.

3. To suggest improvements for each equation so that it will give results similar to the measured soil loss.

The reader is reminded that this study pertains to sheet erosion[1] only and all computations are on a per storm basis.

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[1]Sheet erosion is the detachment of the material from the land surface by raindrop impact and its subsequent removal by prechannel or overland flow (Chow, 1964).

REVIEW OF LITERATURE

The Water Erosion Process

Sheet and rill erosion

Baur (1952) has defined sheet erosion as "removal of a fairly uniform layer of soil or material from the land surface by the action of rainfall and runoff," and rill erosion as "removal of soil by running water with formation of shallow channels that can be smoothed out completely by cultivation." Sheet and rill erosion is a work process in which the energy is supplied by gravity, i.e., falling raindrops and runoff. Borst and Woodburn (1942) demonstrated that it is the impact of the drops on the bare soil and not the runoff velocity that detached large quantities of soil.

The initial phase of the water erosion process is splash erosion which is true sheet erosion (Ellison, 1947). Erosion can exist without runoff due to the progressive movement of soil particles downhill from splashing. The quantity moved downhill increases with increased intensity, drop size, and fall velocity. With drop size and velocity constant, the factors affecting the splash are the resistance of the soil to deformation by the drop and the depth of the water film. Maximum splash occurs shortly after the surface is wetted, after that, splash decreases with increasing time of water application because of the development of a deeper water film and the removal of easily detached soil particles.

The second phase of the water erosion process is runoff as sheet and microchannel flow. The raindrop impact-splash process has high detachment and low transport capacity, whereas sheet and microchannel flow has low detachment and high transport capacity (Smith and Wischmeier, 1962).

Primary factors affecting sheet and rill erosion

Rainfall

Erosion is a mechanical process that requires energy which is supplied by falling raindrops. Ellison (1944, 1947) noticed a link between mass and velocity of falling drops and developed theories on transportation and detachment of raindrop splash. Ekern (1950, 1953) and Osborn (1953, 1954) further developed Ellison's work by conducting experiments in small splash cans and on small plots. Wischmeier (1955) and Wischmeier and Smith (1958) confirmed and quantified the earlier researcher's findings by evaluating 8, 250 plot-years of data. In searching for a parameter that would show a correlation between soil erosion and rainfall, the kinetic energy of rain was found to be highly correlated with soil loss.

Soil

Soil properties affect the susceptibility of a soil to erosion (erodibility). Research to discover these properties has been conducted by Bouyoucos (1935), Middleton (1930 and 1932), and Wallis and Stevan (1961).

In other studies, bulk density has been shown to be a major factor in soil erosion (Meeuwig, 1965; Yamamoto and Anderson, 1973) because of its effect on infiltration rates and overland flow. Smith and Wischmeier (1957) grouped soil properties that influence soil erodibility into two types: (1) properties that affect the infiltration rate and permeability; and (2) properties that resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff. These soil properties were considered by Adams et al. (1958) to be runoff, infiltration, wash erosion, splash erosion, water stable aggregates < 0.10 mm, dispersion ratio, percent silt and clay, bulk density, pores drained by 60 cm water tension, and air permeability at field capacity. Wischmeier, Johnson, and Cross (1971) utilized statistical methods and determined the principle factors in soil erodibility to be percent silt and fine sand, percent sand, percent organic material, permeability, and soil structure.

Topography

Work by Zing (1940) was moderately successful in establishing a relationship between soil loss and a percent slope. However, the best known relationship to date is that by Smith and Wischmeier (1957). Data from various locations in the eastern U.S. were combined and a least squares fit to the data was obtained. The resulting relationship is:

$$A = 0.43 + 0.30\ S + 0.043\ S^2$$

where A is soil loss in tons per acre/year and

S is percent of slope.

Studies on a relationship between soil-loss and slope length were performed by Zing (1940) and Musgrave (1947), but, the most recent relationship was obtained statistically by Wischmeier et al. (1958). As with percent slope, a statistical analysis of data throughout the eastern U.S. was made. Soil-loss was found to be exponentially related to slope length and the magnitude of the slope length exponent affected by soil, rainfall characteristics, steepness of slope, cover, and residue management. It was finally determined at Purdue University in 1956, that for field use the value of the length exponent should be 0.5 $\pm$ 0.1 (Smith and Wischmeier, 1962), i.e.,

$$A = L^{.5 \pm 0.1}$$

where

A = soil loss in tons per acre, and

L = slope length in feet

Cover

Cover is very important because of its strong influence on sheet erosion and its sensitivity to land use. Vegetation (living and dead) breaks raindrop impact which is the major cause of soil detachment. Vegetative cover also restricts overland flow which is the second most important force in the sheet erosion process. Cover also reduces erosion by supplying organic matter, creating root channels, enhancing habitat for soil fauna, and reducing temperature extremes and evaporation at the soil surface (Meeuwig and Packer, 1975). These factors increase infiltration rates and consolidate the soil particles thereby reducing erosion.

Packer (1951) and Marston (1952) found that approximately 65 to 70 percent ground cover is usually needed for effective control of runoff and erosion.

Bauer (1956) classified the major effects of vegetation on runoff and erosion into five categories: (1) interception of rainfall by the vegetative cover; (2) decrease in the velocity of runoff and the cutting action of water; (3) root effects in increasing granulation and porosity; (4) biological activities associated with vegetative growth and their influence on soil porosity; and (5) the transpiration of water leading to subsequent drying out of the soil and therefore increased infiltration rates.

Wischmeier (1975) made a numerical evaluation of the effectiveness of the various types and quantities of vegetative cover in wildlands. His approach, not based on firm research data, is strictly empirical. However, the tables and procedures are the best estimates available for computing the effects of cover on sheet erosion in wildlands. This was accomplished by dividing the effect of cover into raised-canopy, surface contact, and beneath-surface effects and deriving relationships for evaluating each effect as a subfactor.

Development of Soil-Loss Equations

Development of equations for calculating soil loss on agricultural lands began about 1940 in the Corn Belt States. The soil-loss estimating procedure developed in that region between 1940 and 1956 has been generally referred to as the slope practice method. Zing (1940) developed a rational equation which gave a relation between annual total soil loss, degree of slope, and horizontal length of slope. The equation, $X = CS^{1.4} L^{1.6}$, was based on a limited amount of data which was not gathered for the purpose of the study. In the following year, Smith (1941) presented an equation which provides for the effect of soil-climate-crop-treatment, length and degree of slope, and mechanical conservation practices on soil loss. A graphical method resulted for determining conservation practices needed on the Shelby and associated soils of the midwest. Browning, Parish, and Glass (1947) added soil erodibility and management factors to the equations developed by Zing and Smith. A guide was developed for all soil mapped in Iowa which showed the use and limitations of rotation and conservation practices in the control of soil erosion. A method of making the actual calculation of soil loss from midwest claypan soils is discussed by Smith and Whitt (1947). This method utilizes charts and tables for calculating the effects of slope, different farming practices, crops and rotation.

A nationwide committee on soil-loss prediction was formed in 1946 and met in Ohio to try and adapt the corn belt equation to other experimental lands. This committee presented a more complete equation consisting of rainfall, slope, vegetal cover, and soil erodibility factors (Musgrave, 1947). This formula became known as the Musgrave equation.

A graphical solution of the Musgrave Equation was developed by Lloyd and Ally (1952) to provide a quick, practical, "on the spot" method of its solution and was used by the Soil Conservation Service in the northeastern States.

In 1954, the Runoff and Soil Loss Data Center of the Agricultural Research Service was established at Purdue University. Most of the basic runoff and soil-loss data obtained in studies in the United States since 1930 were assembled there for analysis. These analyses resulted in an improved soil loss equation in the latter part of the 1950's which became known as the Universal Soil Loss Equation (Wischmeier and Smith, 1961). This equation was designed to be used in any geographic location and to provide improvements in soil-loss prediction with minimum changes in the basic concepts that were developed during previous work (Smith and Wischmeier, 1962). Some features of the corn belt equation and the soil loss nomogram of the northeastern states were retained. Smith and Wischmeier (1957) analyzed the processes and factors that affect sheet and rill erosion . The processes are raindrop impact and transportation of soil particles by flowing water. The factors are length and slope gradient, cropping, soil, management and rainfall.

A major development which contributed to great improvements in the field of soil loss prediction was the rainfall erosion index (Wischmeier, 1959). Extensive regression analysis of basic soil-loss data were analyzed to determine the best indicator of the capacity of a storm to erode soil. The rainstorm characteristic determined to be such an indicator is the variable whose value is the product of the kinetic energy of the storm and the maximum 30 minute intensity. This erosion index reflects the effects of: (a) rainfall energy, (b) interaction of storm energy and maximum prolonged intensity, (c) antecedent moisture, and (d) total antecedent rainfall energy since the last tillage operation.

Another major development in improving soil-loss prediction was the development of a cropping management factor on the basis of local climate and crop cultural conditions (Wischmeier, 1960). The influences of vegetal growth, crop sequence, tillage practices, fertility, and residue were evaluated and a method of quantitatively determining their effect on erosion determined.

The benefits of all the above research were realized when specific quide lines for farm land conservation practices were published in a handbook by Wischmeier and Smith (1965). All relevant information from past research was orderly arranged to provide useful guidelines for conservation farm planning and also to help estimate gross erosion from watersheds.

The full potential of the Universal Soil Loss Equation was not realized until Wischmeier, Johnson, and Cross (1971) discovered a new statistical parameter that reflects the interaction of different particle sizes. A soil-erodibility nomograph was then developed which can be used to determine the K-value[1] of any soil on the basis of five parameters. These five parameters (percent silt and fine sand, percent sand, percent organic material, structure, and permeability) can be obtained from routine laboratory analysis and standard soil profile descriptions. Prior to the nomograph, the K-value had to be experimentally determined by actual soil loss measurements on standard plots.

Being that the soil-loss equation was derived from data collected from farmland, a numerical evaluation of the applicability of the

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[1]The K-value is the soil erodibility factor from the Universal Soil Loss Equation, i.e., the erosion rate per unit of erosion-index for a specific soil in cultivated continuous fallow, on a 9 percent slope 72.6 feet long.

equation to wildland conditions in the western United States has never been determined. To apply the soil-loss equation in wildland situations, the user had to rely on personal judgment for the C-factor value.[2] Wischmeier (1975) devised graphs and tables for determining the C-factor for undisturbed areas without having any research data on such areas.

The newest developments in the Universal Soil Loss Equation with step-by-step procedures in its use were given by the Soil Conservation Service (1975).

An attempt to modify the Universal Soil Loss Equation to areas west of the Rocky Mountains was made by McCool and Papendick (1976). New relationships to fit Pacific Northwest conditions were developed by modifying the K, LS, and C factors so that those factors would reflect the differences between the Pacific Northwest and the conditions from which the USLE was originally developed.

All of the existing information on soil-loss prediction and erosion and sedimentation control practices was assembled, evaluated, and placed in usable form by the Utah Water Research Laboratory (1976). The manual is concerned with erosion prediction and control during highway construction and represents the "state of the art" in that area.

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[2]The C-factor is the cropping management factor, i.e., the ratio of a soil loss from a field with specified cropping and management, or type of vegetative cover to that from the fallow condition on which the K-factor is evaluated.

Other Soil-Loss Prediction Models

Various other equations have been derived for predicting on-site erosion. Beer, Franham, and Heinmann (1966) also modified the Musgrave Equation for a study of sediment yields in western Iowa. Anderson (1969) modified the Musgrave equation by analyzing updated data for use in the southwestern U.S. Meeuwig (1970) collected data from seven mountain rangeland sites in Utah, Idaho and Montana and developed multiple regression equations for each site. Foster, Meyer, and Onstad (1973) and Foster and Meyer (1975) used a different approach to developing a soil-loss prediction model by limiting their study to deterministic formulations. The approach is based on physical principles of hydrology, hydraulics, sediment transport, and erosion mechanics.

Erosion Equations

Musgrave Equation

The Musgrave equation is (Musgrave, 1947):

$$E = F(K/100)\ (S/10)^{1.35}\ (L/72.6)^{0.35}\ (P_{30}/1.25)^{1.75}$$

where

E = the probable soil loss, in tons per acre per year,

F = a soil factor based upon the erodibility of the soil and other physical factors,

K = a cover factor, which may be the product of several factors related to the use of the land,

S = the steepness of slope, in percent (with 10 percent as the base), and

P = the rainfall. The amount used in the maximum 30-minute rainfall expected in the locality from a 2-year frequency, in inches.

The values for the soil factor, F, are obtained from a table derived directly from the measured rates of erosion, using data from all places where experiments have been conducted for five or more years (Table 1). Such a table provides a scale of values for major soils whose characteristics are widely known and serves as a basis for comparison between soils of similar physical properties to one of those that has been measured (Musgrave, 1947).

The effect of different vegetal covers upon erosion, i.e., the value of F, is obtained from the three groups shown in Table 2. Subgroups are recognized under each of these main groups of crops and cropping practices (Table 3), the magnitude of the effects varying somewhat from region to region. Hay, pasture, woodland or forest providing relatively poor cover has the full relative value of 1. When the cover is excellent, the value is .001 and intermediate degrees of protective qualities fall within these limits. The rainfall factors, P, is obtained from 2-year, 30-minute rainfall maps of the area of concern.

Universal Soil Loss Equation

The complete Universal Soil Loss Equation is:

$$A = RKLSCP$$

where

Table 1. F values for Musgrave Equation (taken from Musgrave, 1947)

Location	F Value	Soil
Geneva, N. Y.	.96	Dunkirk SCL
Zanesville, Ohio	.52	Muskingum SL
La Crosse, Wis.	.45	Fayette SL
Pullman, Wash.	.44	Palouse SL
McCredie, MO	.39	Putnam SL
Dixon Springs, Ill.	.38	Memphis like SL
Bethany, Mo.	.35	Shelby L
Marcellus, N.Y.	.32	Honeoye SL
Clarinda, Iowa	.33	Marshall SL
Blacksburg, Va.	.31	Dunmore SL
Blacksburg, VA	.31	Dunmore SL
Temple, Texas	.28	Austin C
Urbana, Ill.	.26	Carrington SL
Dixon Springs, Ill.	.21	Memphis like SL
Watkinsville, Ga.	.20	Cecil SCL
Marlboro, N.J.	.18	Collington FSL
Guthrie, Okla.	.10	Stephensville FSL (Vernon)
Statesville, N.C.	.09	Cecil SCL
Tyler, Texas	.08	Kirvin FSL
Ithaca, N.Y.	.03	Bath Flaggy SL

Table 2. Relative erosion for different covers (taken from Musgrave, 1947)

Crop	Relative erosion
Continuous row crops (principally cotton, corn, tobacco uncontoured)	100
Small grains (wheat, oats, barley, rye)	15-40
Hay, pasture, woodland and forests less than	1

Table 3. Relative amount of erosion under different vegetal covers (taken from Musgrave, 1947)

Crop or cropping practices	Relative erosion
Forest Duff	.001-1.0
Pastures, humid region or irrigated, excellent	.001-1.0
Range or seeded pasture	1.5
Range or seeded pasture (poor)	5-10
Orchards (a) Perennial cover, (b) Contoured, with winter cover crops	5
Legumes - Grass hayland	5
Crested wheat properly managed	5
Alfalfa	10
Small grain (standing or stubble)	10
Wheat fallow (stubble mulch)	10
Orchards--Vineyards (clean tilled, irrigated and contoured, not terraced)	15
Orchards--Vineyards (non-irrigated: with cover crops)	20
Wheat--Peas (stubble not burned)	20
Small grain (adverse rain at or after seeding)	40
Wheat fallow (stubble not burned)	60
Wheat fallow (stubble burned)	75
Orchards--Vineyards (non-irrigated, clean tilled, no cover crop)	90
Row crops and fallow	100

A is the computed soil loss (sheet and rill erosion) in tons per acre per year;

R, the rainfall factor, is the number of erosion--index unit computed from the characteristics of rainfall during a normal year, for a given geographical area;

K, the soil erodibility factor, is the erosion rate per unit of erosion--index for a specific soil in cultivated continuous fallow, on a 9 percent slope 72.6 feet long;

L, the slope--length factor, is the ratio of the soil loss from the field slope length to that from a 72.6 feet length on the same soil type and gradient;

S, the slope--gradient factor, is the ratio of soil loss from the field gradient to that from a 9 percent slope;

C, the cropping management factor, is the ratio of soil loss from a field with specified cropping and management, or type of vegetative cover to that from the fallow condition on which the K factor is evaluated;

P, the erosion--control practice factor, is the ratio of soil loss with contouring, stripcropping or terracing to that with straight-row farming, up-and-down slope (generally applies only to cropland).

(After SCS, 1976)

Rainfall factor (R)

The rainfall factor may be defined as $R = \Sigma EI/100$. The EI parameter (energy-intensity) is the kinetic energy of the storm rainfall in foot tons per acre inch, and I is the maximum 30 minute intensity (in/hr). Kinetic energy E, can be found using the relationship

$$E = 916 + 331 \log_{10} X$$ (Wischmeier and Smith, 1958)

The sum of the computed storm EI values for a given time period is a numerical measure of the erosivity of all the rainfall within that period. The rainfall erosion index at a particular location is the long term average yearly total of the storm EI values, and reflect the interrelations of significant rainstorm characteristics. Summing these values to compute the erosion index adds the effect of frequency of erosive storms within the year (Wischmeier and Smith, 1965). Maps of iso-erodents (R) are available for the United States, with the most accurate information being the area east of the 104th meridian (Wischmeier and Smith, 1965; Soil Conservation Service, 1975).

Soil erodibility factor (K)

The K-factor is defined as the rate of erosion per unit of erosion index from unit plots on that soil. A unit plot is 72.6 feet long, with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope (Wischmeier and Smith, 1965). The K-value can be determined either experimentally or from a nomogram based on soil properties (Figure 1). The K-value can also be obtained from SCS soil survey publications.

Topographic factor (LS)

The L and S factors may be considered independently, but in the soil-loss equation, they are combined and referred to as the "topographic" or "LS" factor. The LS factor is the expected ratio of soil loss per unit area on a field slope to corresponding loss from the basic 9-percent slope, 72.6 feet long (Wischmeier and Smith, 1965). The equation for the LS factor is:

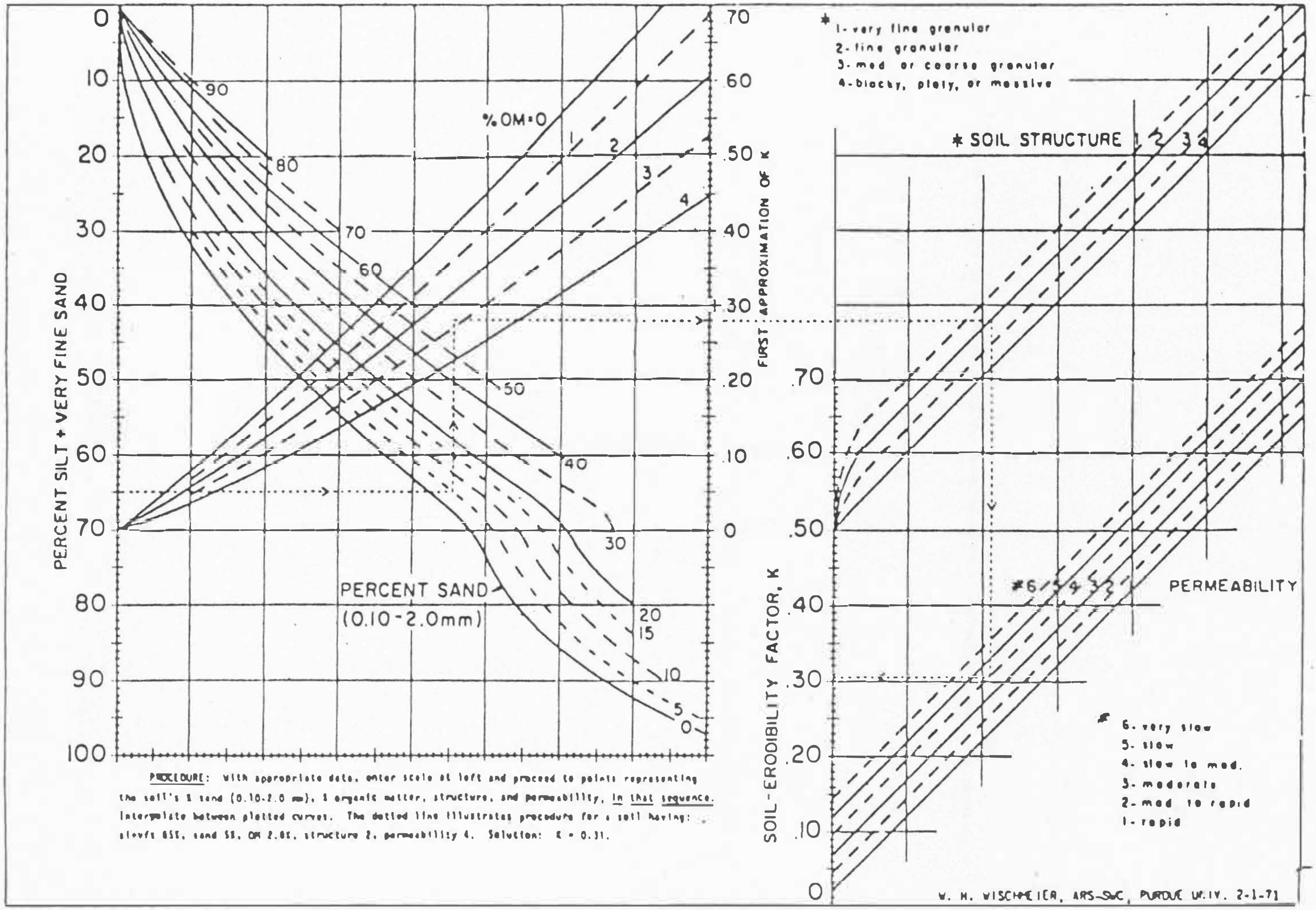

Figure 1. Nomograph for determining soil erodibility factor, K. (Taken from Wischmeier, Johnson, and Cross, 1971)

$$LS = \left(\frac{\lambda}{72.6} \right)^m \left(\frac{430\ X^2 + 30\ X + 0.43}{6.57415} \right)$$ (Wischmeier and Smith, 1965)

where

λ = field slope length in feet

X = sin θ (θ is the slope angle in degrees)

m = .5 if S $\geq$ 5% (S is the slope in percent)

.4 if S = 4%

.3 if S < 3%

The topographic factor may be computed or taken directly from the slope effect chart (Figure 2).

Cropping Management Factor (C)

The C factor is a numerical evaluation of the effectiveness of various types and qualities of cover and management as protection against the erosive forces of rainfall and runoff (Wischmeier, 1975). The evaluation for wildlands is not based on any firm research data, but instead on empirical approach developed by Wischmeier (1975) which separates the C factor into the distinct effects. The C value is then the product of these three effects:

Type I effect. Canopy Cover.--Canopy reduces erosion in that it reduces the impact energy of raindrops on the soil surface. The effectiveness of the canopy is dependent on its height and density. This effect is shown graphically in Figure 3.

Type II effect. Mulch and Close Growing Vegetation.--This effect is important since the impact energy of a raindrop on an object close to the ground will be absorbed. Also, runoff velocity is reduced by

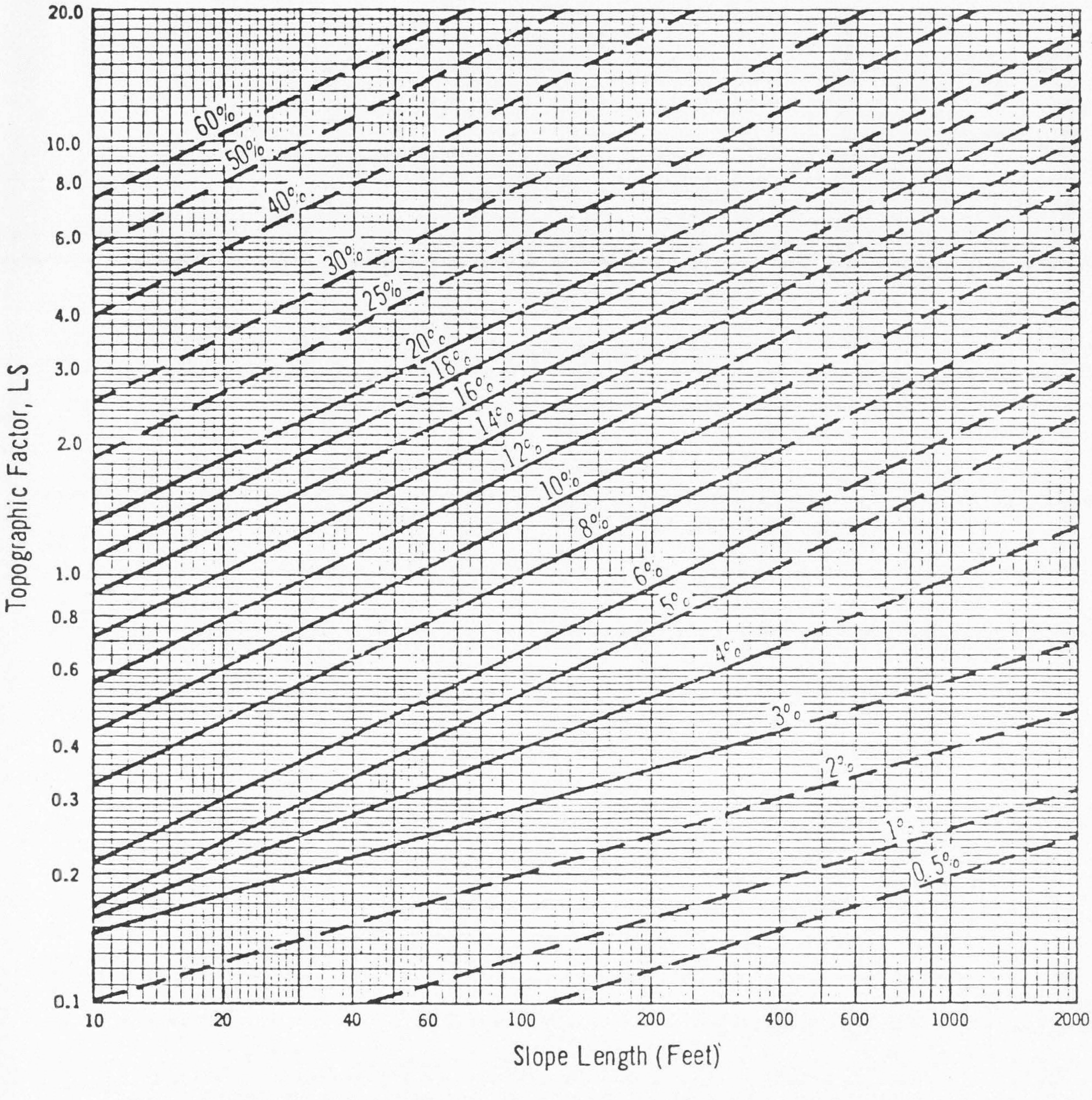

Figure 2. Slope-effect chart (topographic factor, LS) (taken from Soil Conservation Service, 1976)

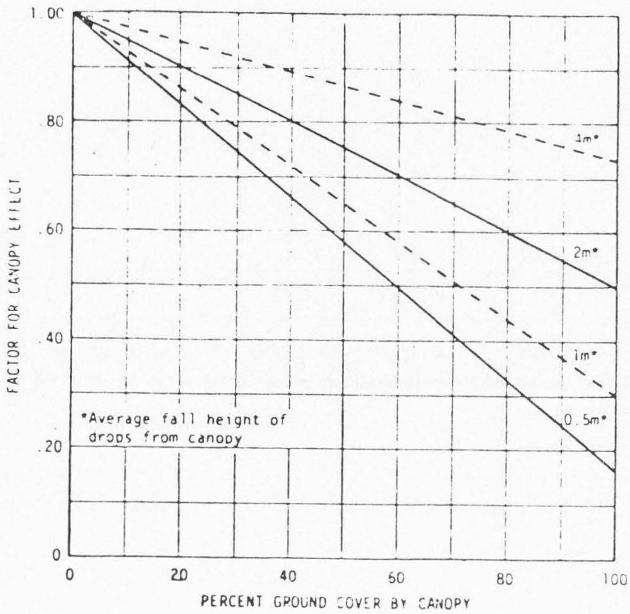

Figure 3. Influence of vegetal canopy on effective EI, assuming bare soil beneath the canopy, and based on the velocities of free-falling waterdrops 2.5 mm in diameter (Taken from Wischmeier, 1975)

mulches and close-growing vegetation. These combined effects greatly reduce the soil-loss potential. Figure 4 shows Wischmeier's (1975) estimate of these effects.

Type III effect. Residual effects of Land Use.--For wildlands, the Type III effect is a "rooting" effect due to the effect of the root network of plants classified as weeds or grasses. In short, the thick fibrous roots of grasses that are close to the surface do more to prevent soil-loss than weeds that have little lateral-root network

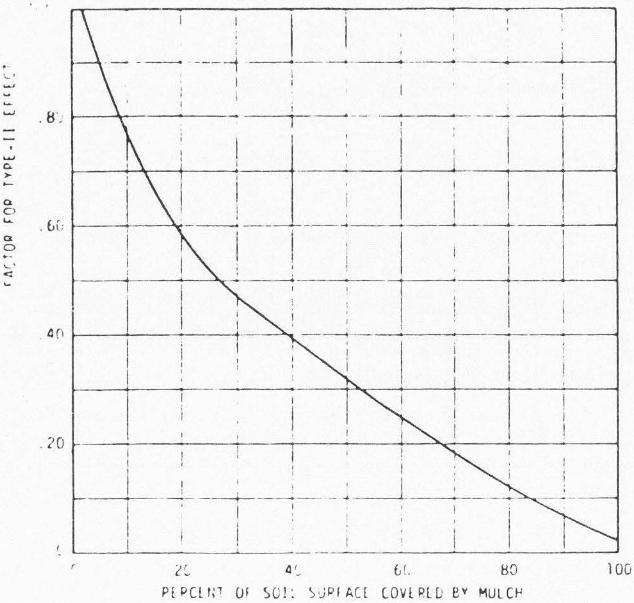

Figure 4. Effect of plant residues or close-growing stems at the soil surface on C-factor (does not include subsurface root effects) (taken from Wischmeier, 1975).

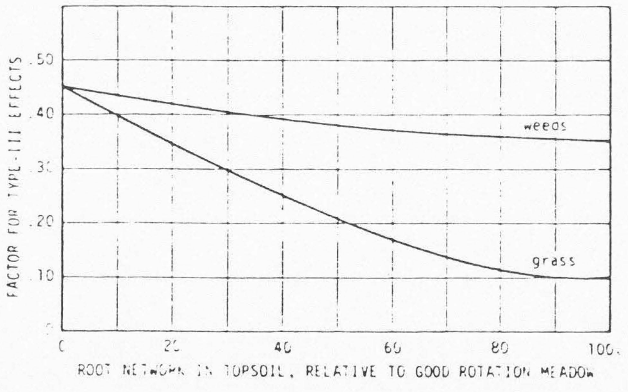

Figure 5. Type III effects of undisturbed land areas on C-factor. (Taken from Wischmeier, 1975).

near the surface. Figure 5 graphically shows the Type III effect.

The product of the Type I, Type II, and Type III effects calculated for their respective ranges in values, results in Table 4. In regard to the accuracy of Table 4, Wischmeier (1975) states:

> The C-value tables are not presented as firm research data but as the best estimates now available for use in computing the contributions of undisturbed lands to watershed sediment yield.

Erosion Control Practice Factor (P)

The P factor only applies to cropland and will not be discussed here. In wildlands, the value of P is always 1.

Accuracy

The accuracy of the Universal Soil Loss Equation is best summarized by Wischmeier (1976);

> Soil losses computed by the equation must be recognized as the best available estimates rather than as absolute data. All empirically derived prediction equations involve experimental error and potential estimation error due to the effects of unmeasured variables.
>
> The prediction accuracy of the equation was checked against 2,300 plot-years of soil loss data from 189 field plots at widely scattered locations. The published iso-erodent map, EI distribution curves, table of soil loss ratios, and slope effect chart were used to evaluate the equation factors and predict the average annual soil loss for each of the 189 plots. The predicted loss for each plot was then compared with the measured average annual soil loss for the period of research record on that plot.
>
> The mean annual soil loss for the 189-plot sample was 11.3 tons per acre. The average prediction error was 1.4 tons, and 159 of the 189 predictions

Table 4. "C" values for permanent pasture, rangeland and idle land 1/ (taken from Soil Conservation Service, 1976)

Vegetal Canopy			Cover that Contacts the Surface					
Type and Height of Raised Canopy 2/	Canopy Cover 3/ %	Type 4/	Percent Ground Cover 0	20	40	60	80	95-100
Column No.	2	3	4	5	6	7	8	9
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.10	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

1/ All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists.

2/ Average fall height of waterdrops from canopy to soil surface: m = meters.

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

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface, and/or undecayed residue.

> (84 percent) were within 2 tons of the measured losses. About 5 percent of the predictions differed from the measured losses by a little more than 4.5 tons (40 percent of the overall mean). Significantly, however, two-thirds of the 88 deviations that exceeded 1 ton were from comparisons with soil loss records short enough to represent less than half of a normal 20- to 22 year rainfall cycle. They were probably biased by cyclical effects as a result. When its factors are evaluated from the tables and charts, the equation predicts the average annual loss for a 22-year rainfall cycle.

Modified Universal Soil Loss Equation

A modified version of the Universal Soil Loss Equation was developed by the Utah Water Research Laboratory (1976) for predicting soil loss due to water erosion on highway construction sites, and for determining the effectiveness of various erosion control measures. This equation is of the form:

$$A = RKLSVM$$

in which,

A = computed amount of soil loss per unit area for the time interval represented by factor K, generally expressed as tons/acre/year,

R = rainfall factor (same as for original Universal Soil Loss Equation).

K = soil erodibility factor (same as for Universal Soil Loss Equation).

LS = topographic factor (length and steepness of slope)

VM = erosion control factor (vegetative and mechanical measures).

Topographic Factor (LS)

The LS factor is of the same basic form as the LS factor from the Universal Soil Loss Equation except for some slight modifications. The equation for the LS factor is:

$$LS = \left(\frac{0.43 + 0.35 + 0.43S^2}{6.613} \right) \left(\frac{\lambda}{72.6} \right)^m \left(\frac{10,000}{10,000 + S^2} \right)$$

in which

LS = topographic factor,

λ = slope length in feet,

S = slope steepness in percent, and

m = exponent dependent upon slope steepness

i.e., $m = .3$ for $S < 0.5\%$

$m = .5$ for $.5 < S < 10\%$

$m = .6$ for $S > 10\%$

Erosion Control Factor (VM)

The VM factor is applied in the equation as a single unit and accounts for the effects of all erosion control measures that may be implemented on any particular construction site. These effects include vegetation, mechanical manipulation of the soil surface, chemical treatments, etc. However, in wildlands, the VM factor uses the same values as the C factor in the original Universal Soil Loss Equation.

METHODS AND MATERIALS

Introduction

This study is based on data from 2805 simulated rainfall plots which were collected by other researchers (Table 5). The data were gathered from various rangelands in Utah, Idaho, Nevada, and Australia and consists of a variety of rangeland communities, soils, slopes, rainfall intensities and geographic locations. The diversity in data made it an excellent source on which to test erosion equations under many different conditions. A Rocky Mountain infiltrometer (Dortignoc, 1951) was used by most of the researchers to collect their data. The Rocky Mountain Infiltrometer uses a 2.5 ft^2 (.23 m^2) plot and simulates high intensity rainfall 3.0 in/hr (7.5 cm/hr) or greater. The other rainfall simulators used were:

1. A modular-drip type described by Blackburn et al. (1974) which has a plot size of 9 ft^2 (.836 m^2) and can vary rainfall intensities from .2 in/hr to 3.3 in/hr.

2. A modular-drip type [patterned after Meeuwing (1971) and described by Malekuti (1975)] designed especially for use on steep slopes and bare soils which utilized a 4 ft^2 (.371 m^2) plot and 3 in/hr (7.6 cm/hr) intensities. Runoff was measured at selected time intervals during 23 to 60 minute runs. Sediment was measured by collecting the total runoff and sediment from each plot and letting the water evaporate off. The sediment remaining was then oven-dried and weighed.

Table 5. List of data sources.

Data Source	Number of Plots
Australia	355
Nevada	
Wet plots	448
Dry plots	448
P-J Grazing	696
Sagebrush (Idaho)	279
Mine Sites	251
P-J Chaining	460
Geologic Types	147

Brief Description of Data Sources

Australia rangeland communities

Gifford (1976) studied infiltration and sediment production in the northern territory Australia, near Alice Springs. The study was conducted under antecedent moisture conditions, with surface soils at field capacity, with surface crust scalped off under antecedent moisture conditions, and with surface crust scalped off with soils at field capacity. A brief description of the plant communities (Table 6) is given by Gifford (1976). A Rocky Mountain Infiltrometer was used to collect the data, all of which were on gentle slopes.

Table 6. Description of Australia rangeland communities.

Plant Community	Symbol	Dominant Plant Life Forms	Surface Soil Description	Slopes
Mulga-perennial grass scrubland	MPG	Shrubby mulga (<u>Acacia</u> spp.) associated with perennial grasses and shrubs. Occurs in groved and ungroved patterns.	Neutral to acid red earths, sandy loam to sandy clay loams.	Slight (1:250) to flat
Mulga-shortgrass scrubland	MSS	Mulga (usually ungroved) with annual shortgrasses, forbs, and shrubs.	Neutral red earths, sandy loam to sandy clay loam.	Slight
Low-open-woodland	WDL	Sparse low trees over short grasses and forbs, and some shrubs.	Non-calcareous earthy sands, generally deep, clayey sand or loamy sand.	Slight
Floodplain	FLP	Short-lived short-grasses and forbs.	Neutral to slightly alkaline, loamy sand to loam.	Flat
Scald	SLD	Devoid of vegetation.	Surface soil removed by wind and water, leaving a hand-setting vesicular crust.	Slight
Gilgai	GLG	A mosaic pattern is characterized by depressions (perennial grasses and forbs) and interspaces (forbs).	Red, alkaline, cracking clays, interspaces contain more stones	Flat
Bluebush	BLB	Shrubby <u>Kochia</u> spp. and forbs	Stone-covered calcareous loams over calcareous blocky clays.	Flat to gentle slopes.

Data from Gifford (1976).
(Taken from Jaynes, 1977).

Table 7. Nevada rangeland communities.

Plant Community[1/]	Symbol
Black sagebrush/Shadescale saltbrush	SBS
Big sagebrush	BSG
Big sagebrush/rubber rabbitbrush	BSR
Douglas rabbitbrush	DRB
Douglas rabbitbrush/winterfat	DRW
Utah juniper	UJP
Single-leaf juniper/Utah juniper	PUJ
Big sagebrush/bluebunch wheatgrass/balsamroot	SWB
Big sagebrush/Sandberg bluegrass/phlox	SBP
Pinyon-juniper/low sagebrush/sandberg bluegrass	PJS
Crested wheatgrass	CWG
Big sagebrush/sandberg bluegrass/arrow leaf balsamroot	BSA
Pinyon-juniper/black sagebrush	PJB
Big sagebrush/snowberry	BSS
Snowberry/big sagebrush/bluebunch wheatgrass/ Wooly Wyethia	SSW

[1/] Scientific names of plant species are in Appendix A.

Specific data on rainfall application rates, plant cover, and sediment production were available for applicability to the equations.

Nevada rangeland communities

Blackburn (1973) studied infiltration rates and sediment production in 28 plant communities and soils of five watershed areas in central and eastern Nevada. Fifteen of these plant communities were used for this study (Table 7). Simulated rainfall from a drip type infiltrometer (Blackburn et al., 1974) with application rates of 3 inches per hour and 1.5 inches per hour and durations of 30 minutes and 60 minutes, respectively was used for the study. Two different soil moisture conditions were used, soil initially air dry and soil initially at field capacity. The data included all the necessary information needed to accurately compute each equation.

Grazing study on chained and unchained Pinyon-Juniper site in southeastern Utah

Busby (1977) carried out a research project to determine the effect livestock grazing had on infiltration and erosion rates of unchained, debris-in-place, and windrowed pinyon-juniper sites. The study area was located near Blanding, Utah and is a pinyon-juniper woodland community, with sandy-loam soils and gentle slopes. The vegetation-grazing conditions were as follows (after Busby, 1977):

1. Unchained Woodland
    a. Grazing not excluded
    b. Grazing excluded 1967

c. Grazing excluded 1969

d. Grazing excluded 1971

2. Debris in Place (DIP)

a. Grazing not excluded

b. Grazing excluded 1967

c. Grazing excluded 1969

d. Grazing excluded 1971

3. Windrowed

a. Grazing not excluded

b. Grazing excluded 1967

c. Grazing excluded 1971

Treated areas were seeded with crested wheatgrass. A Rocky Mountain infiltrometer was used and soils were prewet to field capacity. Some of the available information was lacking specific soil and slope data, however, most of it had all the necessary values needed for this study.

Infiltrometer studies on a plowed big sagebrush site

Gifford and Busby (1974) did an intensive infiltrometer study over a 4-year period (1968-1972) on a plowed big sagebrush site near Holbrook in southern Idaho. The slopes of the area are gentle with a south aspect and the soils are a silty loam underlain by a basaltic material. The principle plant species before treatment included big sagebrush, Sandberg bluegrass, squirreltail, Idaho fescue, brown snakeweed, small rabbitbrush, bluebunch wheatgrass, and snowleaf balsamroot. After treatment (September, 1968) principle plant species included crested wheatgrass, cheatgrass, alfalfa, intermediate wheatgrass, broom snakeweed and small rabbitbrush. A Rocky Mountain infiltrometer was used for the study and all plots were prewet before the runs began. Specific values for rainfall application rates, plant cover, and sediment production were available.

Infiltration studies on mine spoils and tailings

Infiltration and sediment production data were collected by Burton (1976) and Thompson (1977) on a wide variety of mine spoils and tailings in various locations in Utah (Table 8). Data were collected on both flat and steep slopes on various exposures under antecedent moisture conditions. The infiltrometer used was one patterned after Meeuwig (1971) and described by Malekuti (1975); it was designed especially for steep slopes and bare soils. Except for a few sites, vegetation was nonexistent. The mine spoils data contained all necessary information needed to solve the erosion prediction equations.

Infiltration and erosion studies on pinyon-juniper conversion sites in central and southern Utah

Research to gather information concerning infiltration rates and sediment production from converted and untreated pinyon-juniper sites in central and southern Utah was carried out by Williams et al. (1969), Gifford et al. (1970), and Williams (1969) on 28 sites near Price, Eureka, Blanding, and Milford (Table 9). All plots were prewet and a

Table 3. Site characteristics for mined areas in Utah.

Mining Site	Symbol	% Soil > 2mm	Texture of Soil <2 mm	% Slope
Sampled in 1975				
Five Mile Pass	FMP	44	Clay loam	70 (16)[1/]
Lewiston Canyon	LEW	--	Silt loam	21[2/]
Golden Gate	GOL	36	Sandy loam	(2)
Silver City	SIL	56 (15)	Silt loam	73 (19)
Sunrise	SUN	70	Clay-sandy loam	68
Spor Mountain	SPR	63	Sandy loam	82
Brush Beryllium	BRU	18	Sandy clay	55 (13)
Keystone Wallace	KYW	4	Silt loam	27
Old Hickory	OLD	58	Sandy loam	74
Bowana Copper	BOW	62	Sandy loam	5
Rattlesnake Ranch	RAT	21	Clay loam	61
Fry Canyon	FRY	22	Silt loam	88
White Canyon	WHT	60	Silt loam	68 (7)
Dutchman Flat	DUT	26	Silt loam to clay	61
Alta, Upper Emma	ALU	52	Sandy loam	64
Alta, Parking Lot	ALP	47	Sandy loam	74
Alta, Bel Vega	ALB	63	Silt loam	79
Pacific	PAC	57 (45)[2/]	Sandy loam	65 (11)[2/]
Stubbs Clay	STU	43	Silty clay	55 (13)
Mill Creek	MLC	63	Sandy loam	80
Kimberly, South	KMS	33	Sandy loam	16
Kimberly, North	KMN	33	Sandy loam	16
Box Creek Clay	BOX	43	Sandy clay loam	63 (14)[3/]
Hiawatha	HIA	72	Sandy loam	9
Old Frisco	FRS	50 (39)[2/]	Clay loam	76 (56)[2/]
Castle Gate	CAS	45	Sandy loam	50
Stauffer, S.E.	STS	61	Clay loam	20
Stauffer, N.W.	STN	67	Loam	12
Sampled in 1976				
Five Mile Pass	FML	49	Silty clay	39
Mercur	MCR	0	Clay loam	10
Chief #1	CHF	68 (58)	Sandy loam	101
Scofield	SCO	44 (35)	Sandy clay loam	60 (5)
Joe's Valley	JOE	51	Loamy sand	60
Henifer	HEN	40	Sandy clay loam	72
Rock Candy Mtn.	RCM	61	Sandy loam	55
Marysvale	MAR	77 (50)	Sandy loam	63 (17)
Bullion Canyon	BUL	70	Sandy loam	58
Milford	MIL	45	Loamy sand	45
King David	KND	51	Sandy loam	55

Table 8. Continued.

Mining Site	Symbol	% Soil > 2 mm	Texture of Soil < 2 mm	% Slope
Geneva	GEN	58 (36)	Sandy loam	59 (5)
Upper Marysvale	UPM	58	Sandy clay loam	54
Firefly	FRF	33	Sandy loam	66
Vanadium Queen	VAN	46	Sandy loam	79
Natural Bridges	NAT	41	Clay loam	59
Dog Valley	DOG	50	Sandy clay loam	78
Utah International	UTI	70 (75)	Sandy loam	81 (5)
Keefer Wallace	KEW	39 (49)	Sandy clay loam	48 (6)
Cedar City Canyon	CCC	44 (48)	Sandy loam	60 (5)

Date from Burton (1976) and Thompson (1977). (Taken from Jaynes, 1977)

1/ Numbers in parentheses apply to spoils topography designated as relatively "flat."

2/ Tailings.

3/ Stockpile.

Table 9. List of study sites for chained and unchained pinyon-juniper communities in central and southern Utah.

Location	Site	Symbol
Price	Pinnacle Bench	PB
	Coal Creek	CC
	Wood Hill	WH
	West Huntington	HN
Blanding	Brush Basin	BB
	Alkali Ridge	AR
	Area 149	149
Eureka	Boulter	BR
	Government Creek	GC
	Fry Canyon	FC
	Beaver	BR
Milford	Indian Peaks	IP
	Jockeys	JY
	Arrow Head Mine	AM

Data from Williams (1969)

Rocky Mountain infiltrometer was used to simulate high intensity rainfall. Slopes of all the study sites were gentle and the soils were entisols, aridisols, and mollisols. All values needed to solve the erosion prediction equations were able to be extracted from this study data.

Infiltration and erosion study on
different geologic types,
Price Basin

During 1974 and 1975 a diffuse source salinity study was conducted in the Price River Basin, Utah (Ponce, 1975). Data was collected from 26 different sites on 14 different geologic rock types (Table 10). All infiltrometer runs were made with a Rocky mountain infiltrometer on 10 percent slopes. Soils of the area are mainly derived from sedimentary rocks and glacial outwash. Principle plant communities are subalpine forest and big sagebrush with a mixture of pinyon juniper shadescale, and greasewood. Detailed soil data were not available, but soil descriptions were; otherwise all data were complete for the purpose of this study.

Data Analysis

The 2805 plots were systematically organized so that specific questions could be answered regarding each equation. The questions to be answered concerned the accuracy of the equations in the following situations:

1. All 2805 plots pooled
2. Each data source

Table 10. Different geologic types for salinity study.

Geologic Type	Brief Description
A. Mancus shale members	
1. Masuh (M)	gray, marine shale
2. Blue gate (BG)	light gray, calcareous marine shale
a. Upper BG (UBG)	
b. Middle BG (MBG)	
c. Lower BG (LBG)	
3. Tununk (T)	gray marine siltstone and claystone
4. Mancus Undivided (MUD)	
B. Cedar Mountain (CM)	modular shale with fluvial sandstone beds
C. Alluvial Deposits (AD)	gravel surfaces, mainly terraces and pediments undergoing erosion
D. Gravel Caps (GC)	gravel surfaces
E. Black Hawk Fm (BH)	Sandstones
F. Price River Fm (PR)	Series of interbedded sandstone and mudstone
G. North Horn Fm (NH)	Varigated shales with lenses of sand-stone and fresh-water limestone
H. Colton Fm (C)	Fluvial red beds with channel sandstones
I. Green River Fm (GR)	Lacustrine shale and siltstone with numerous fossils and oil shale

Data from Ponce (1975)

3. effect of different antecedent moisture conditions
4. effect over time
5. effect of different plant communities
6. effect of different geologic types
7. mine sites
8. effect of different application rates
9. effect of treated versus untreated big sagebrush
10. effect of treated versus untreated pinyon juniper

In order to evaluate the above situations, data from the total number of plots were selected that would pertain to each specific question as outlined above. This is illustrated in Figure 6. The data were then further subdivided or pooled as was necessary to evaluate a specific effect as will be explained in the results.

Each equation was computed by substituting the "best available numbers" for its factors. The "best available numbers" were arrived at by determining a factor value as objectively as possible from the directions in the literature given for the use of each equation. If specific values were not available from the researchers (for instance, slope gradient or soil particle size), then a value was estimated from descriptions of the study areas and personal communication with the researcher.

Each equation was computed for each plot and this predicted sediment yield could then be compared with the observed sediment yield (converted to tons per acre) from the same plot. The comparison took place in two ways:

1. Computing the ratio of predicted/observed erosion.

DATA

SITUATION	AUSTRALIA	NEVADA	MINE SITES	P-J GRAZING	SAGEBRUSH (IDA.)	GEOLOGIC TYPES	P-J CHAINING	POOLED
ANTECEDENT MOISTURE	WET DRY	FIELD CAPACITY AIR DRY			PRE-WET		PRE-WET	AUSTRALIA(WET)+ NEVADA(WET) AUSTRALIA(DRY)+ NEVADA(DRY)
TIME	2 SAMPLING DATES -SEPT. -NOV.							
PLANT COMMUNITIES	5 DIFFERENT PLANT COMMUNITIES	16 DIFFERENT PLANT COMMUNITIES		P-J (UNTREATED)	BIG SAGEBRUSH (BEFORE PLOWING)		P-J (UNTREATED) 14 SITES	P-J (CHAINING) + BIG SAGEBRUSH (NEV.)
GEOLOGY						13 DIFFERENT GEOLOGIC FORMATIONS		
SPOILS AND TAILINGS			58 DIFFERENT SITES					
APPLICATION RATES		3 IN./HR. FOR 1/2 HR. 1 1/2 IN./HR. FOR 1 HR.						
PLOWED BIG SAGEBRUSH					12 DIFFERENT SAMPLING PERIODS AFTER PLOWING			
PINYON - JUNIPER (UNTREATED)				GRAZING PRIOR TO 1967 GRAZING EXCLUDED IN: 1967, 1969, 1971				
TREATED PINYON-JUNIPER (WINDROWED)				GRAZING PRIOR TO 1967 GRAZING EXCLUDED IN: 1967, 1971				
TREATED PINYON-JUNIPER (DEBRI IN PLACE)				GRAZING PRIOR TO 1967 GRAZING EXCLUDED IN: 1967, 1969, 1971				

Figure 6. Data source - situation matrix.

2. Computing the coefficient of determination (R^2) and F-value for each group of data that pertains to a specific situation.

The number of ratios of predicted/observed that fit in a particular interval was tallied and frequency diagrams were made for each equation for all plots pooled. This was done to give an overall picture of the predictability of the three equations.

The R^2 and F values were used from all plots pooled down to the smallest subdivisions in order to determine how much variability each equation explains for a certain situation.

The correlation elements (r) between the measured sediment yield and each independent variable (i.e., the R, k, L, S, and C factors) was also computed in order to determine how much each independent variable contributes in predicting sediment yield.

Computation of Equations

Modified Musgrave Equation

The original Musgrave Equation, as a described earlier, could not be used in this study because accurate values for all of its factors aren't defined. But, it was of interest to see if a modification of the original Musgrave equation could be of value for predicting sediment yields on rangelands. The modified Musgrave Equation as used here is:

$$A = RK\ (C/100)\ (S/10)^{1.35}\ (L/72.6)^{0.35}$$

where:

A = the probable soil loss, in tons per acre,

R = the rainfall factor (from the Universal Soil Loss Equation)

K = soil erodibility factor (from Universal Soil Loss Equation)

C = a cover factor

S = the slope steepness in percent, and

L = the slope length in feet.

The difference between this modification and the original Musgrave Equation is the replacement of $(P_{30}/1.25)^{1.75}$ with R and the replacement of F with K.

P_{30} could not be used in predicting sediment yields on a per-storm basis since it is the value of the 2 year - 30 minute storm. However, the R-value from the Universal Soil Loss Equation could be computed for a single storm which will be explained later.

As can be seen from Table 1, the soil factor, F, from the Musgrave is given for specific soils only. In order to compute the equation for all the areas covered in this study, a better means of computing the soil factor is called for. Such a means is the K-factor from the Universal Soil Loss Equation which can be determined from the nomograph of Wischmeier, Johnson, and Cross (1971)

Universal Soil Loss Equation

The Universal Soil Loss Equation (see Literature Review) was used without any changes, i.e., as prescribed by the Soil Conservation Service (1976) and Agricultural Research Service (1971) without any personal interpretations. The equation was used on a per-storm basis (Agricultural Research Service, 1971) using the procedure given by its developers.

Highway Construction Erosion Prediction Equation

Even though this equation is very similar to the Universal Soil Loss Equation, the changes in the LS factor may be an improvement over the USLE in wildland situations. Other than the LS factor, all other factors in the two equations have the same values.

Computation of individual factors

R-factor

The rainfall erodability factor (R), is the number of erosion-index units computed from the characteristics of rainfall during the period in which sediment yield is predicted. It is common to the above three equations and has the same value for each. As was mentioned in the Literature Review,

$$R = \frac{E \times I}{100}$$

where:

E = the total kinetic energy of a storm in foot-tons per acre inch,

I = the maximum 30-min intensity of the storm.

In computing the R-factor, two cases had to be considered depending on the data: (1) data collected with a Rocky Mountain infiltrometer in which the rainfall intensity changed throughout the run, and (2) data collected with a modular-drip type infiltrometer in which the rainfall intensity was held constant.

Case 1. Rainfall intensity data from the Rocky Mountain infiltrometer was collected at intervals from 0-3, 3-8, 8-13, 13-18, 18-23, and 23-28 minutes. The maximum 30-minute intensity, I, in this case, was taken to be the weighted average intensity of the five intervals that make up the 28 minute period. The rainfall energy parameter, E, was figured by summing up the computed kinetic energy for each time period. This was accomplished as follows:

1. Compute kinetic energy (K.E.) for each interval from the Wischmeier and Smith (1958) regression equation

$$Y = 916 + 331 \log_{10} X$$

where

Y is K.E. in foot-tons per acre inch, and

X is rainfall intensity in inches per hour

2. Multiply Y for each interval by the rainfall amount in inches to give K.E. in foot-tons per acre.

3. Sum the K.E. from (2) to give the E-value for the simulated storm.

The above 3-step procedure can be summarized in one equation of the form:

$$E = \sum_{i=1}^{n} [(916 + 331 \log_{10} X_1) (X_1 * T_1)] +$$

$$[(916 + 331 \log_{10} X_2) (X_2 * T_2)] + . .$$

$$. . + [(916 + 331 \log_{10} X_i) (X_i * T_i)]$$

where:

E = total kinetic energy for the simulated storm in foot-tons per acre,

X = rainfall intensity in inches per hour,

T = time interval in which intensity was determined, and

n = the number of intervals in which intensity was determined.

Case 2. The modular and drip type rainfall simulators operate at a constant intensity which simplifies the computation of E and I. I is just the intensity in which the run was made and

$$E = (916 + 331 \log_{10} X) (X * T)$$

where E = total kinetic energy for the simulated storm in foot-tons per acre,

X = rainfall intensity in inches per hour, and

T = the time interval for the complete run.

The R-value was adjusted to compensate for the difference between natural and simulated rainfall. This was necessary because the three equations evaluated in this study are based on data from natural rainfall and the measured sediment from the infiltrometer plots is a result of action by simulated rainfall. A reliable parameter for comparing simulated rainfall to natural rainfall was provided by Meyer (1965). Since the kinetic energy of a rainstorm is proportional to rainfall erosivity,[3] the ratio of the kinetic energy of a simulated rainstorm to that of a natural rainstorm would be the relative erosivity of simulated to natural rainfall: (1) drop diameter, and (2) velocity upon impact. However, drop diameter is not a concern here since it is directly proportional to the mass of a raindrop and the mass of the accumulated raindrops (rainfall amount) is the same for both simulated

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[3]Rainfall erosivity is power or property of rainfall to erode a particular material (soil in this case).

and natural rainfall. This leaves only the ratio of the velocities squared as a parameter for comparing simulated to natural rainfall. Mathematically, the above discussion is:

$$\text{Relative erosivity} = \frac{M_s V_s^2}{M_N V_N^2} = \frac{\text{K.E. of simulated rainfall}}{\text{K.E. of natural rainfall}}$$

where

M_s = mass of the simulated rainfall,

V_s = velocity of the simulated rainfall,

M_N = mass of the natural rainfall, and

V_N = velocity of the natural rainfall

But, $M_s = M_N$

Thus,

$$\text{Relative erosivity} = \frac{V_s^2}{V_N^2}$$

Relative erosivity for the Rocky Mountain infiltrometer. A value of .43 was used as the relative erositivity ratio between the Rocky Mountain infiltrometer (Type "F" nozzle) and natural rainfall. This can be verified by consideration of the velocities (mean drop size diameter) upon impact of natural and simulated rainfall. The mean drop diameter of a raindrop from a Type-F nozzle is approximately 3.7 mm (Figure 7) and would have an impact velocity of 19 feet per second (Figure 8) with an average fall height of 7 feet (Dortijnac, 1951). Natural raindrops, with a mean drop size diameter of 3.7 mm, would have a terminal velocity (and impact velocity) of 29 feet per second (Figure 9),

$$\text{Relative erosivity} = \frac{V_s^2}{V_N^2} = \frac{(19)^2}{(29)^2} = .43$$

Relative erosivity for modular infiltrometer used in mine studies. The infiltrometer used by Burton (1976) and Thompson (1977) was such that the impact velocity of the simulated raindrops upon impact was 14 feet per second for the 3 inch per hour intensity with which it was operated (Burton, 1976). Terminal velocity for natural rainfall with an intensity of 3 inches per hour is 26.2 feet per second (Figure 10 and Figure 9). So,

$$\text{Relative erosivity} = \frac{V_S^2}{V_N^2} = \frac{(14)^2}{(26.2)^2} = .28$$

Relative erosivity for modular infiltrometer used in Nevada rangeland studies. The terminal velocity of the infiltrometer as used by Blackburn (1973) was described by Blackburn, et al. (1976) to be 70 percent of terminal velocity when the simulated raindrops fall from a height of 7 feet. Thus,

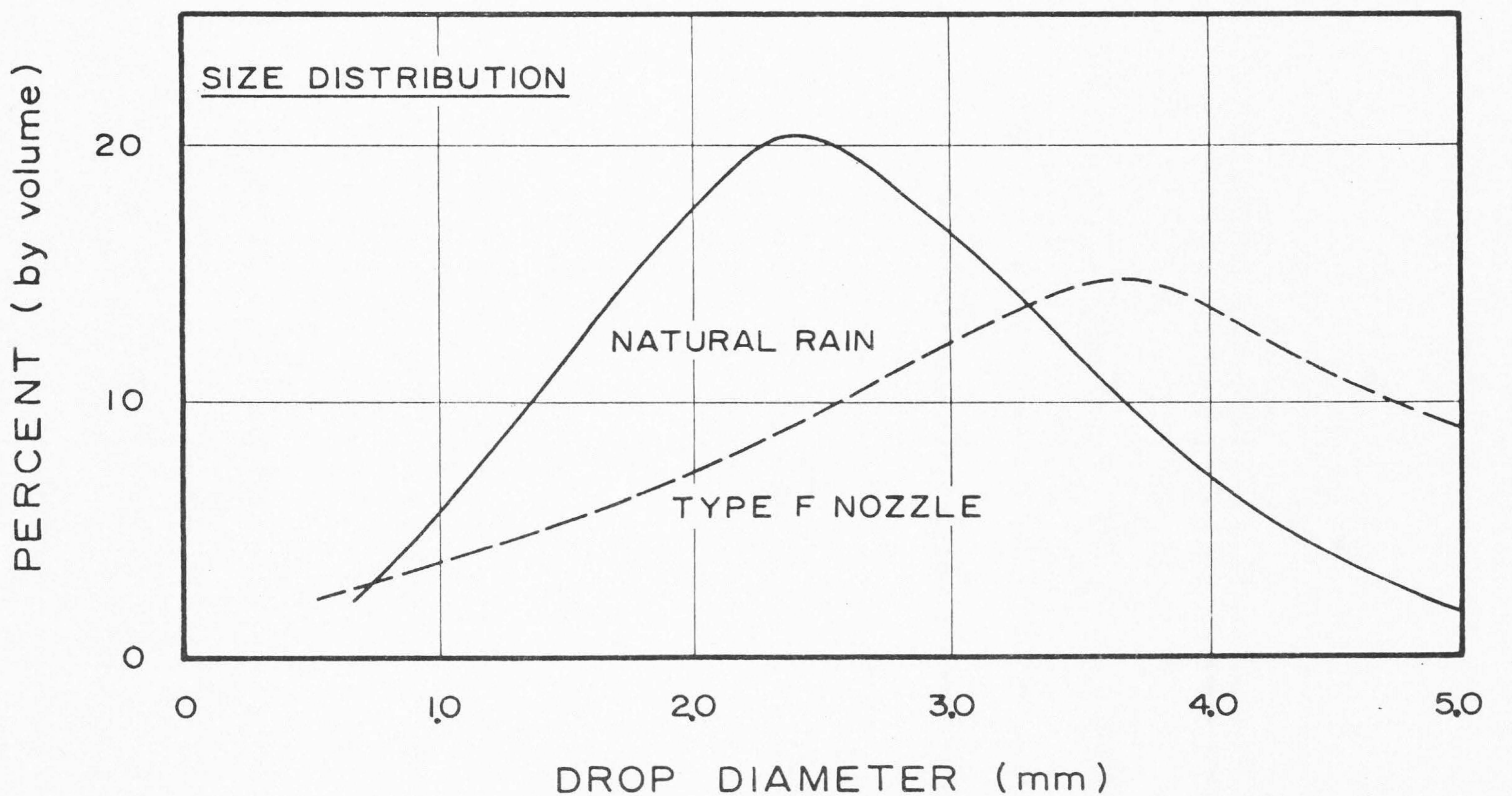


Figure 7. Physical characteristic of natural raindrops as compared with simulated raindrops from Type F nozzle (taken from Meyer and McCune, 1958).

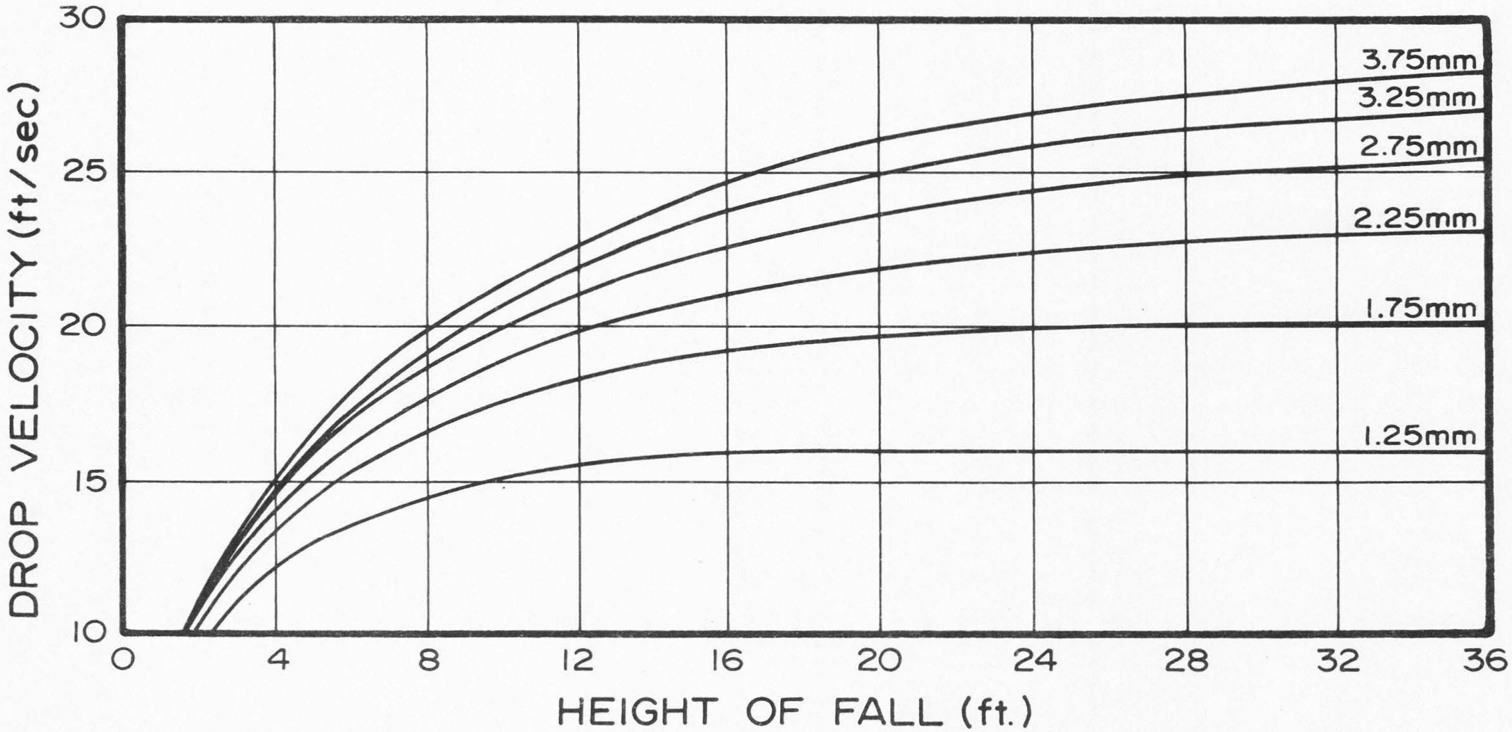


Figure 8. The relationship of drop velocity to the height fallen from zero velocity for various drop sizes (taken from Meyer 1958).

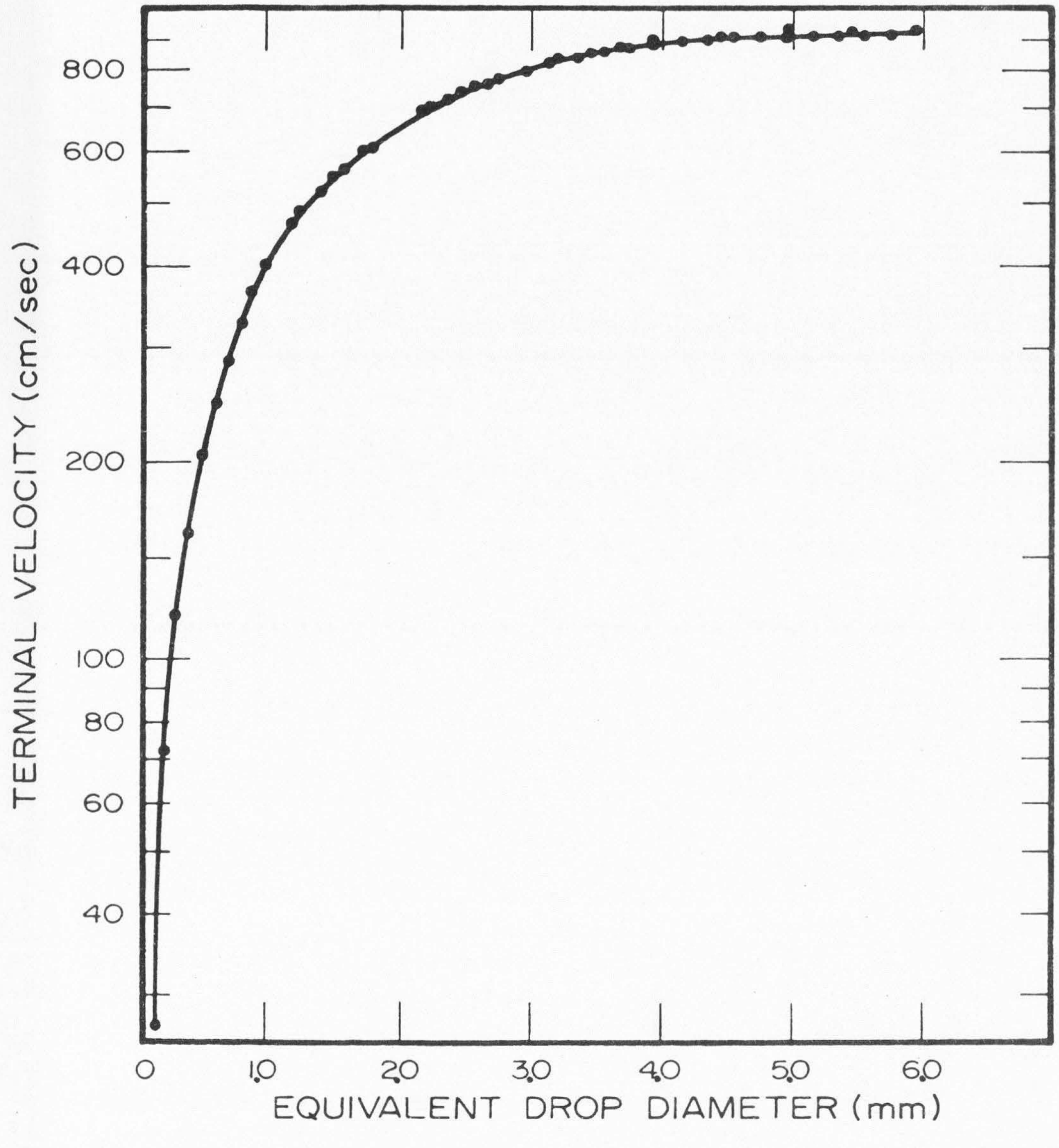


Figure 9. Terminal velocities of water-drops of different sizes in stagnant air (taken from Wischmeier, 1958).

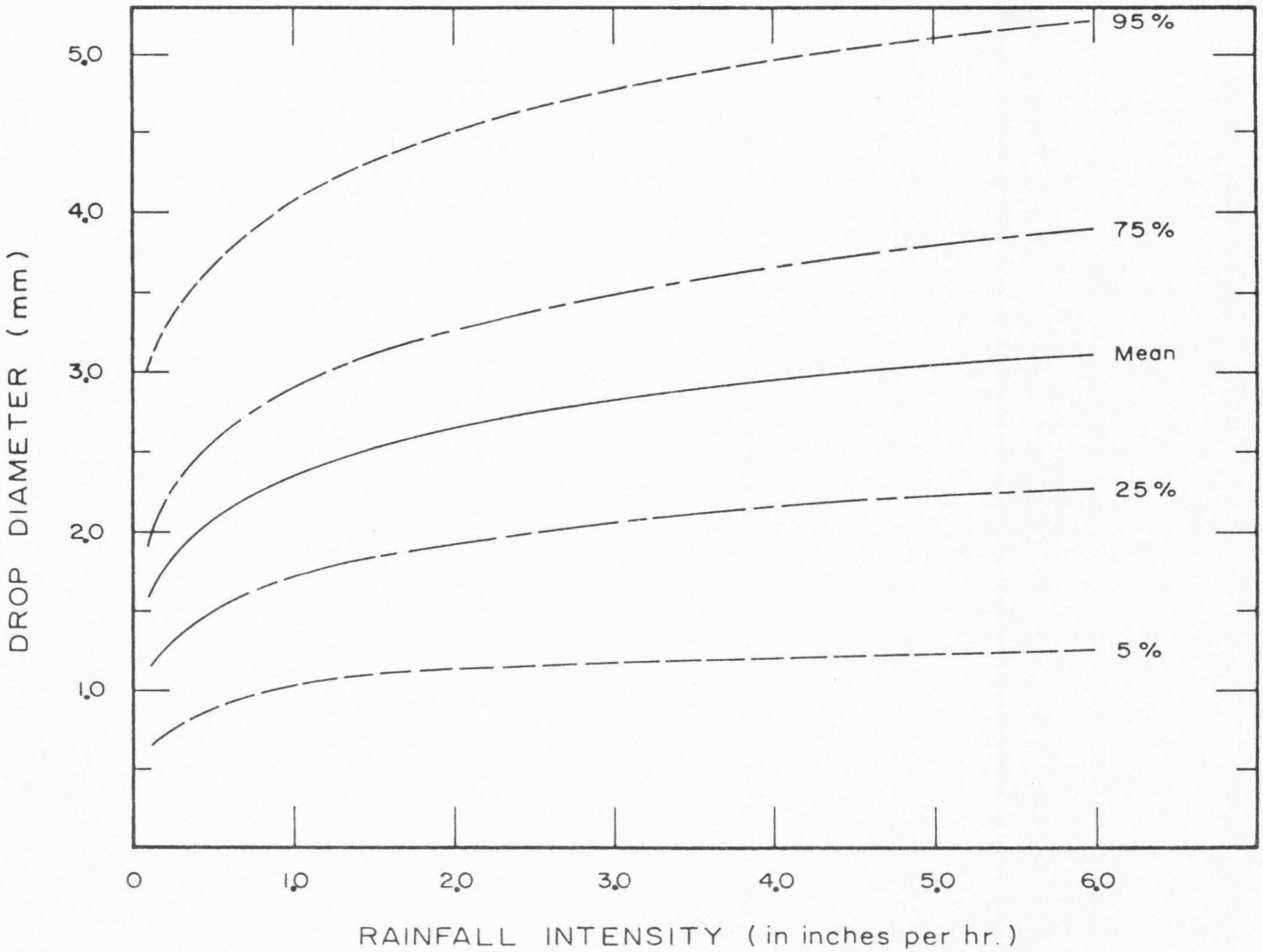


Figure 10. Drop size distribution of natural rainfall (taken from Wischmeier and Smith, 1958).

$$\text{Relative erositivity} = \frac{V_S^{\,2}}{V_N^{\,2}} = (.70)^2 = .49$$

K-factor

The K factor (used in all equations) was determined directly from the soil erodibility nomograph (Figure 1). Most of the data used in this study included percent sand, silt, clay, organic matter and infiltration rates, all of which are needed to solve the nomograph for K. The percent silt and very fine sand parameter on the nomogram was estimated by utilizing the guidelines presented by Erickson (1973). Permeability class was determined by fitting the infiltration constant to Table 11.

Some of the data did not include a particle size analysis. "K" values were then estimated from the textural class of the soil by using Erickson's guidelines (1973).

LS-factor

The LS factor is different for each erosion prediction equation, but, values for L and S are the same. For the slope length, L, the length of the infiltration plot was used. S, the slope gradient, was taken directly from the data, or in a few cases, from personal communication with the researcher who collected the data.

C-factor

The C-factor for the Universal Soil Loss Equation and the modified Universal Soil Loss Equation is the same. The Utah Water Research Laboratory (1976) has taken Table 4 , "C" values for permanent pasture, rangeland, and idle land, and put it in graphical form for ease of use

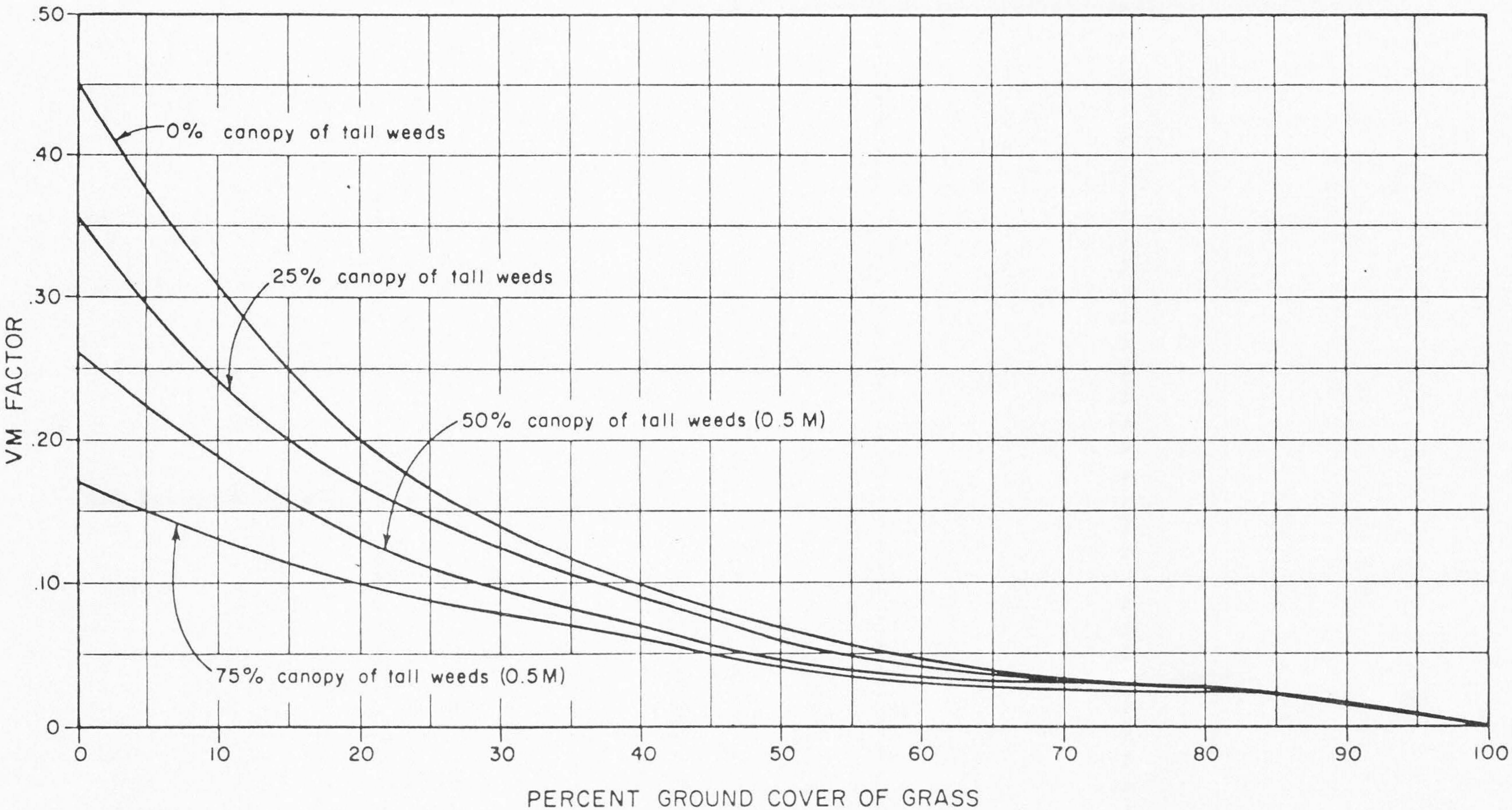


Figure 11. Relationship between grass density and VM or C factor. (Taken from Utah Water Research Laboratory, 1976)

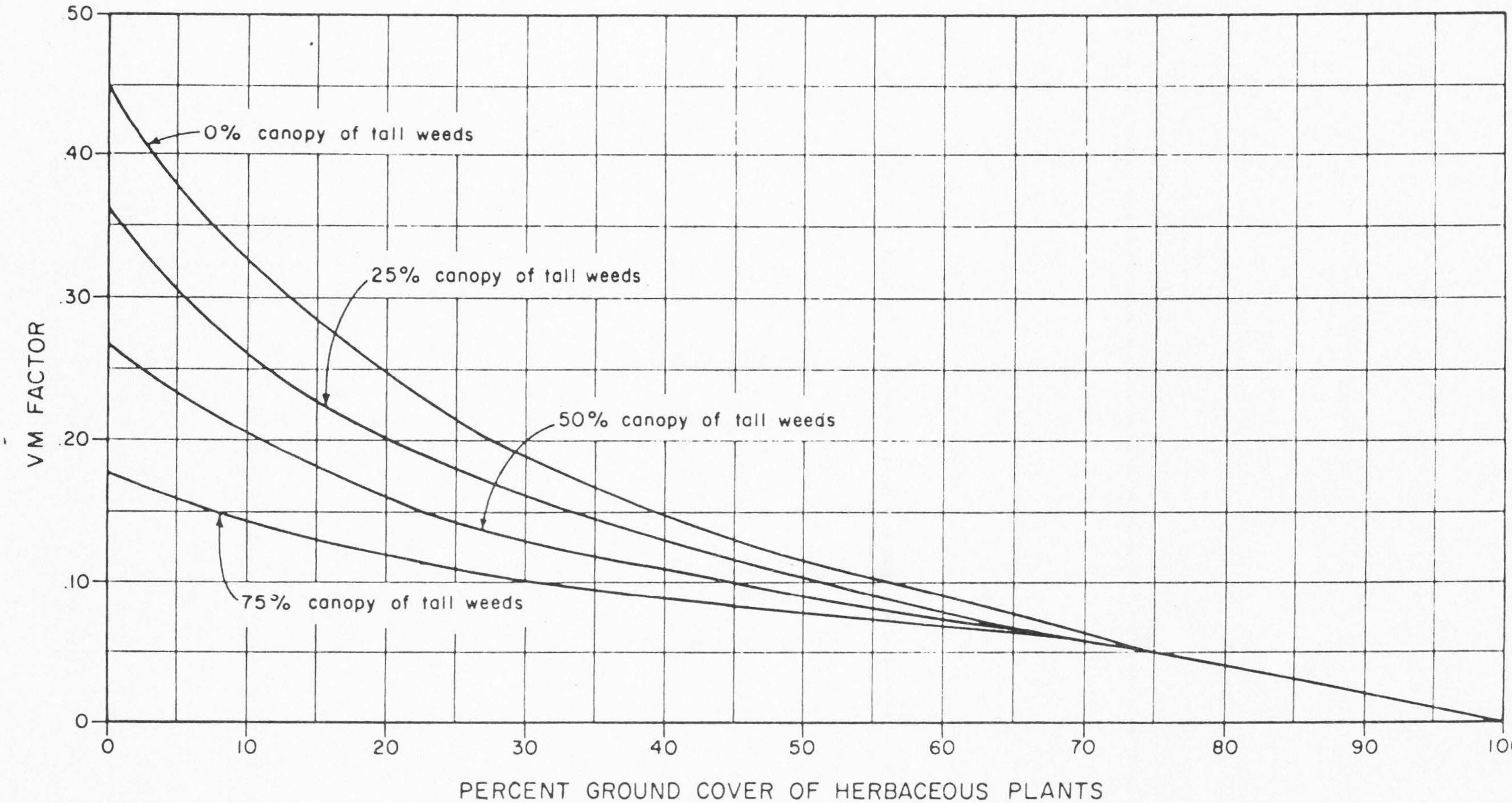


Figure 12. Relationship between forb density and VM or C factor. (Taken from Utah Water Research Laboratory, 1976)

(Figure 11, 12). All C-values were taken directly from the graphs for this study.

Table 11. Permeability class related to infiltration constant.

Permeability Class	Infiltration Constant (in/hr)
Very slow	<0.06
Slow	.06-0.2
Moderately slow	0.2-0.6
Moderate	0.6-2.0
Moderately rapid	2.0-6.0
Rapid	>6.0

The "C"-value for the modified Musgrave equation was taken to be:

$$C = \frac{\text{percent bare soil}}{10}$$

In this way, the "C" values will fall in the range given by Musgrave (1947) in Table 3, i.e., from 1 to 10 for range or seeded pasture. Also, this method of evaluating "C" is objective and will be consistent for all the data.

Improvement of Equations

An attempt was made to improve the three equations evaluated in this study by reducing the variability between the predicted and observed sediment yields. Each factor in an equation was optimized with an exponent by applying multiple regression techniques. In this way, all the factors could be calculated according to the literature and the equation could give better results by raising the factors to an optimum power.

The dependent variable for each equation (Y), is the measured sediment yield in tons per acre for the run in which the data needed to compute the equation was obtained. The independent variables are listed in Table 12. Log_N of each equation was taken, putting it in the form of:

$$\log_N(Y) = \log_N(X_{i1}) + \log_N(X_{i2}) + \log_N(X_{i3}) + \log_N(X_{i4}) + \log_N(X_{i5})$$

where

Y = measured sediment yield in tons per acre,

X_{i1} = rainfall factor,

X_{i2} = soil erodibility factor,

X_{i3} = slope length factor,

X_{i4} = slope steepness factor

X_{i5} = cover factor, and

i = subscript for equation used.

Optimizing the independent variables by multiple regression results in the following regression model:

$$\log_N(\hat{Y}) = \beta_{i0}\log_N(e) + \beta_{i1}\log_N(X_{i1}) + \beta_{i2}\log_N(X_{i2}) +$$

$$_{i3}\log_N(X_{i3}) + {}_{i4}\log_N(X_{i4}) + {}_{i5}\log_N(X_{i5})$$

which is equivalent to:

$$Y = \beta_{i0}\, X_{i1}^{\beta_{i1}}\, X_{i2}^{\beta_{i2}}\, X_{i3}^{\beta_{i3}}\, X_{i4}^{\beta_{i4}}\, X_{i5}^{\beta_{i5}}$$

Table 12. Independent variables for each equation as used in multiple regression analysis

Equation	Number	Description
Universal Soil Loss	X_{11}	Rainfall factor, "R"
	X_{12}	soil erodibility factor - "K"
	X_{13}	slope length factor, "L" = $(X/72.6)^m$ where m = .5 for S $\geq$ 5%, .4 for S = 4%, .3 for S $\leq$ 3%
	X_{14}	slope gradient factor, S = $\frac{430X^2 + 30X + 0.43}{6.57415}$
	X_{15}	cover factor, "C"
Modified Musgrave Equation	X_{21}	rainfall factor, "R"
	X_{22}	soil erodibility factor, "h"
	X_{23}	slope length factor = $(L/72.6)^{0.35}$
	X_{24}	slope gradient factor = $(5/10)^{1.35}$
	X_{35}	cover factor, "C"
Highway Erosion Construction Equation	X_{31}	rainfall factor, "R"
	X_{32}	soil erodibility factor, "K"
	X_{33}	slope length factor, L = $(\lambda/72.6)^m$ $(10{,}000/10{,}000 + S^2)$ where m = .3 for S < 5%, .5 for S $\leq$ S $\leq$ 10%, .6 for S > 10%
	X_{34}	slope gradient factor, S = $\frac{0.43 + 0.35 + 0.0435^2}{6.613}$

RESULTS AND DISCUSSION

General

In order to simplify the interpretations and presentation of the results, all R^2 values less than .10 were not included in the figures since there was essentially no correlation in those situations. Only the situations in which there was some predictability ($R^2 \geq .10$) are plotted in the figures. Specific values for R^2, F, and N are given in Appendix B. Significant levels of .10, .05 and .01 are indicated with 1, 2, and 3 asterisks (*), respectively. The absence of any asterisks in a figure signify that significance is below the .10 level.

Results from Analysis Pooled Over All Data

Predicted/observed ratios

Frequency distributions for the ratios of predicted/observed for each equation using all the data are shown in Figure 13. Any predicted value less than the corresponding observed sediment yield produces a ratio between zero and unity. Any estimate greater than the observed yield produces a value greater than unity which can be much greater since it is not limited by an upper bound as in the case of the less than observed ratio. Figure 13 shows that: (1) the Universal Soil Loss Equation underestimates sediment yield 67.5 percent of the time and overestimates the observed amount 32.5 percent of the time; (2) the modified Musgrave Equation underestimates sediment yield 81.4

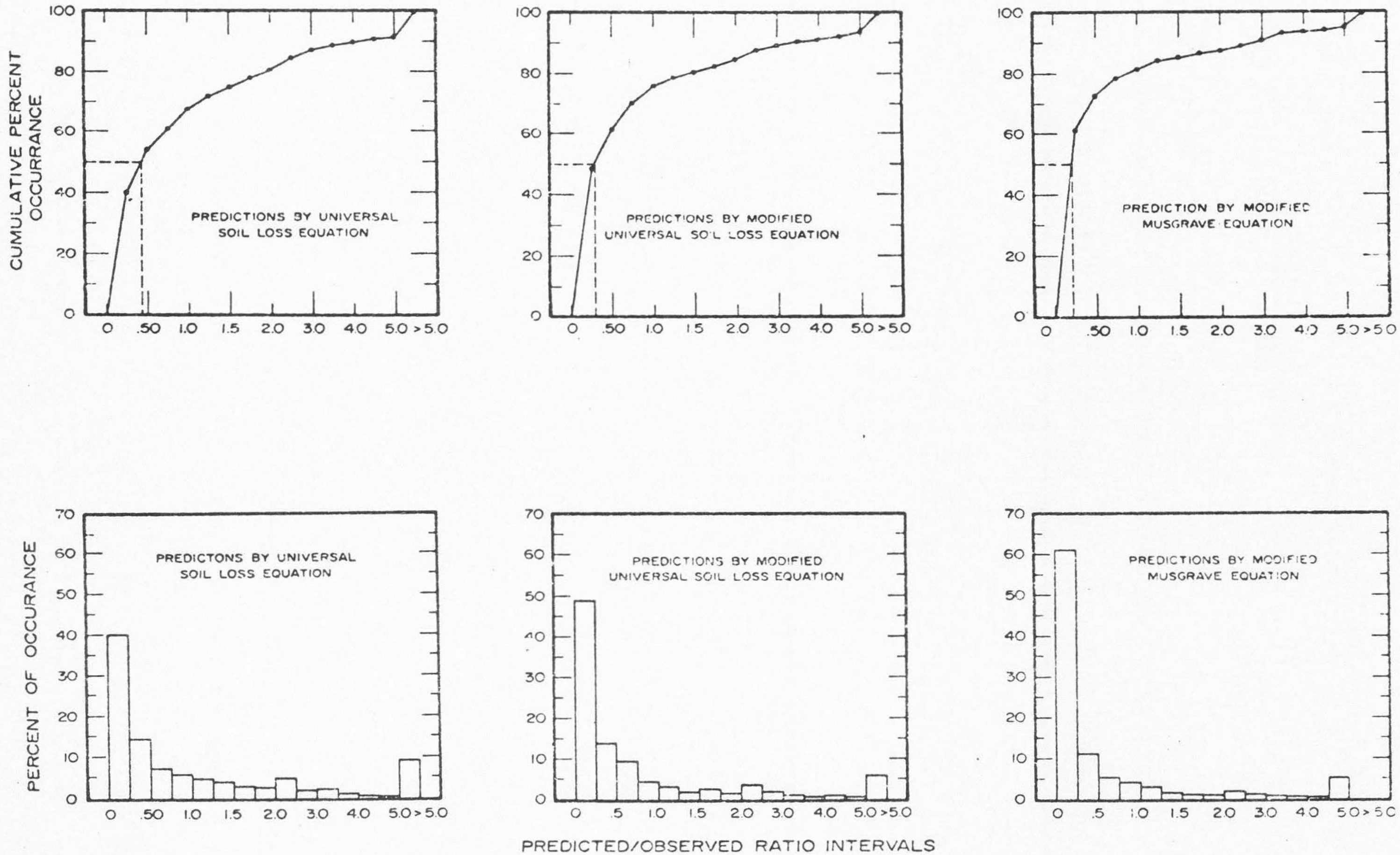


Figure 13. Percent frequency distributions of predicted/observed ratios using data from all plots pooled.

percent of the time and overestimates the observed amount 18.6 percent of the time; and (3) the modified Universal Soil Loss Equation underestimates observed sediment yields 74.9 percent of the time and overestimates observed yields 25.1 percent of the time. Thus, all three equations tend to underestimate sediment yield when used on a per-storm basis. The frequency distributions for each equation exhibits a definite clustering in the ratio interval of 0 to .25 indicating that the largest number of predictions are approximately one-quarter of the observed value. The medians (Figure 13) for the Universal Soil Loss Equation and the modified Universal Soil Loss Equation lie in the interval .25 to .50 and the median for the modified Musgrave equation lies in the 0 to .25 interval indicating that the modified Musgrave predicts values slightly lower than the other two equations.

Coefficients of determination

The coefficient of determination (R^2) for each equation using all plots pooled, is shown in Table 13. The Universal Soil loss equation and modified Universal equation explained only 10 percent of the total plot-to-plot variation in soil loss and the modified Musgrave equation explained only 13 percent. In general, then, the equations are not very applicable in a "universal" sense, for predicting sediment yields on rangelands on a per-storm basis.

Table 13. R^2 values for three erosion prediction equations using data pooled over all data sources (N = 2805)

Equation	R^2 1/
Universal Soil Loss	.10
Modified Musgrave	.13
Modified Universal Soil Loss	.10

1/ All values are significant at the .05 level.

Correlation coefficients for individual parameters of each equation

An analysis of the correlation coefficient (r) between the observed sediment yield and the independent variables of the three equations was made in order to determine which factors had the most influence on explaining sediment yield. The results are presented in Table 14.

The variable best explaining sediment yield is the slope factor (S), which in each case is 10 percent (R^2 = .10). The rainfall factor (R), which accounts for the driving force of the erosion process, explained only 7 percent of soil loss. The soil erodibility factor (K) explained the smallest amount of variance in sediment yield (0.4 percent). The slope length factor (L) indicated a negative relationship with soil loss, i.e., sediment yield is inversely proportional to slope length. Since only three different values of slope length were

Table 14. Correlation coefficients for independent variables from three erosion prediction equations using data pooled over all data sources (N = 2903).

Equation	Independent Variable	r
Universal Soil Loss	R	.26
	K	.06
	L	-.10
	S	.32
	C	.15
Modified Musgrave	R	.26
	K	.06
	L	-.23
	S	.32
	C	.25
Modified Universal Soil Loss	R	.26
	K	.06
	L	-.29
	S	.32
	C	.15

available for this study (i..e. three different infiltrometer plot lengths), it is difficult to draw any conclusions. But, the slope length factor (L) was derived from data collected from plots of a fixed length (72.6 feet) and then extrapolated to slopes of different lengths. Thus, it cannot be ruled out that a negative relationship between sediment yield and slope length does indeed exist on short slope lengths (2.0 to 3 feet).

Individual Data Sources

When the equations were applied to the individual data sources, mostly zero correlations resulted. Scatter diagrams for all data sources are given in Figures 14 to 21. The best results were from the Australian data with R^2 values of .41 for each equation (Figure 22). The only other data sources that had R^2 values greater than .10 were the mine sites.

Most of the data sources consisted of infiltrometer runs made over a wide range of circumstances. However, when they were subdivided into the various situations as shown in Figure 6, R^2 values were varied with a range from 0 to .99 (as will be shown in the following pages).

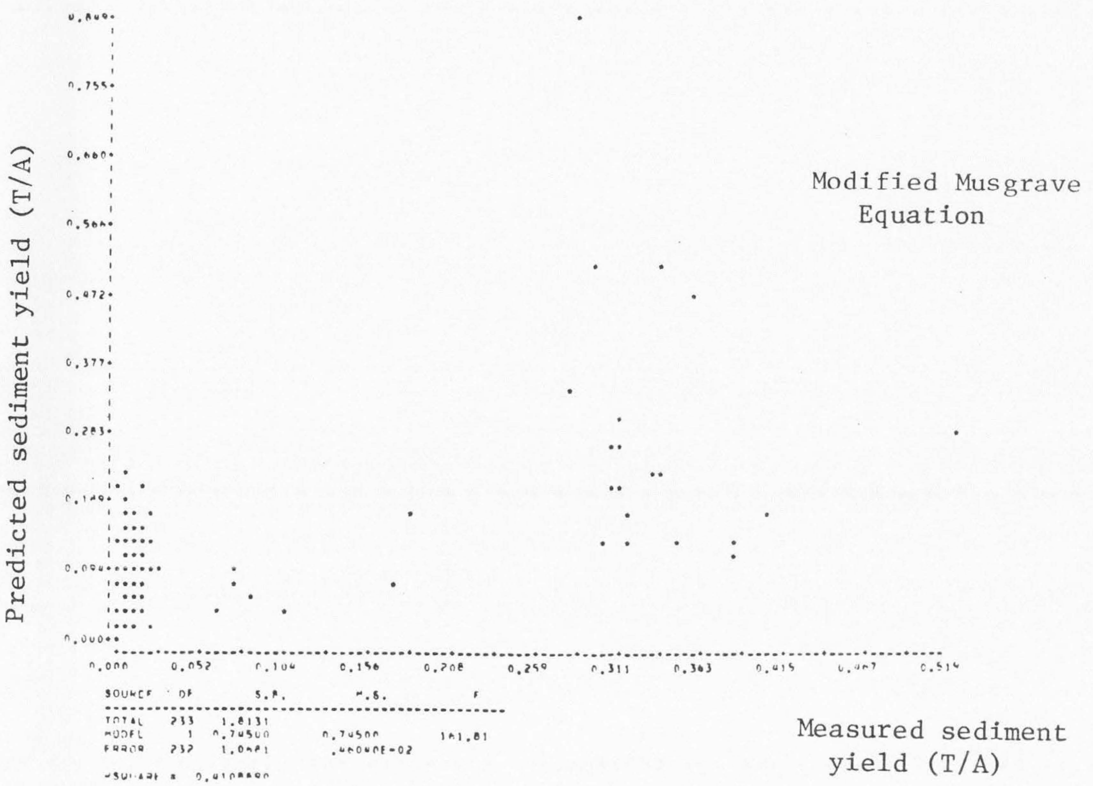
Antecedent Moisture Conditions

The Australia and Nevada data were each obtained from soils under antecedent moisture conditions and also from soils prewet to field capacity; the Sagebrush (Idaho) and Pinyon Juniper-chaining studies sediment data were from soils prewet to field capacity. The Australian data had relatively good correlation between predicted and observed sediment yield, the best correlation occurring under wet conditions (Figure 23). However, on the basis of all the data mentioned above, no conclusions can be made as to the effect of antecedent moisture on the predictability of the equations since all the data (except Australia) had coefficient of determinations which, for all practical purposes, were zero.

Time Periods

Coefficients of determination for the September and November sampling periods in which the Australia data were collected are shown in Figure 24. Considerable difference exists in R^2 values between data

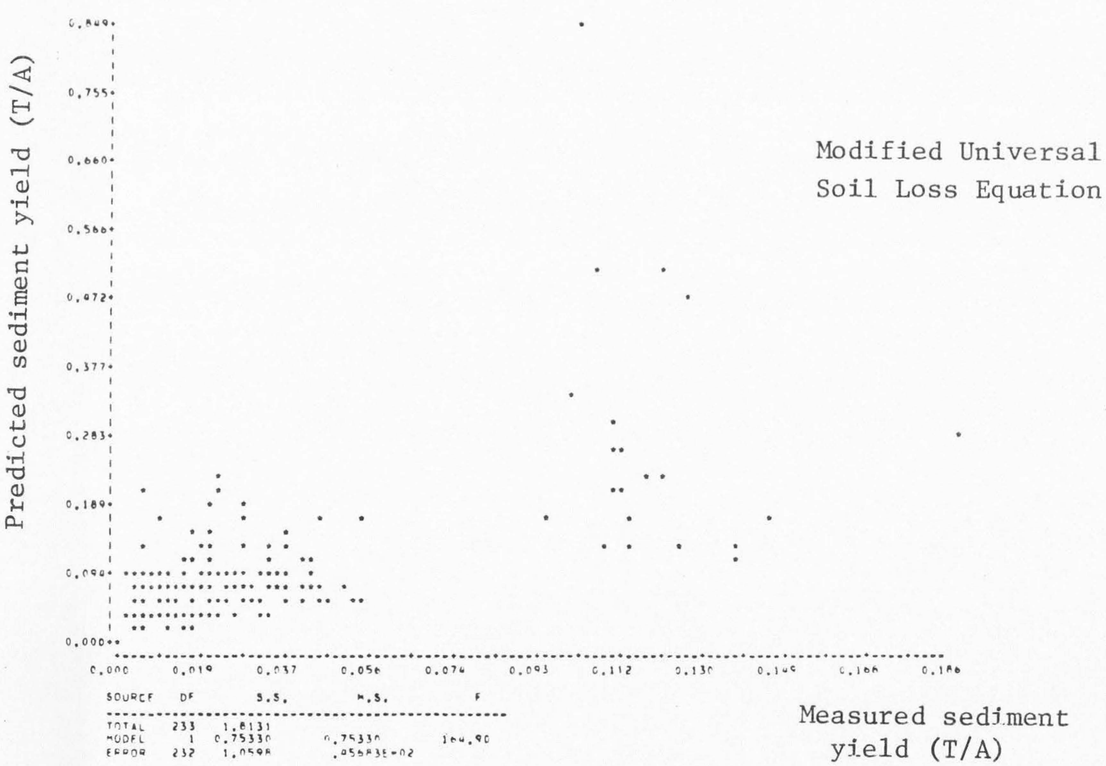
Figure 14, Pages 66 and 67: Scatter diagrams for three erosion prediction equations using data from Australia rangeland study pooled over all plots



SOURCE	DF	S.S.	M.S.	F
TOTAL	233	1.8131		
MODEL	1	0.74500	0.74500	161.81
ERROR	232	1.0681	.46040E-02	

RSQUARE = 0.4108890

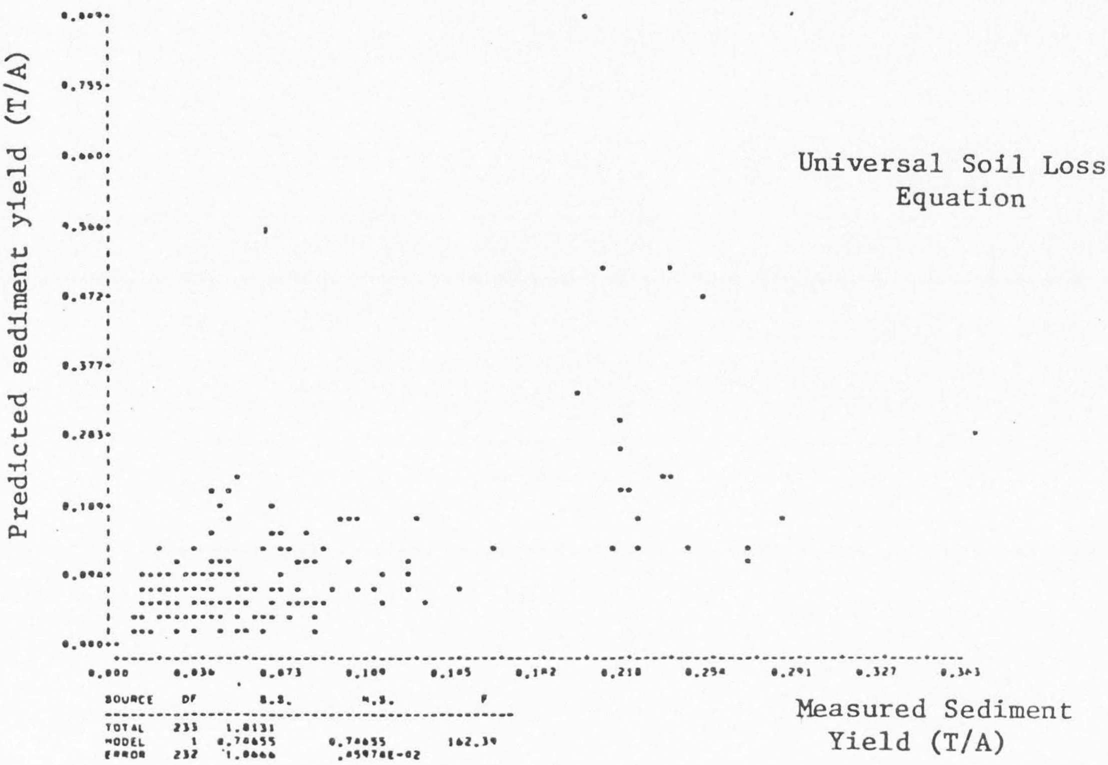
Y = .5633169E-01 + 0.5759563 * X



SOURCE	DF	S.S.	M.S.	F
TOTAL	233	1.8131		
MODEL	1	0.75330	0.75330	164.90
ERROR	232	1.0598	.45683E-02	

RSQUARE = 0.4154673

Y = .2853147E-01 + 1.758932 * X

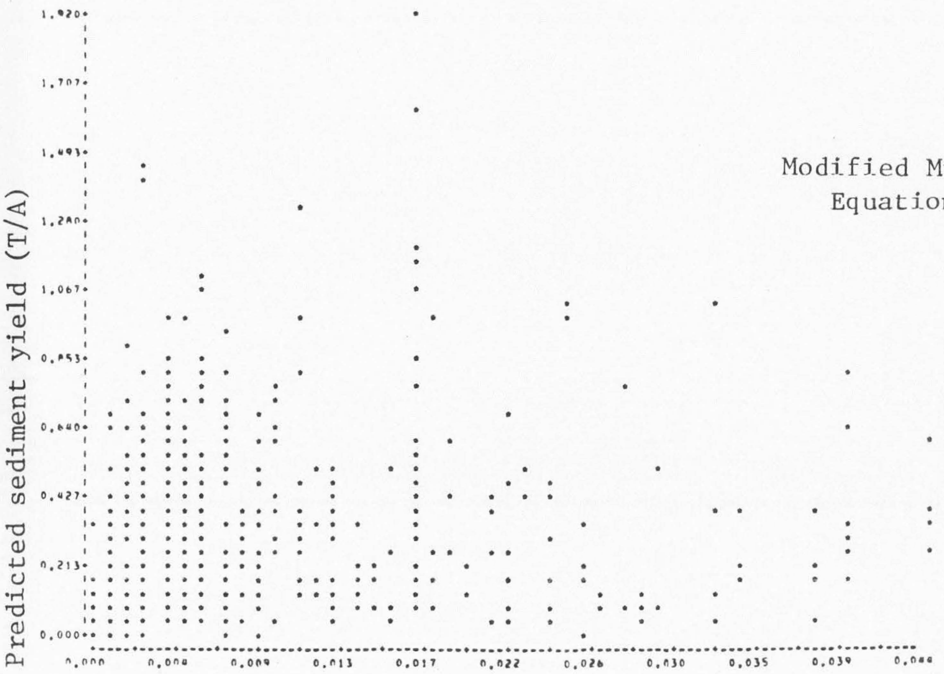


SOURCE	DF	S.S.	M.S.	F
TOTAL	233	1.8131		
MODEL	1	0.74655	0.74655	162.39
ERROR	232	1.0666	.45974E-02	

RSQUARE = 0.4117435

Y = .2313282E-01 + 0.8991257 * X

Figure 15, pages 69 and 70: Scatter diagrams for three erosion prediction equations using data from Nevada rangeland (Nev.) study pooled over all plots



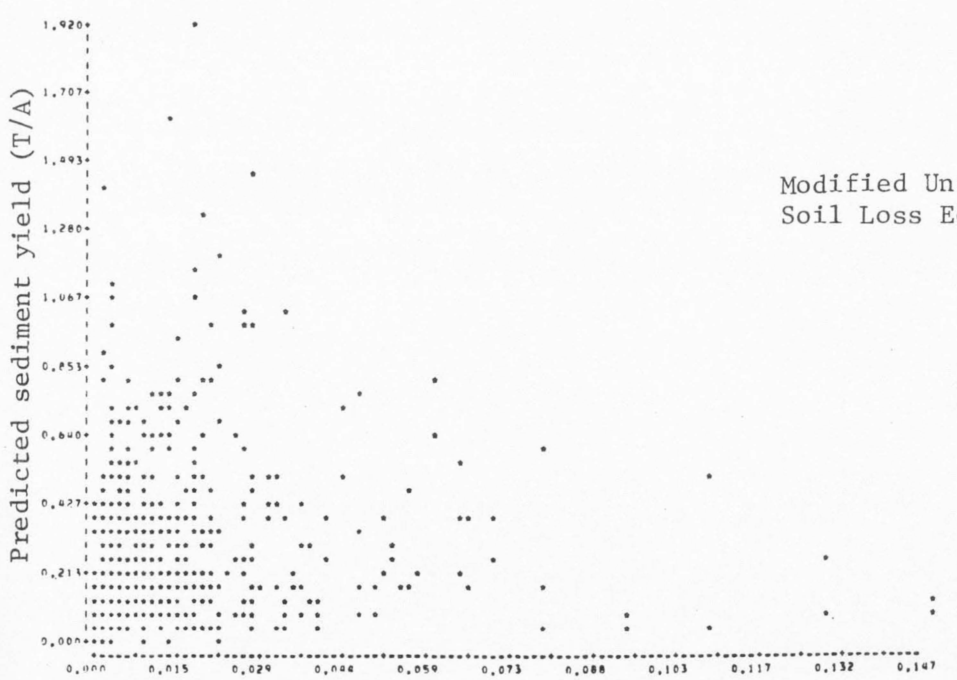
Modified Musgrave Equation

Measured sediment yield (T/A)

SOURCE	DF	S.S.	M.S.	F
TOTAL	732	40.186		
MODEL	1	0.75157	0.75157	13.932
ERROR	731	39.435	.53946E-01	

RSQUARE = 0.0187022

Y = .2380600 + 3.810542 * X



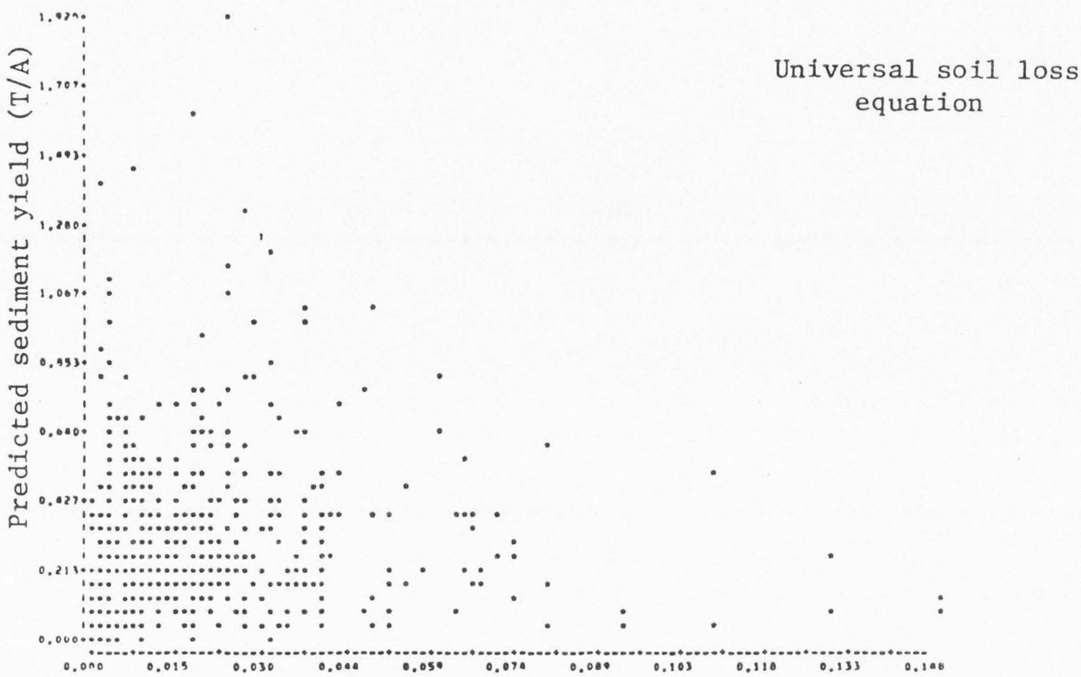
Modified Universal Soil Loss Equation

Measured sediment yield (T/A)

SOURCE	DF.	S.S.	M.S.	F
TOTAL	732	40.186		
MODEL	1	0.16271	0.16271	2.9718
ERROR	731	40.024	.54752E-01	

RSQUARE = 0.0040490

Y = 0.2562846 + 0.8467957 * X

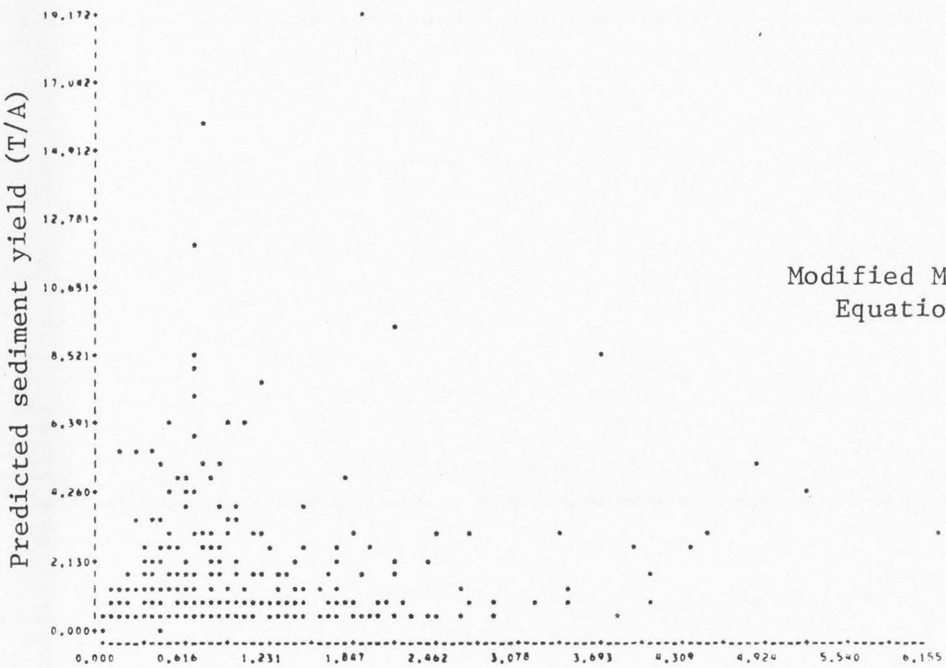


SOURCE	DF	S.S.	M.S.	F
TOTAL	732	40.186		
MODEL	1	0.20828	0.20828	3.8083
ERROR	731	39.978	.54689E-01	

RSQUARE = 0.0051828

Y = 0.2524872 + 0.8760385 * X

Figure 16, pages 72 and 73: Scatter diagrams for three erosion prediction equations using data from pinyon-juniper (grazing) study pooled over all plots



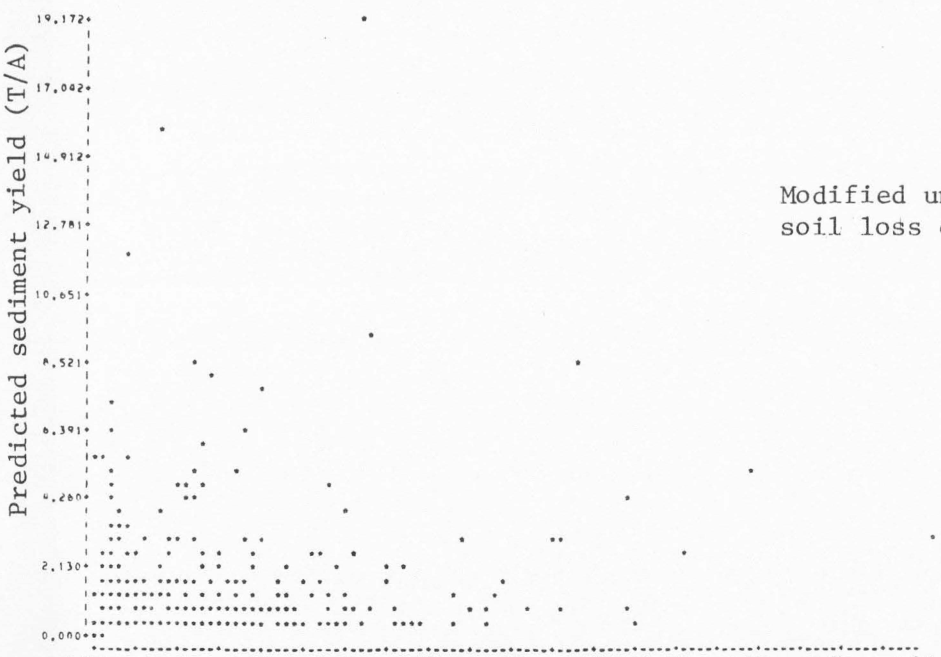
Modified Musgrave Equation

SOURCE	DF	S.S.	M.S.	F
TOTAL	683	1690,7		
MODEL	1	112,51	112,51	48,622
ERROR	682	1578,2	2,3140	

RSQUARE = 0,0665482

Y = 0,4569896 + 0,5555505 * X

Measured sediment yield (T/A)



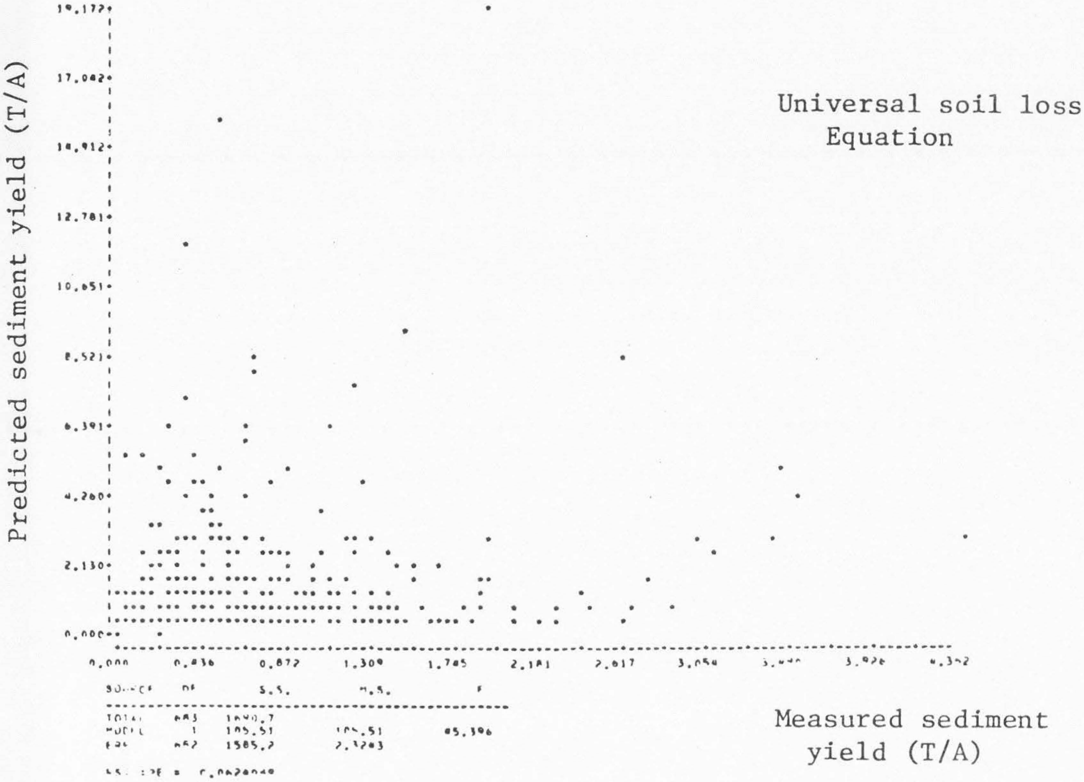
Modified universal soil loss equation

SOURCE	DF	S.S.	M.S.	F
TOTAL	683	1690,7		
MODEL	1	77,671	77,671	32,841
ERROR	682	1613,0	2,3651	

RSQUARE = 0,0459413

Y = 0,5637121 + [illegible] * X

Measured sediment yield (T/A)

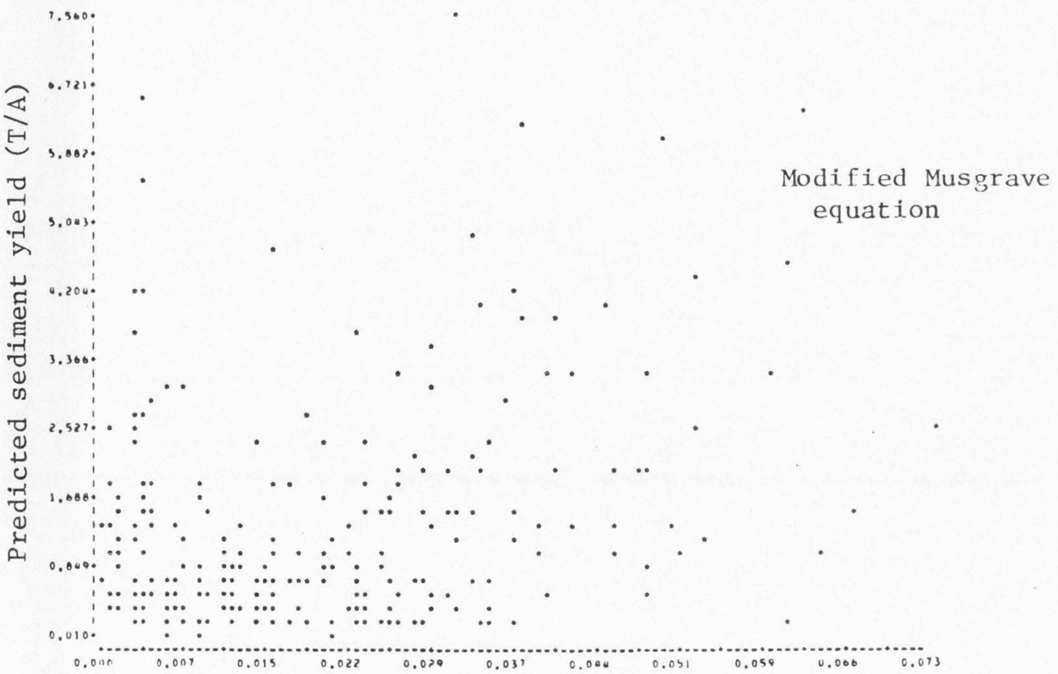


SOURCE	DF	S.S.	M.S.	F
TOTAL	[illegible]	[illegible]		
MODEL	1	105.51	[illegible]	[illegible]
ERROR	[illegible]	1585.2	[illegible]	

[illegible]

[illegible]

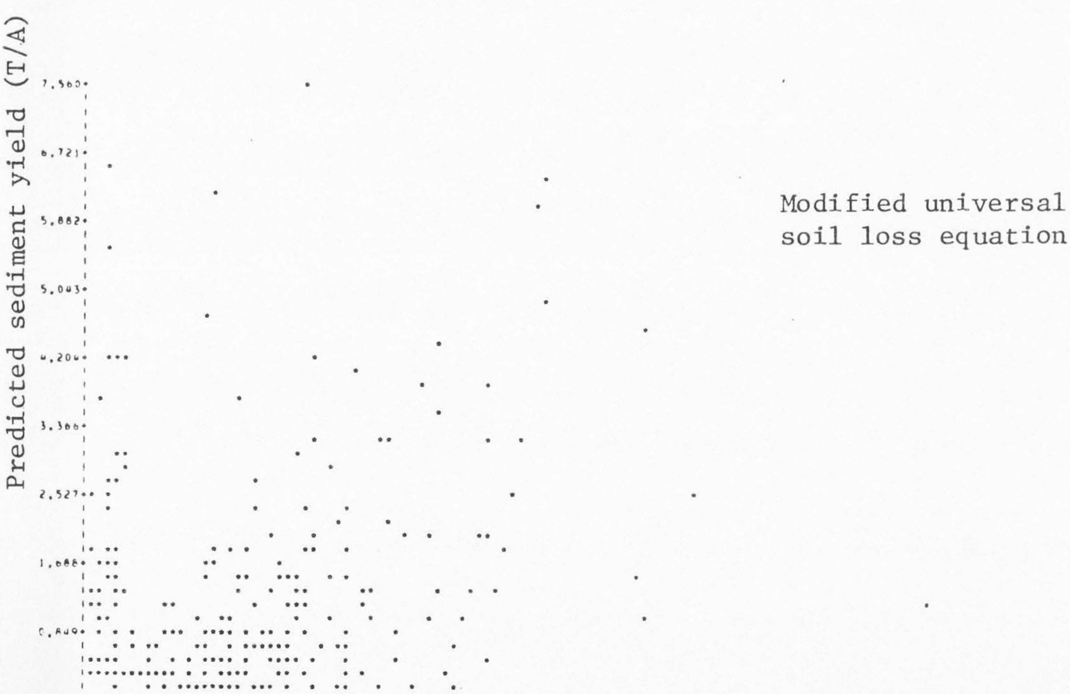
Figure 17, pages 75 and 76: Scatter diagrams for three erosion prediction equations using data from big sagebrush (Ida) study pooled over all plots



SOURCE	DF	S.S.	M.S.	F
TOTAL	278	460,54		
MODEL	1	33,375	33,375	21,643
ERROR	277	427,16	1,5421	

RSQUARE = 0,0724704

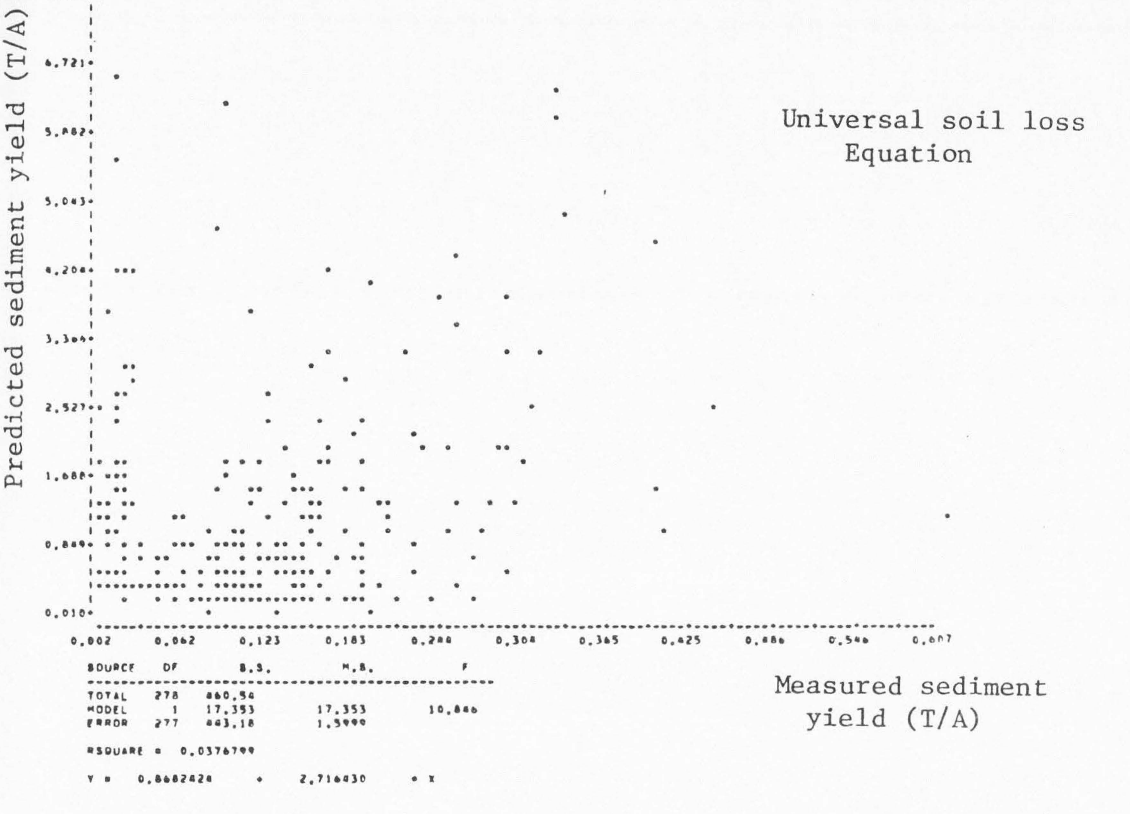
Y = 0,7660821 + 22,73979 * X



SOURCE	DF	S.S.	M.S.	F
TOTAL	278	460,54		
MODEL	1	17,640	17,640	11,032
ERROR	277	442,90	1,5989	

RSQUARE = 0,0383026

Y = 0,8659227 + 5,362376 * X

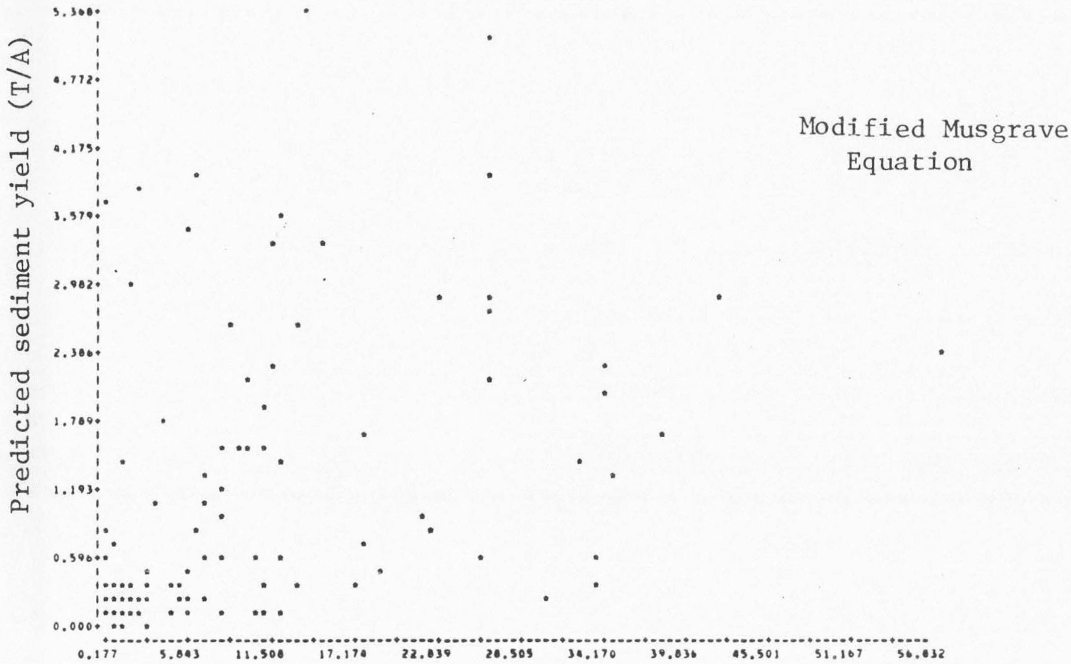


SOURCE	DF	S.S.	M.S.	F
TOTAL	278	460,54		
MODEL	1	17,353	17,353	10,846
ERROR	277	443,18	1,5999	

RSQUARE = 0,0376799

Y = 0,8682424 + 2,716430 * X

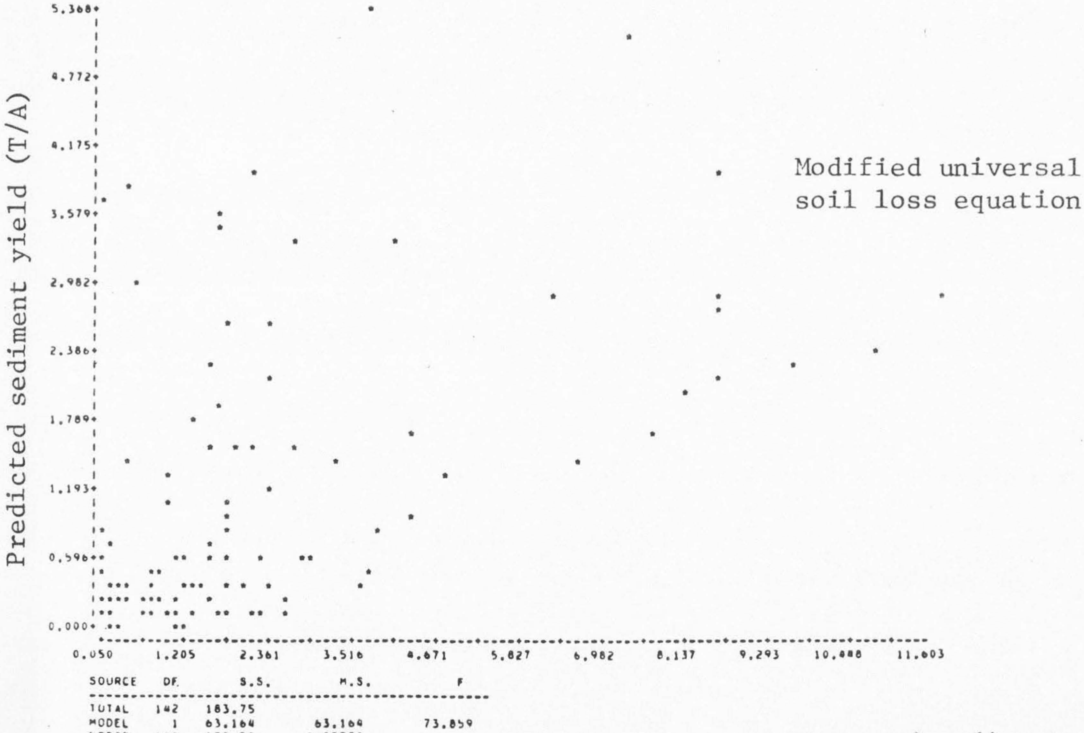
Figure 18, pages 78 and 79: Scatter diagrams for three erosion prediction equations using mine site data collected in 1975 and pooled over all plots



SOURCE	DF	S.S.	M.S.	F
TOTAL	142	183.75		
MODEL	1	39.543	39.543	38.664
ERROR	141	144.20	1.0227	

RSQUARE = 0.2152028

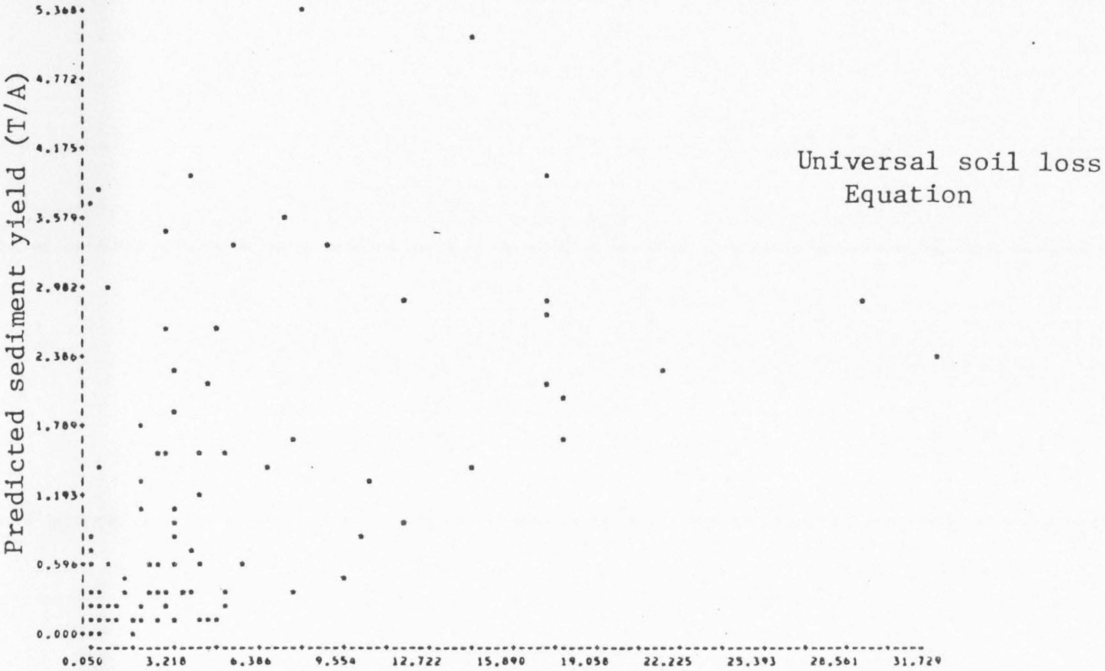
Y = 0.4110145 + .4998139E-01 * X



SOURCE	DF	S.S.	M.S.	F
TOTAL	142	183.75		
MODEL	1	63.164	63.164	73.859
ERROR	141	120.58	0.85520	

RSQUARE = 0.3437559

Y = 0.3369511 + 0.2788561 * X

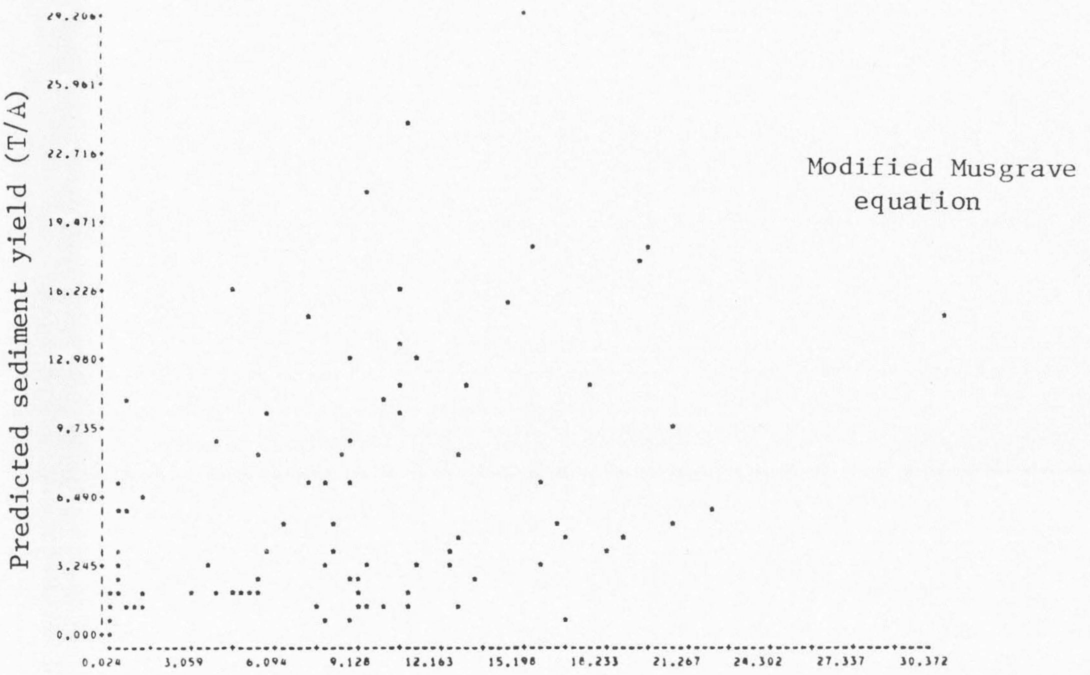


SOURCE	DF	S.S.	M.S.	F
TOTAL	142	183.75		
MODEL	1	57.227	57.227	63.776
ERROR	141	126.52	0.89730	

RSQUARE = 0.3114436

Y = 0.4157576 + 0.1138079 * X

Figure 19, pages 81 and 82: Scatter diagrams for three erosion prediction equations using mine site data collected in 1976 and pooled over all plots

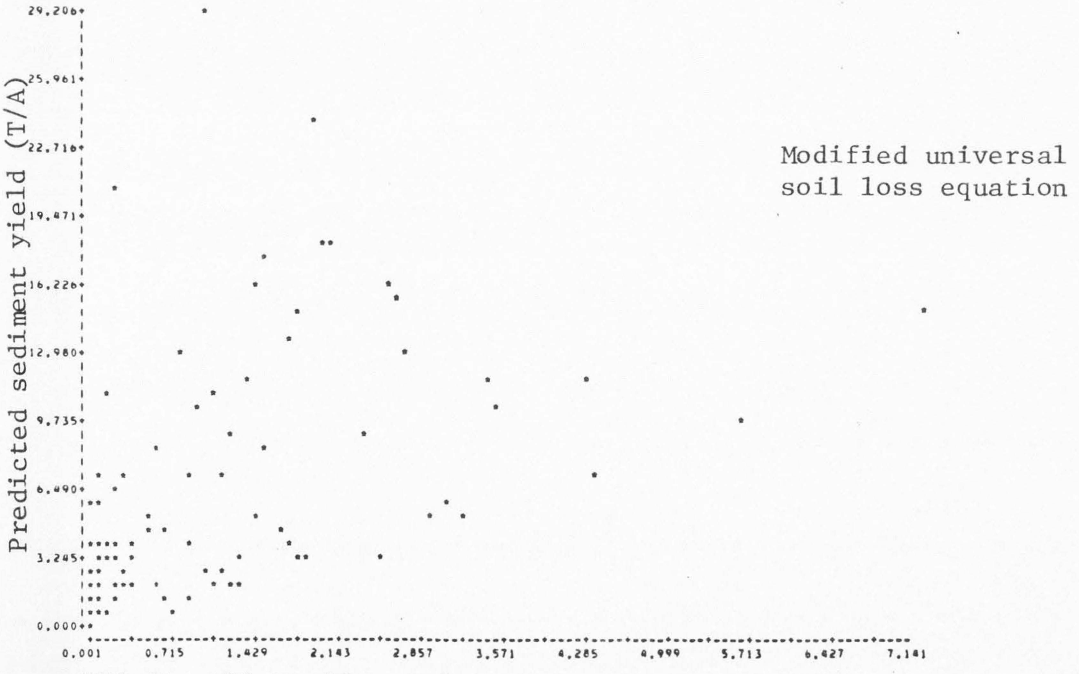


SOURCE	DF	S.S.	M.S.	F
TOTAL	107	3524.1		
MODEL	1	824.22	824.22	32.360
ERROR	106	2699.9	25.470	

RSQUARE = 0.2338829

Y = 2.154034 + 0.4177330 * X

Measured sediment yield (T/A)

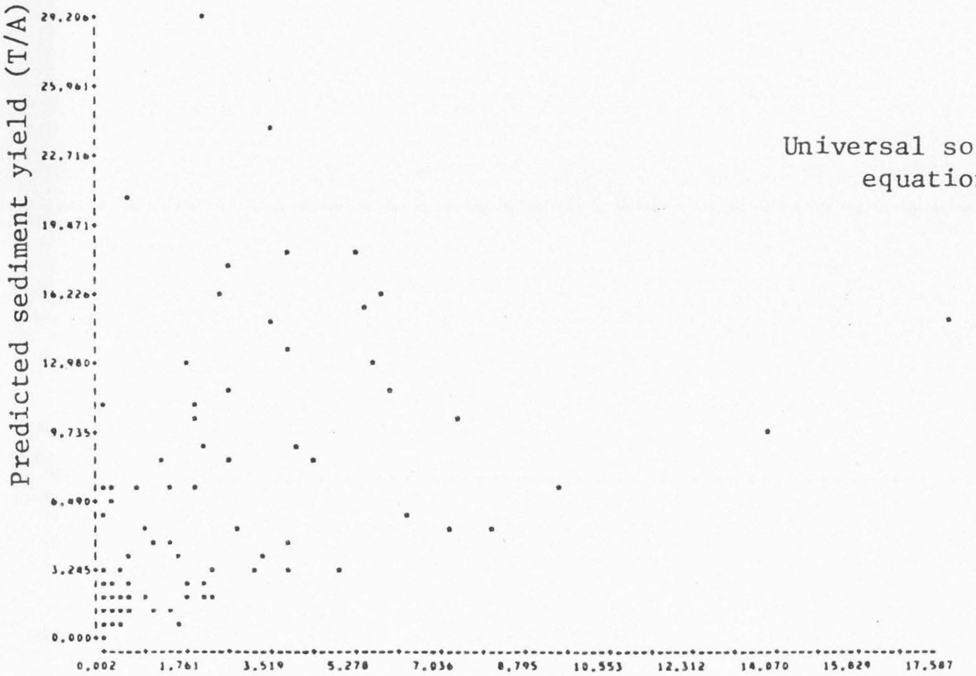


SOURCE	DF	S.S.	M.S.	F
TOTAL	107	3524.1		
MODEL	1	914.11	914.11	37.125
ERROR	106	2610.0	24.622	

RSQUARE = 0.2593902

Y = 3.035839 + 2.268338 * X

Measured sediment yield (T/A)

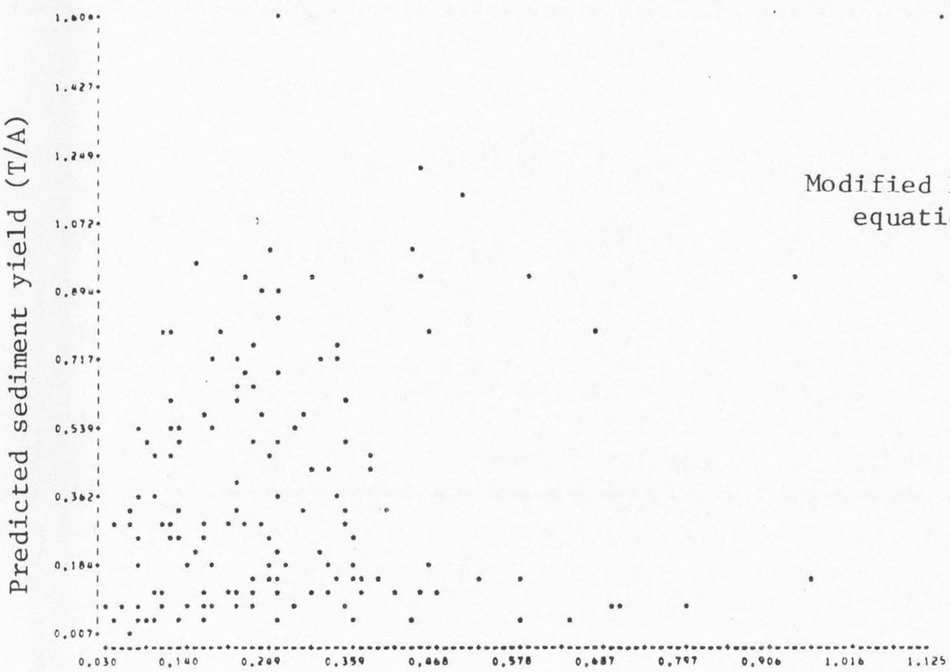


SOURCE	DF	S.S.	M.S.	F
TOTAL	107	3524.1		
MODEL	1	819.80	819,80	32.134
ERROR	106	2704.3	25.512	

RSQUARE = 0.2326277

Y = 3.354682 + 0.9452939 * X

Figure 20, pages 84 and 85: Scatter diagrams for three erosion prediction equations using data from geologic type study, pooled over all plots



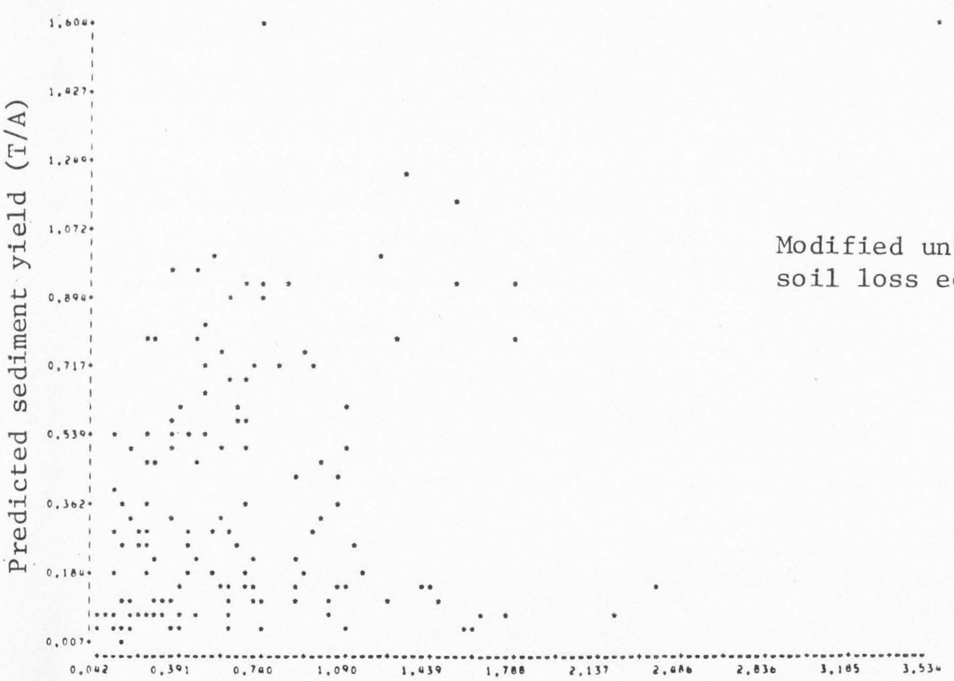
Modified Musgrave equation

SOURCE	DF	S.S.	M.S.	F
TOTAL	146	15,711		
MODEL	1	0,61586	0,61586	5,9159
ERROR	145	15,095	0,10410	

RSQUARE = 0,0392002

Y = 0,2609623 + 0,3507465 * X

Measured sediment yield (T/A)



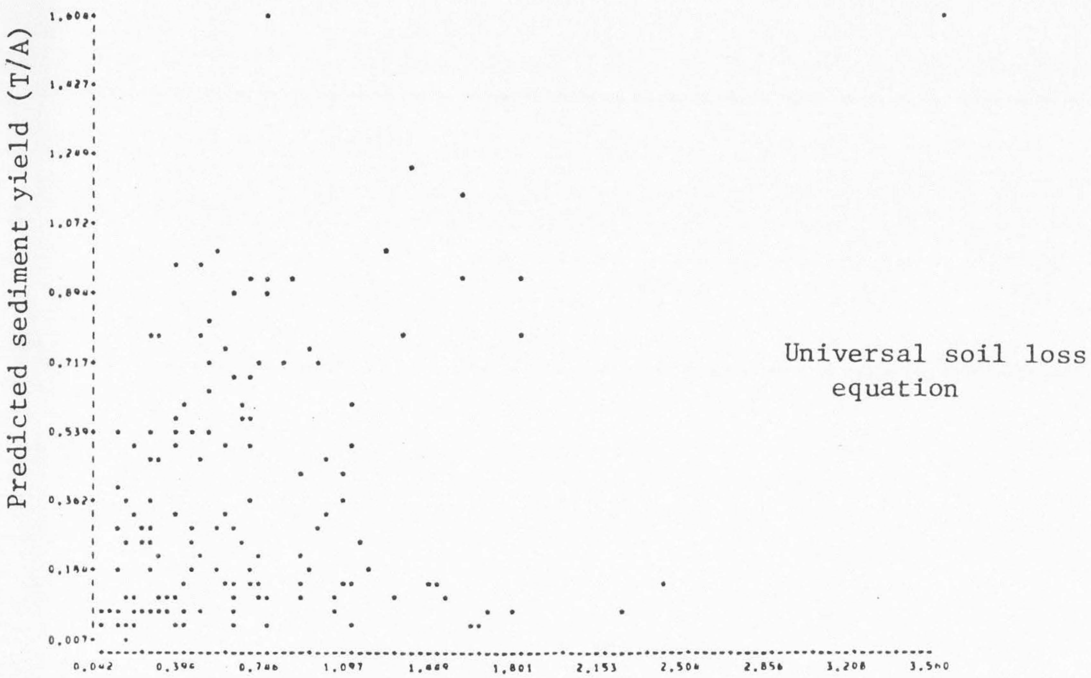
Modified universal soil loss equation

SOURCE	DF	S.S.	M.S.	F
TOTAL	146	15,711		
MODEL	1	1,0573	1,0573	10,463
ERROR	145	14,653	0,10106	

RSQUARE = 0,0673006

Y = 0,2448270 + 0,1645404 * X

Measured sediment yield (T/A)

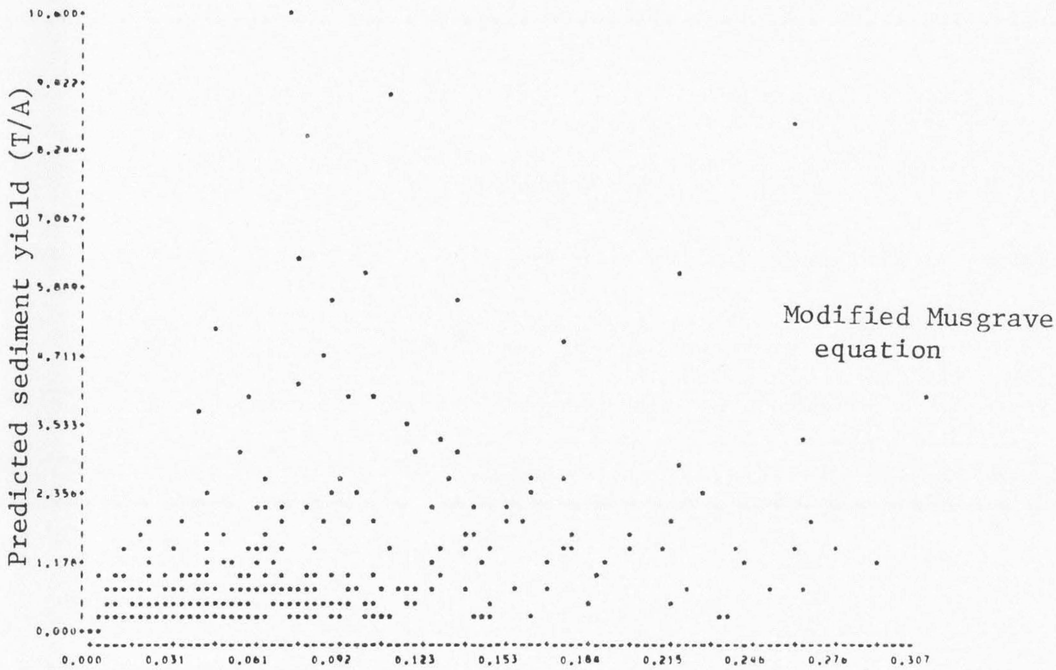


SOURCE	DF	S.S.	M.S.	F
TOTAL	146	15,711		
MODEL	1	1,0573	1,0573	10,462
ERROR	145	14,653	0,10106	

RSQUARE = 0,0672956

Y = 0,2448231 + 0,1633344 * X

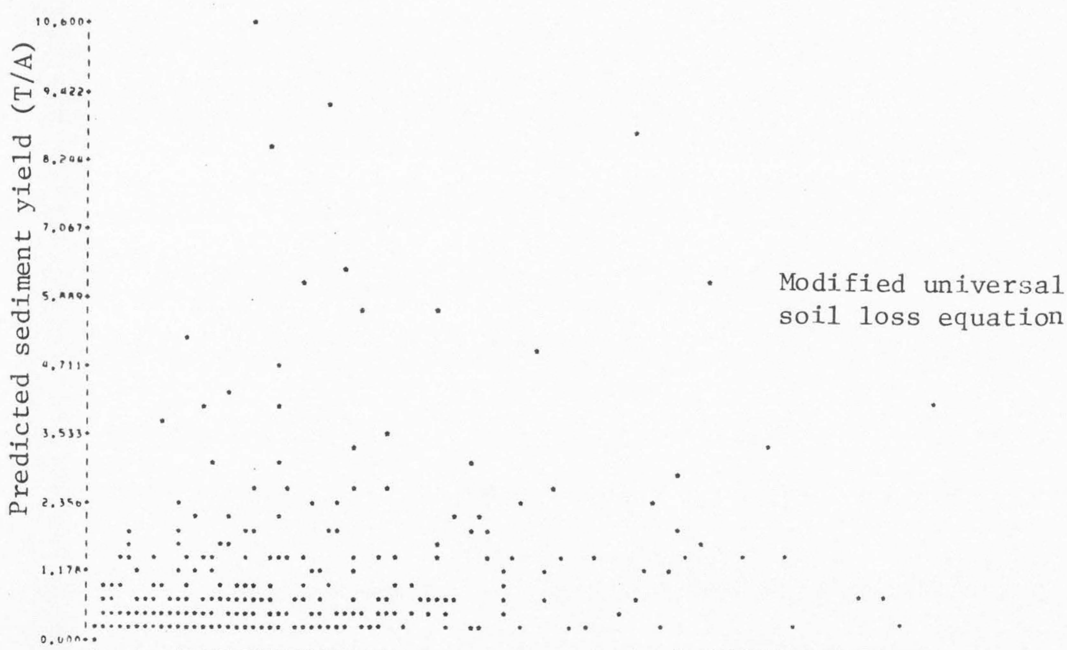
Figure 21, pages 87 and 88: Scatter diagrams for three erosion prediction equations using data from pinyon-juniper (chaining) study pooled over all plots



SOURCE	DF	S.S.	M.S.	F
TOTAL	415	680.11		
MODEL	1	82.382	82.382	57.060
ERROR	414	597.73	1.4438	

RSQUARE = 0.1211303

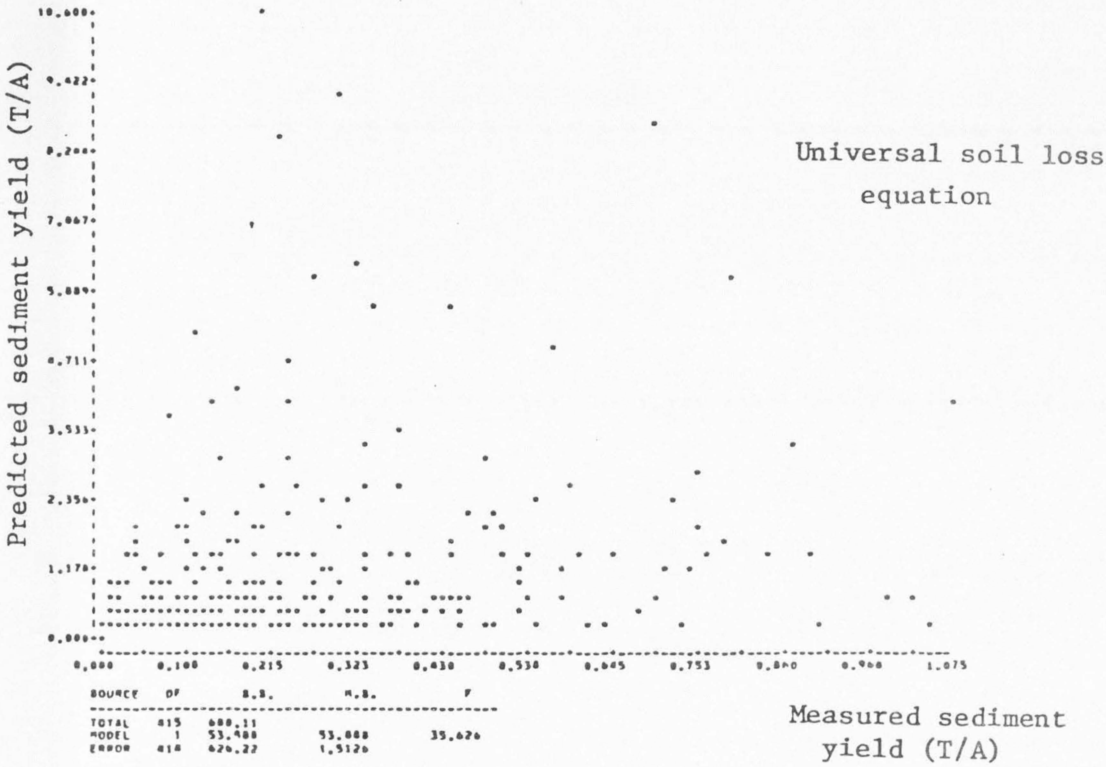
Y = 0.3027822 + 7.672537 * X



SOURCE	DF	S.S.	M.S.	F
TOTAL	415	680.11		
MODEL	1	53.780	53.780	35.540
ERROR	414	626.33	1.5129	

RSQUARE = 0.0790761

Y = 0.4428125 + 2.500417 * X

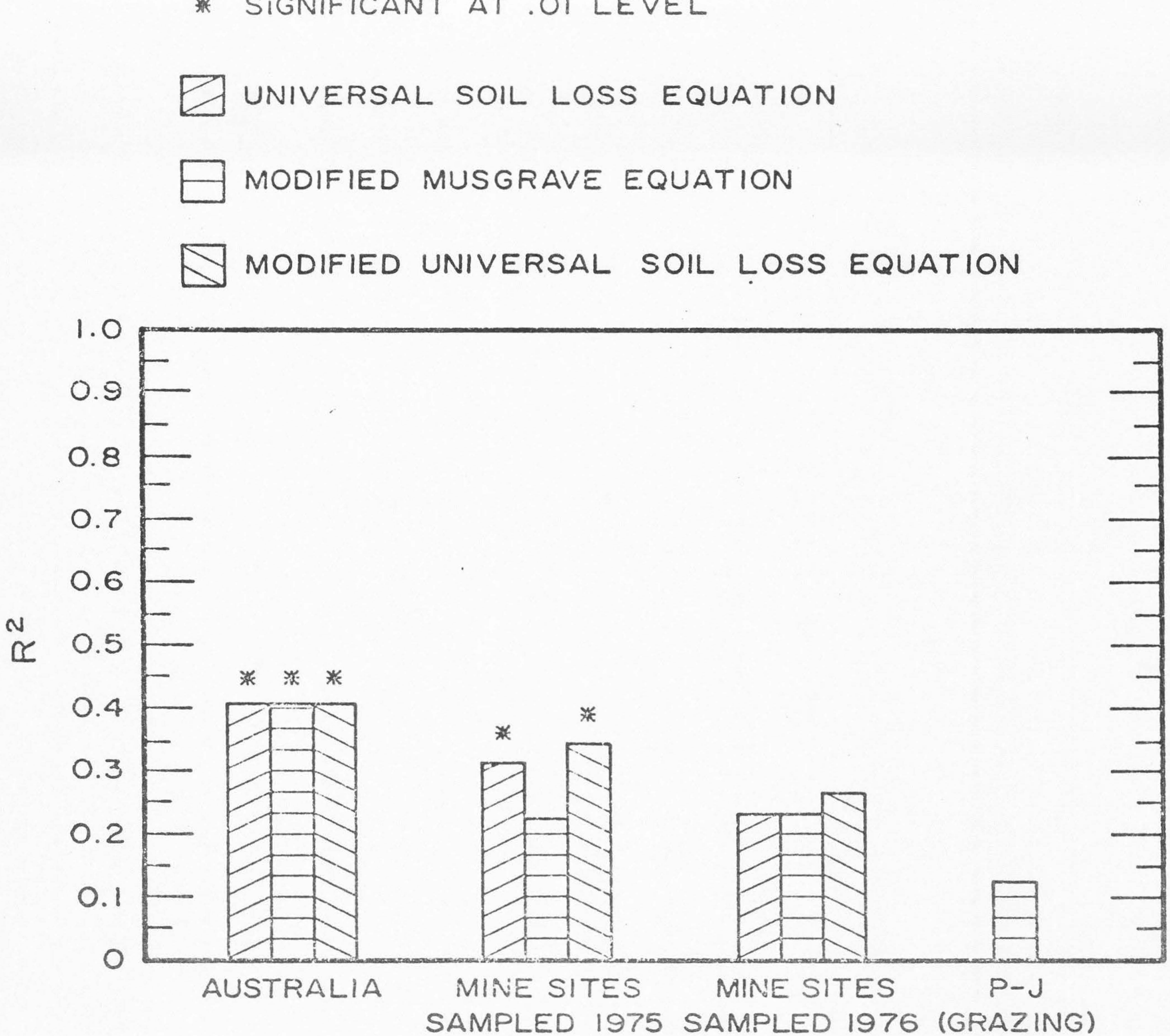


SOURCE	DF	S.S.	M.S.	F
TOTAL	415	680.11		
MODEL	1	53.888	53.888	35.626
ERROR	414	626.22	1.5126	

RSQUARE = 0.0792350

Y = 0.0430825 + 1.020436 * X

Figure 22. R^2 values equal to or greater than .10 indicating amount of variance explained by three erosion prediction equations using data pooled over each individual data source.



* SIGNIFICANT AT .01 LEVEL
UNIVERSAL SOIL LOSS EQUATION
MODIFIED MUSGRAVE EQUATION
MODIFIED UNIVERSAL SOIL LOSS EQUATION
R^2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AUSTRALIA
MINE SITES SAMPLED 1975
MINE SITES SAMPLED 1976
P-J (GRAZING)

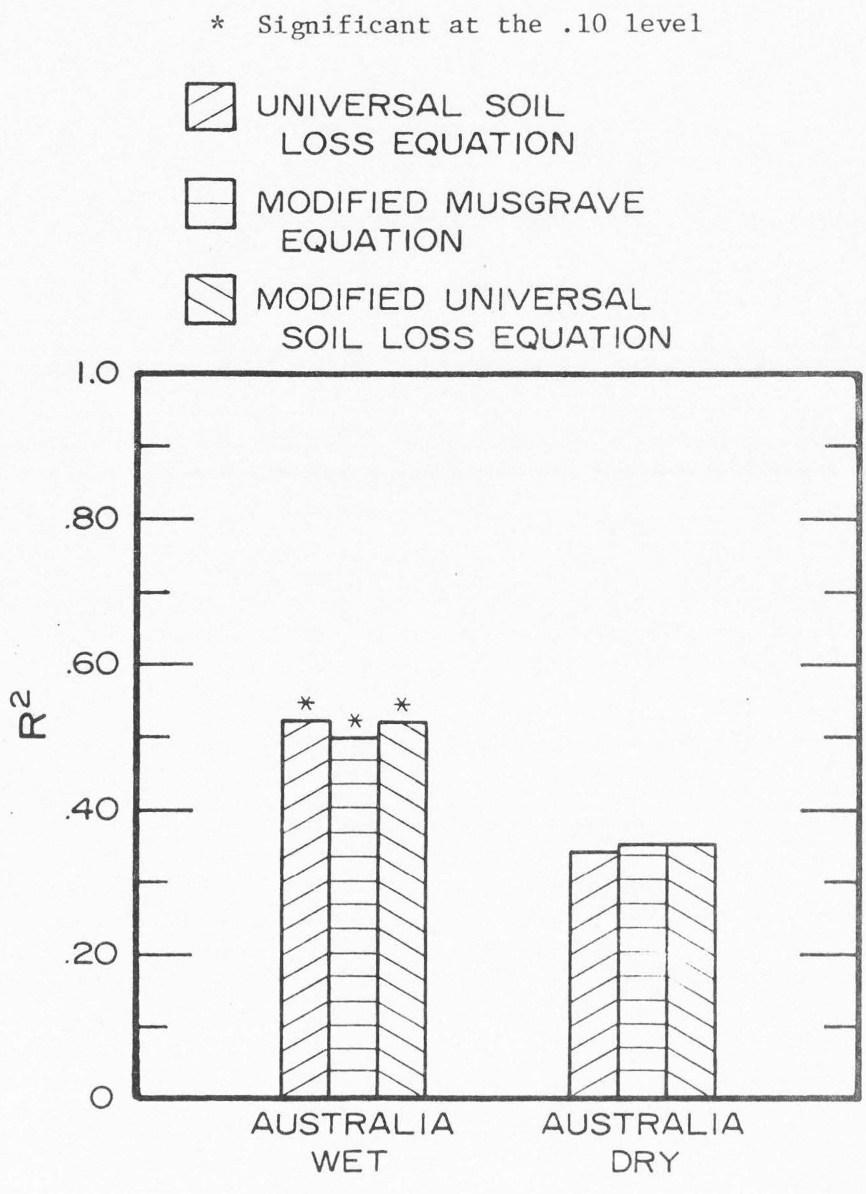


Figure 23. R^2 values indicating amount of variance explained by three erosion prediction equations for Australia data under wet and dry antecedent moisture conditions.

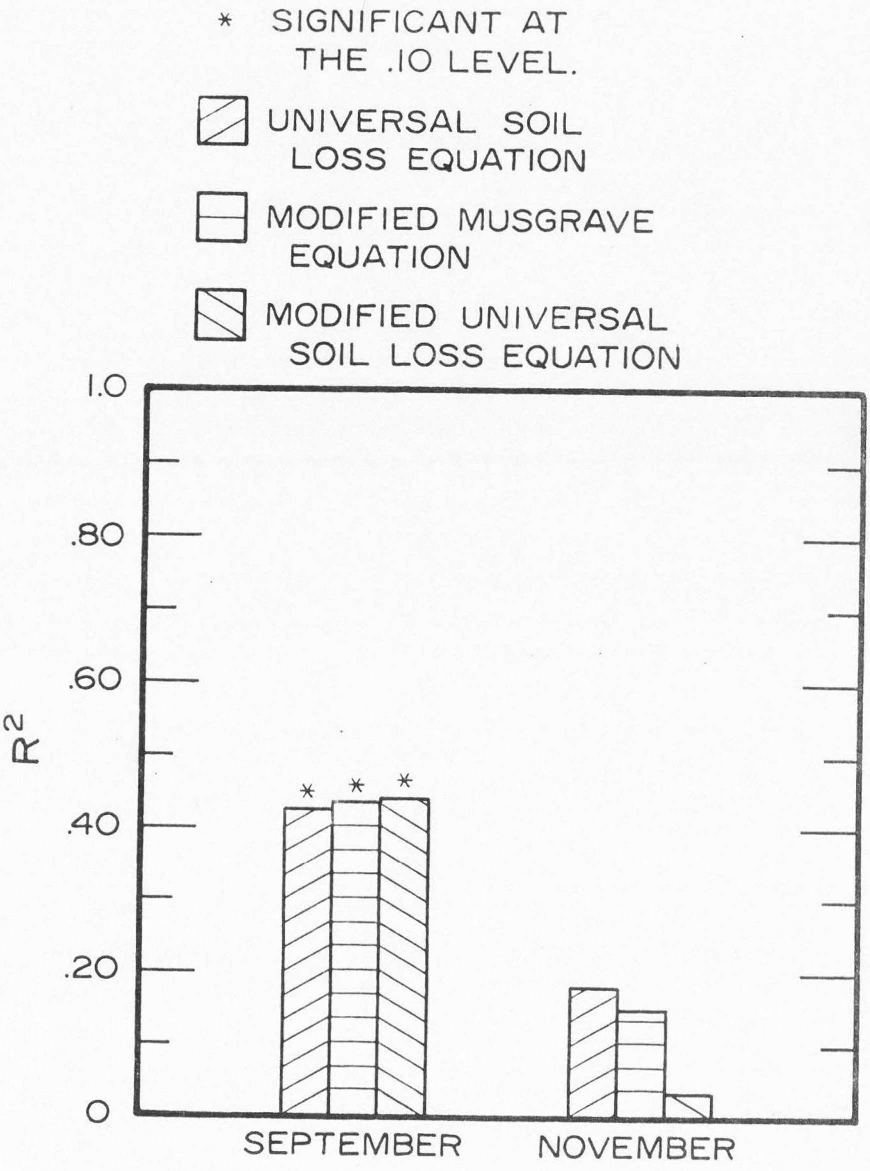


Figure 24. R^2 values indicating amount of variance explained by three erosion prediction equations for Australia data collected during two different sampling periods. Data are pooled over wet and dry antecedent moisture conditions, all plant communities, and mulga grove and mulga intergrove situations.

(pooled over wet and dry antecedent moisture conditions and all plant communities) collected in September and November. No reason for the difference can be determined, but, a seasonal effect on the predictability of the erosion equations cannot be ruled out.

Plant Communities

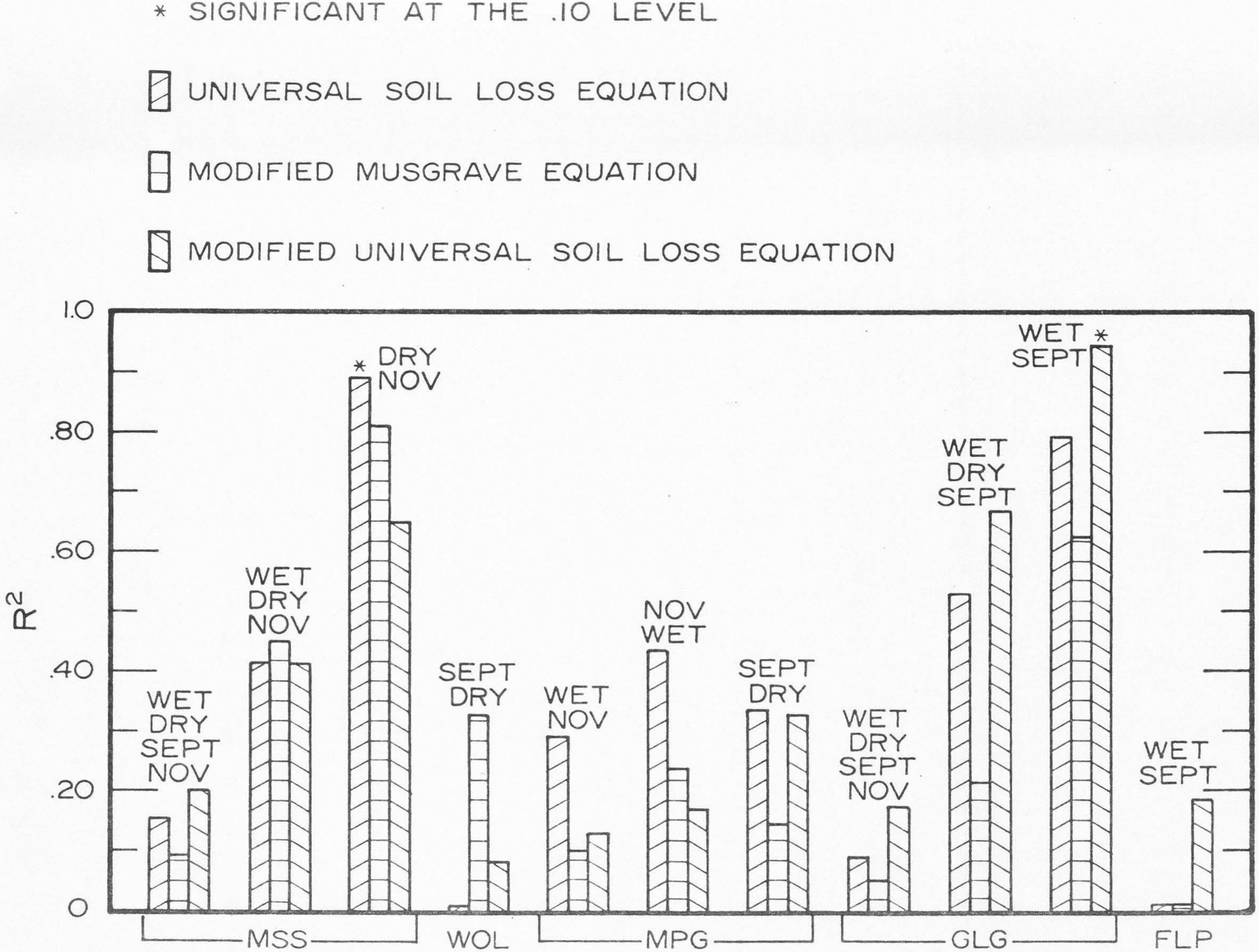
Australia rangeland communities

All R^2 values equal to or greater than .1 for all combinations of various plant communities, wet and dry antecedent moisture conditions, and September and November sampling periods are given in Figure 25. No one equation shows to be the best predictor for these particular plant communities. In all cases, however, the predictions are best with only three interactions (i.e., one date, one plant community, and one antecedent moisture condition). The mulga-shortgrass (MSS) and gilgai (GLG) communities show a definite increase in R^2 values when moving from five to three interactions. This finding does not support a universal applicability of the erosion prediction equations, instead, it shows good prediction is possible under specific conditions.

Nevada rangeland plant communities

There are no consistent patterns or trends when the equations were applied to the Nevada rangeland plant communities under two different application rates and two different antecedent moisture conditions (Figure 26). The best R^2 values for the Universal Soil Loss equation and the modified Universal Soil Loss equation were in the big sagebrush/rabbitbrush community (BSR). The modified Musgrave

Figure 25. Australia rangeland plant communities with R^2 values equal to or greater than .10, indicating amount of variance explained by three erosion prediction equations. All data pooled over mulga grove, mulga intergrove, and mulga intermediate communities together with the indicated combination of WET, DRY, SEPT, NOV.


* SIGNIFICANT AT THE .10 LEVEL
UNIVERSAL SOIL LOSS EQUATION
MODIFIED MUSGRAVE EQUATION
MODIFIED UNIVERSAL SOIL LOSS EQUATION
R^2
1.0
.80
.60
.40
.20
0
WET DRY SEPT NOV
WET DRY NOV
* DRY NOV
SEPT DRY
WET NOV
NOV WET
SEPT DRY
WET DRY SEPT NOV
WET DRY SEPT
WET * SEPT
WET SEPT
MSS
WOL
MPG
GLG
FLP

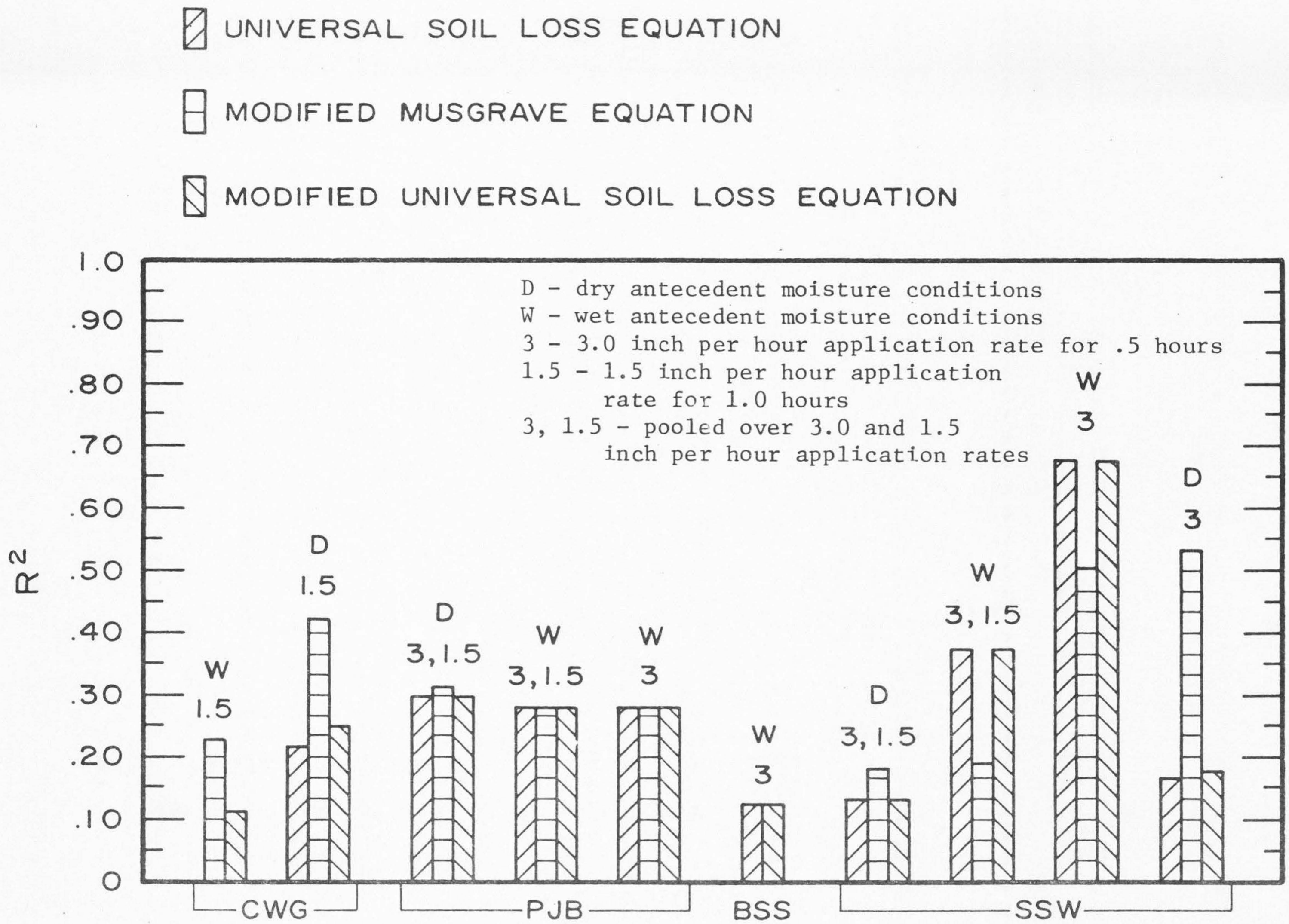


Figure 26. Nevada rangeland plant communities with R^2 values greater than or equal to .10 indicating amount of variance explained by three erosion prediction equations. (No R^2 values are significant at or above the .10 level).

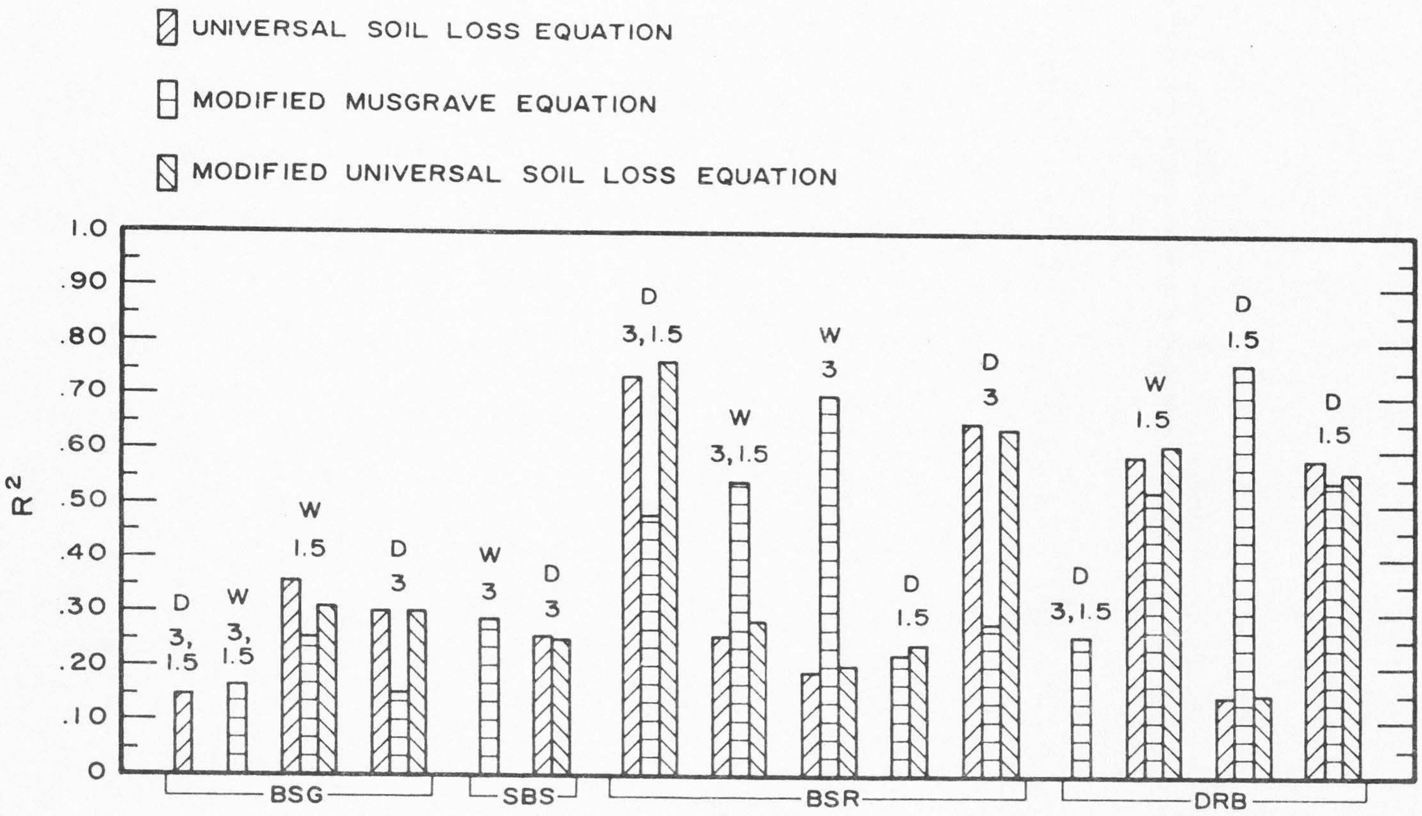


Figure 26. Continued.

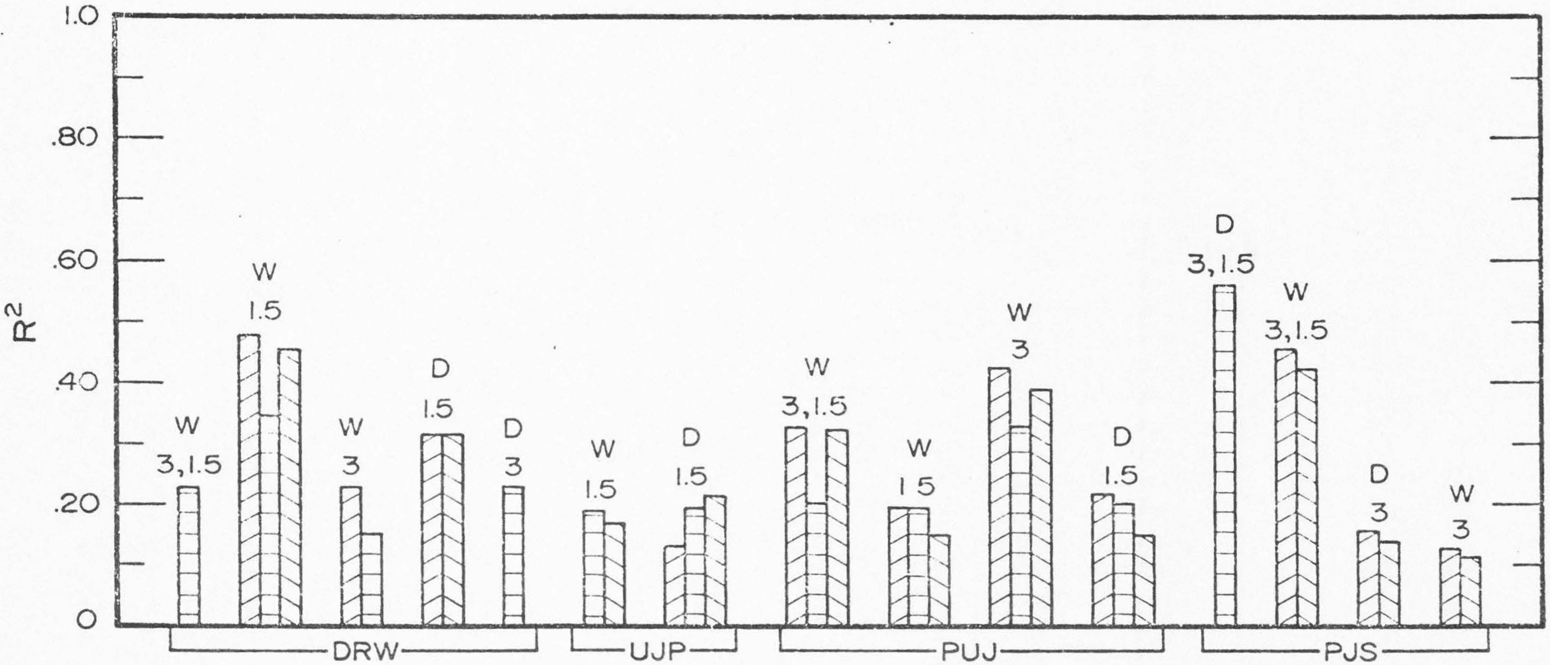


Figure 26. Continued.

equation explained soil loss the best in the Douglas rabbitbrush community (DRB). In all the other communities, the three equations had R^2 values between 0 and .76. The pinyon-juniper/black sagebrush community (PJB) is of interest since R^2 values were very close to the same for all three equations in three different situations. This circumstance illustrates the concept of a "universal" equation; regardless of the application rate or antecedent moisture condition, the predictability remains the same.

Pinyon-juniper (P-J) plant communities, varying geographic locations in Utah

Variability in predicting soil loss in untreated pinyon-juniper plant communities was very high with only two P-J sites (CC and HN) having relatively good R^2 values (Figure 27). But, the CC and HN sites each had data from only three plots resulting in a low level of significance. Thus, the erosion prediction equations are not very suitable for use in untreated pinyon-juniper communities in central and southern Utah.

Untreated big sagebrush plant communities

The only R^2 value greater than 0.1 for the big sagebrush communities was .1 for the modified Musgrave equation calculated from big sagebrush (Ida) data sampled August 6, 1968, before plowing.

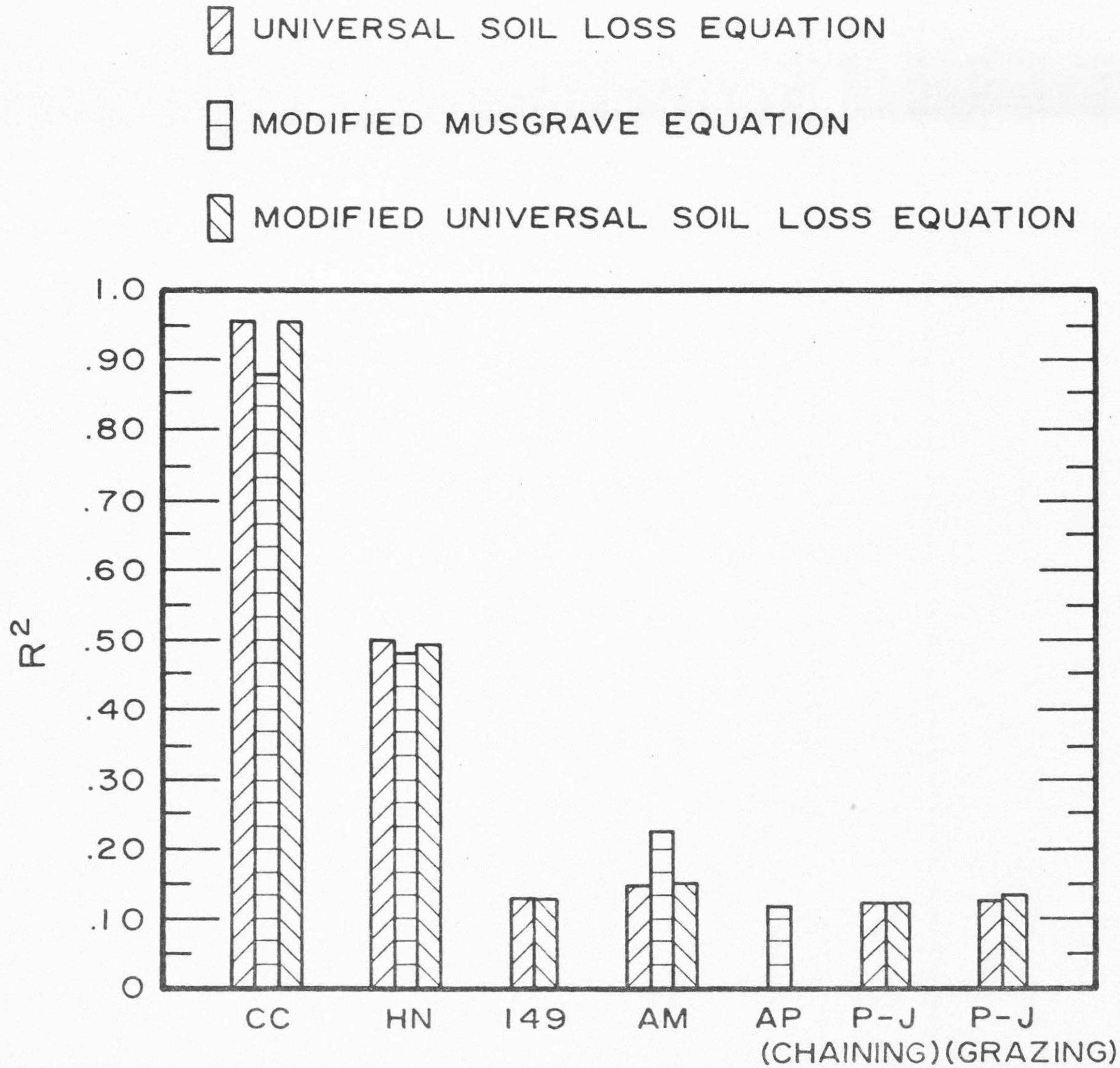


Figure 27. R^2 values for all untreated pinyon-juniper sites equal to or greater than 0.1 indicating amount of variance explained by three erosion prediction equations. P-J (chaining) and P-J (grazing) data were from plots before treatment, but have been moderately grazed. (No R^2 values are significant at or above the .10 level.)

Geologic Types

The R^2 values for all the geologic type data (Price River Basin) pooled was less than 0.1 for each equation. However, when the Price River Basin was subdivided into different geologic types, relatively good coefficients of determination were obtained. Predictability was fairly consistent with most R^2 values between .3 and .6 (Figure 28). No one equation was the best predictor of sediment yield on all geologic types. However, the modified Musgrave equation showed the highest R^2 values. This shows a possibility for subdividing a watershed into different geologic types, applying a chosen erosion equation, and then integrating the predicted sediment yield from each geologic type in the watershed to give the total predicted sheet erosion for the entire watershed.

Mine Sites

The three prediction equations explained sediment yield the best on mine spoils and tailings. Many R^2 values on individual sites ranged from about .70 to as high as .99 (Figures 30 and 31). The R^2 values for all sites sampled in 1975 pooled over tailings and spoils and all sites sampled in 1976 pooled over tailings and spoils were not exceptional (Figure 29). However, when the tailings and spoils sites were separated, sediment yield was explained better on tailings than spoils, especially on the mine sites sampled in 1975. The individual sites in Figures 30 and 31 show no consistent trends or patterns among sites that were on flat and steep slopes and sites that were revegetated.

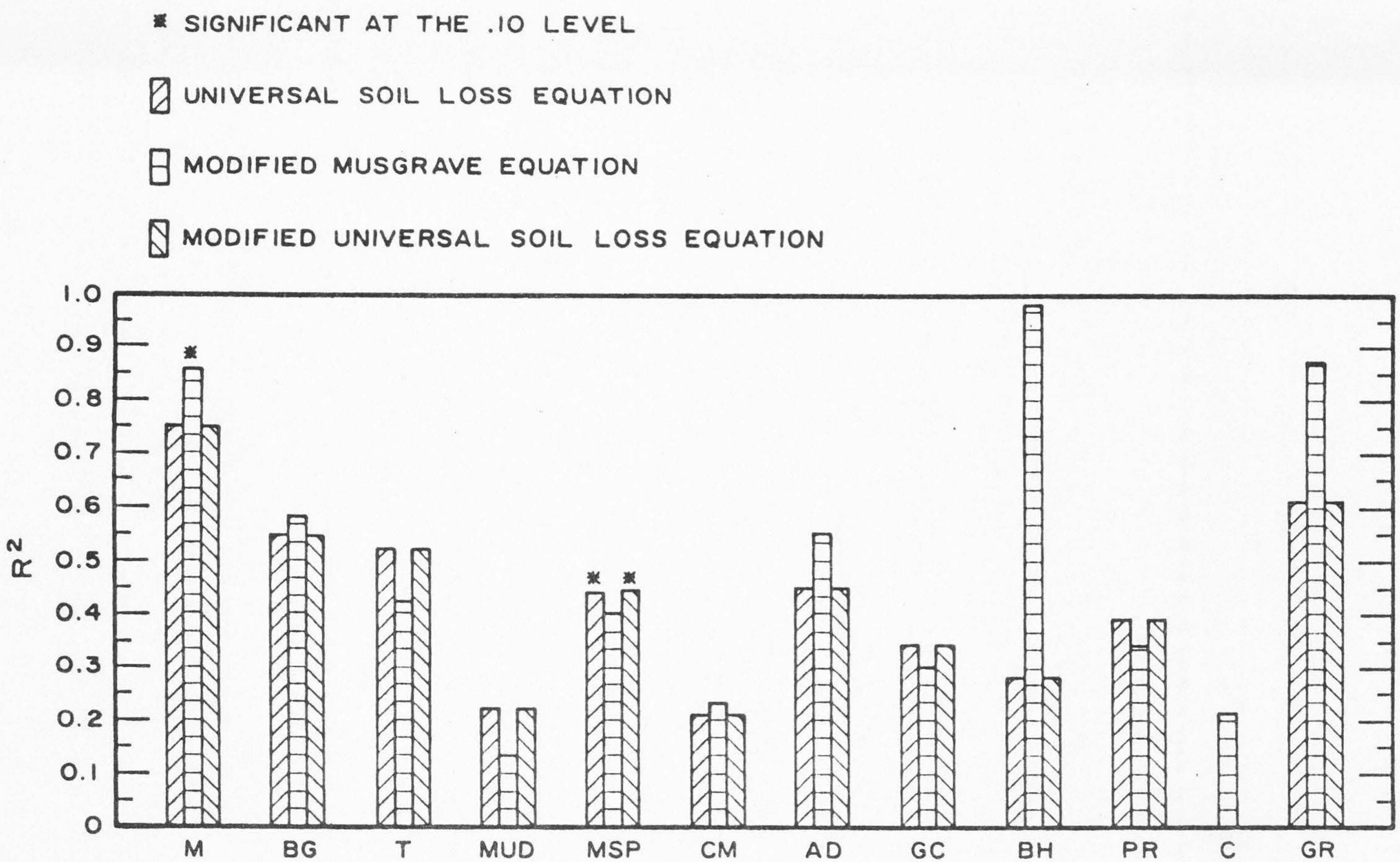
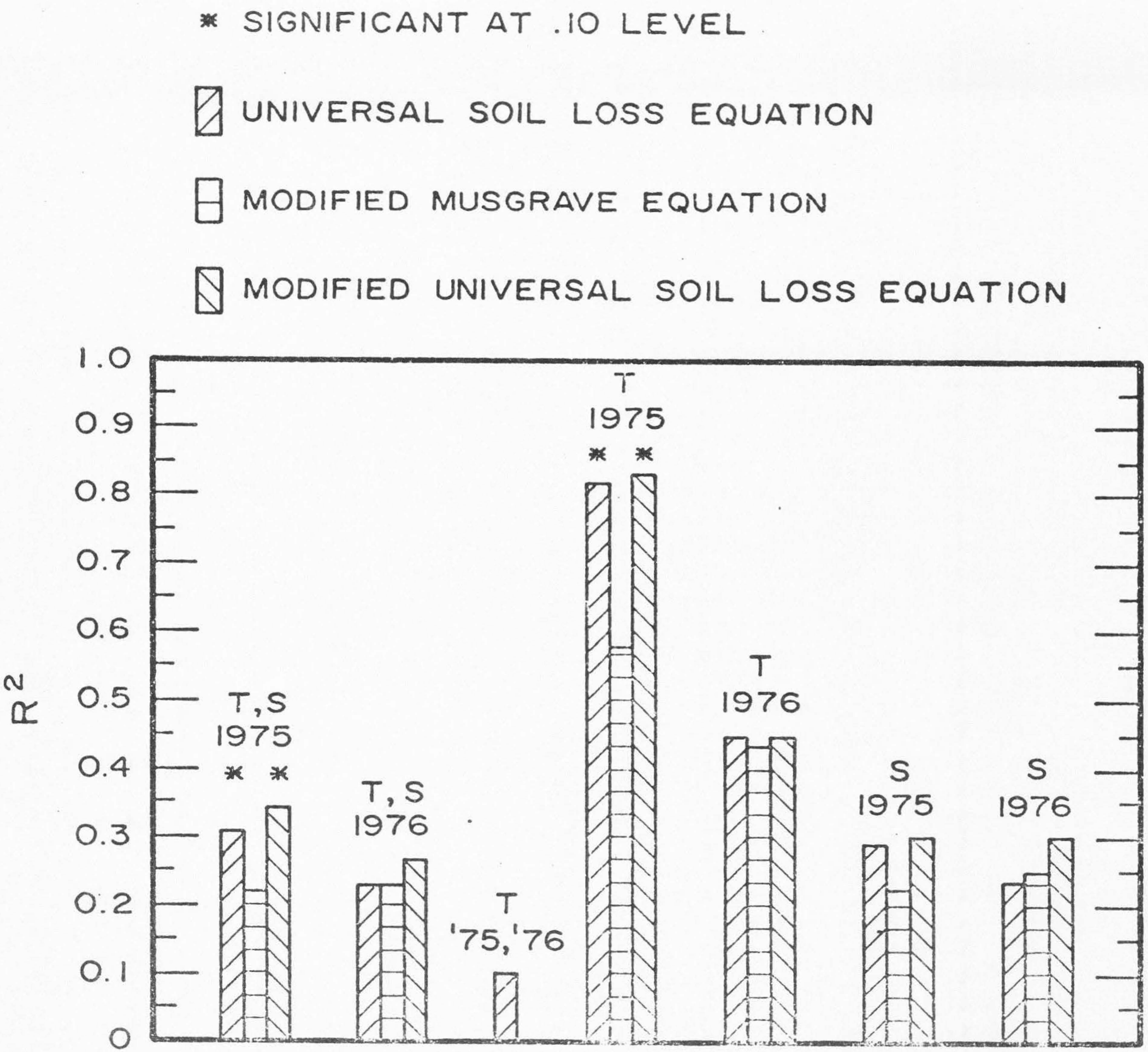


Figure 28. R^2 values equal to or greater than .10 indicating the amount of variance explained by three erosion prediction equations using data from different geologic types.

Figure 29. R^2 values greater or equal to .10 indicating amount of variance explained by three erosion prediction equations using data for mine sites pooled over two sampling periods and tailings and spoils, and data subdivided into sampling period, spoils, tailings.


* SIGNIFICANT AT .10 LEVEL
UNIVERSAL SOIL LOSS EQUATION
MODIFIED MUSGRAVE EQUATION
MODIFIED UNIVERSAL SOIL LOSS EQUATION
R^2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
T, S 1975
T, S 1976
T '75, '76
T 1975
T 1976
S 1975
S 1976

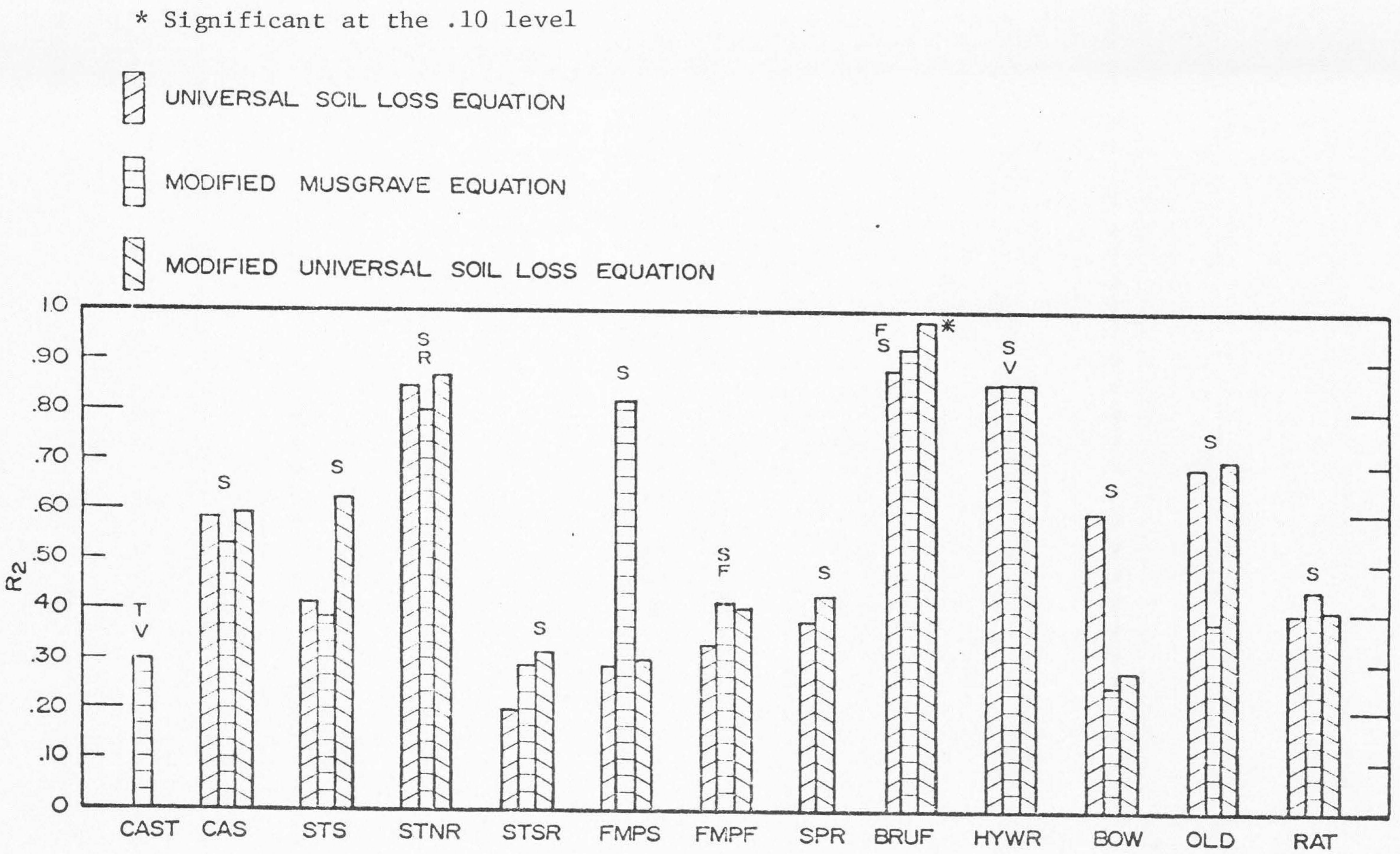


Figure 30. R^2 values equal to or greater than .10 for individual mine sites sampled in 1975, indicating amount of variance explained by three erosion prediction equations.

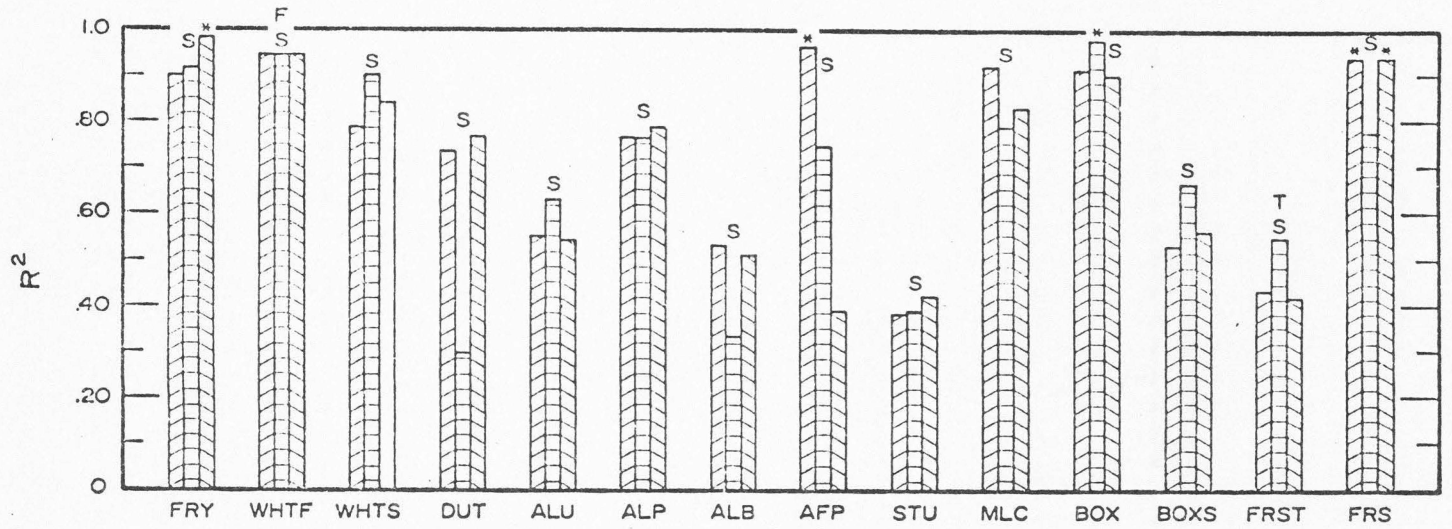
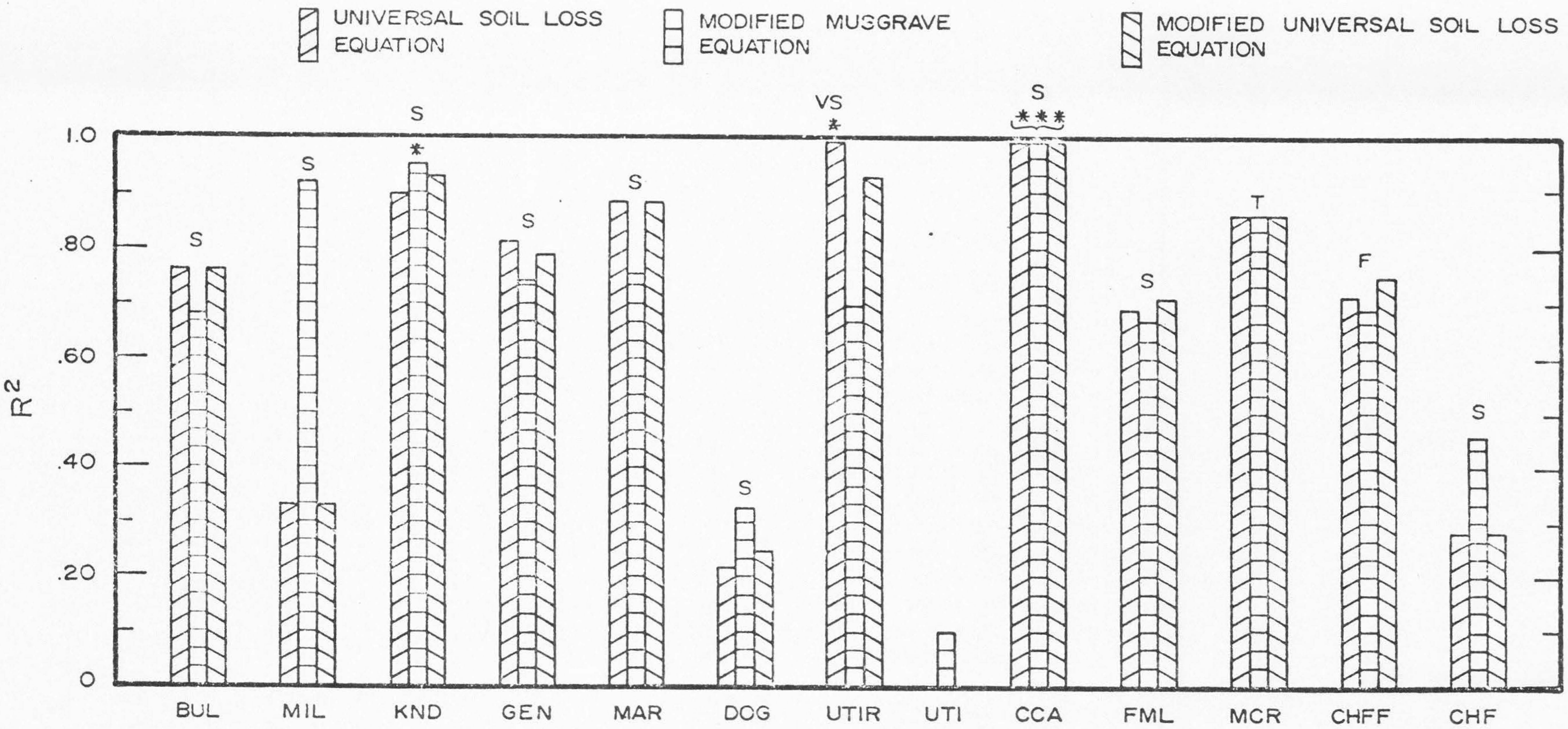


Figure 30. Continued.



*Significant at the .10 level

***Significant at the .01 level

Figure 31. R^2 values equal to or greater than .10 for individual mine sites sampled in 1976, indicating amount of variance explained by three erosion prediction equations.

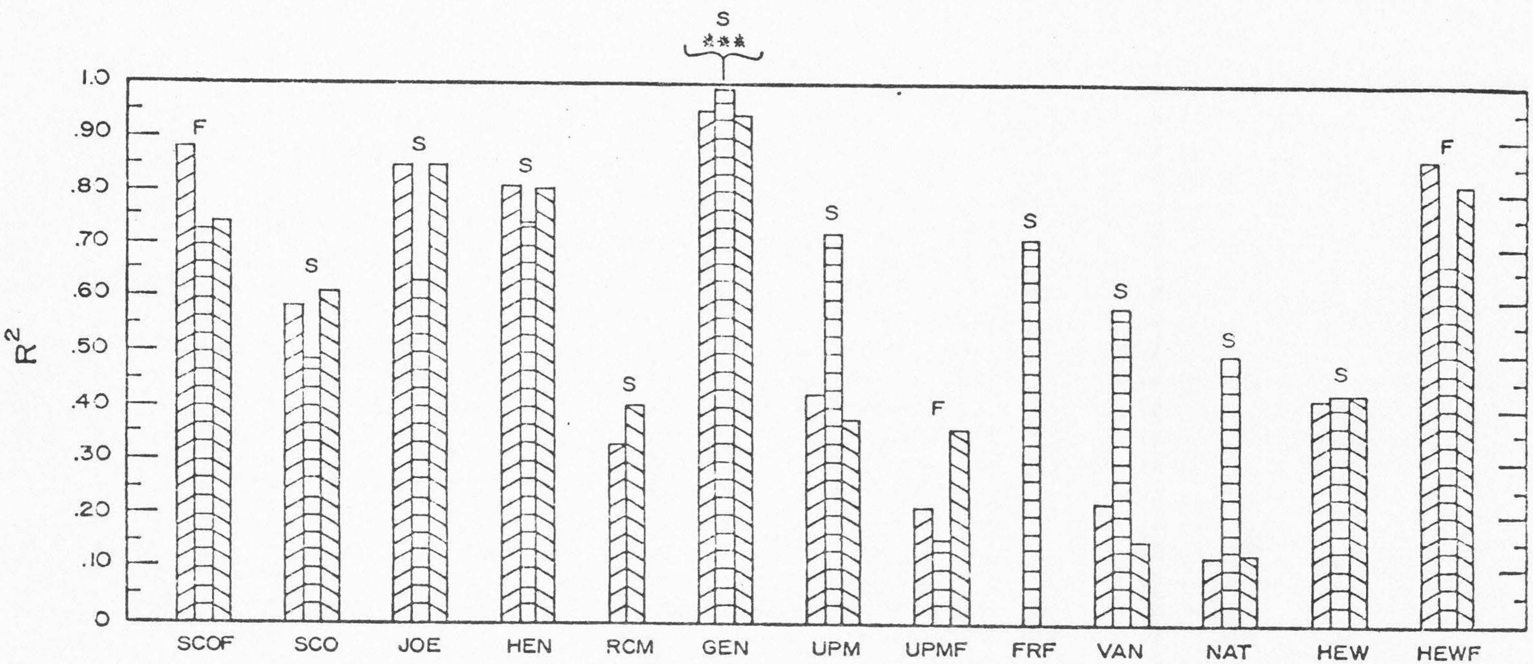


Figure 31. Continued.

The nature of mine spoils and tailings, i.e., their relatively simple composition as compared to rangeland plant communities, is the most likely reason for the high R^2 values because: (1) they have little or no vegetation, (2) any vegetation that may exist is new and has not had enough time to affect soil properties, (3) the slopes are all approximately the same angle (critical angle) due to the nature of the mining operation; and (4) the soils are in the earliest stages of formation with no structure and are somewhat similar to soils in a cultivated fallow condition (the erosion equations were derived from data in cultivated fallow conditions).

Plowed Big Sagebrush

The amount of variance in predicting sediment yields by the three equations differed in respect to the sampling period (Figure 32). An increasing trend in R^2 values appeared during the 1969 to 1970 sampling periods, and then a decrease in R^2 values occurred from 1970 to 1972 when cattle were grazing the plowed area. Prior to plowing (August 6, 1968), the predictability of the three equations was very low. This shows a trend in that the equations are more applicable in a plowed big sagebrush situation than when the big sagebrush was undisturbed. This could perhaps be due to a similarity between the plowed condition and a fallow condition from which data for the derivation of the equations was collected. (Similar results were noted from the mine sites results.) Once grazing began, (trampling, compaction, etc.) very little sediment yield variance was explained.

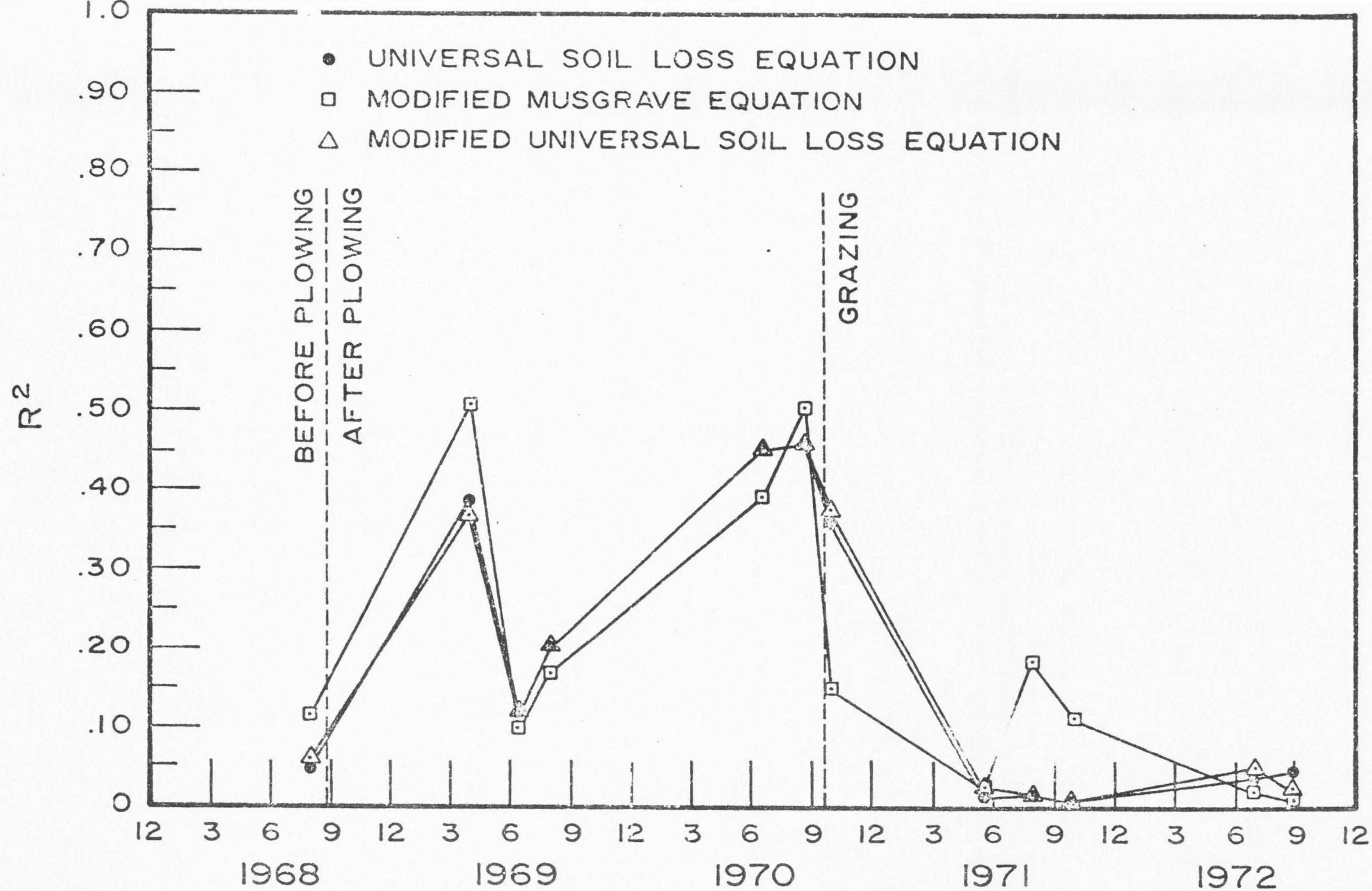


Figure 32. R^2 values for various sampling dates on the big sagebrush (Ida) sampling site indicating amount of variance explained by three erosion prediction equations. (No R^2 values are significant at or above the .10 level.)

These findings are similar to those of Gifford and Busby (1974) where it was found that easily measured soil cover characteristics do not adequately reflect the hydrologic performance of a big sagebrush site which has been grossly modified by activity such as plowing or grazing.

It is interesting to note that R^2 values obtained by Gifford and Busby (1974) using multiple regression techniques were very close to the R^2 values obtained from the three erosion equations evaluated in this study for the sampling periods given in Table 15.

Table 15. Similarity in R^2 values between results from Gifford and Busby (1974) and the Universal Soil Loss (1) modified Musgrave (2), and modified Universal Soil Loss (3), equations

Date	Gifford and Busby (1974) (R^2)	Equations 1, 2 & 3 (R^2)
June 20, 1970	.45	1 - .45 2 - .39 3 - .45
June 27, 1970	.42	1 - .46 2 - .50 3 - .46
October 3, 1970	.38	1 - .36 2 - .15 3 - .37
July 25, 1972	.08	1 - .03 2 - .02 3 - .04

Grazed and Chained Pinyon-Juniper

One Site, Southeastern Utah

R^2 values shown in Figure 33 do not show any definite trends or patterns when the three erosion equations were applied to any intensively sampled grazed and chained pinyon-juniper site. Unchained woodland and debris-in-place conditions showed a slight increase in predictability after grazing was excluded for two years, but then showed a decrease after four years of protection. The opposite effect was true of the windrowed treatment.

Modification of Erosion Equations by

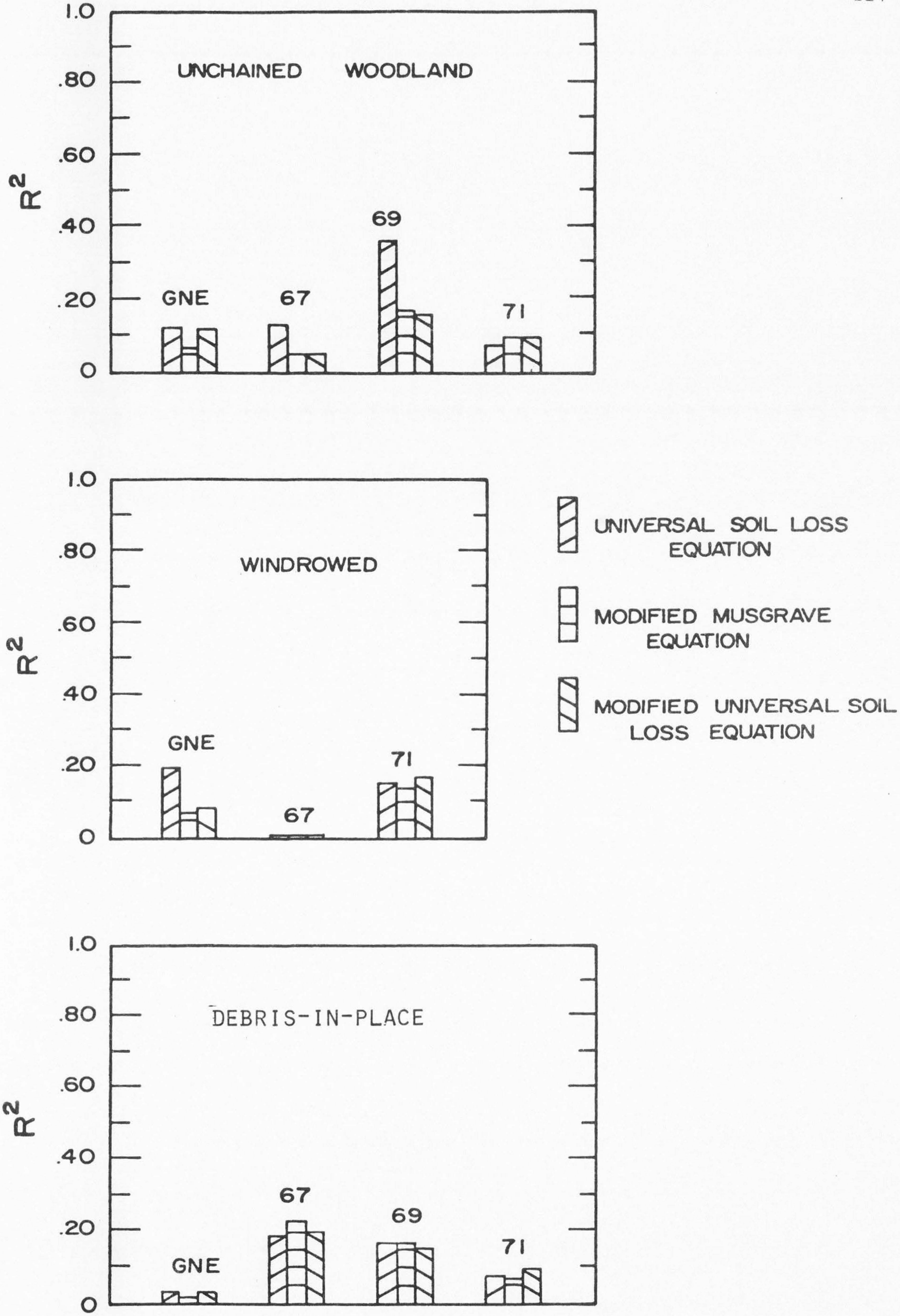
Multiple Regression Techniques

Only a slight improvement in R^2 values resulted when the factors of each equation were optimized with exponents determined by a least squares fit using multiple regression techniques to arrive at a new prediction equation (Table 16).

Table 16. Comparison of R^2 values in three erosion prediction equations before and after optimization of coefficients using multiple regression techniques

Equation	Before		After	
	R^2	N	R^2	N
Universal Soil Loss	.10	2903	.13	2903
Modified Musgrave	.13	2903	.16	2903
Modified Universal Soil Loss	.10	2903	.14	2903

Figure 33. R^2 values indicating amount of variance explained by three erosion prediction equations using data from the pinyon-juniper (grazing) study. All data is pooled over four sampling periods. (No R^2 values are significant at or above the .10 level.)


1.0
.80
.60
.40
.20
0
R^2
UNCHAINED WOODLAND
GNE
67
69
71
WINDROWED
GNE
67
71
DEBRIS-IN-PLACE
GNE
67
69
71
UNIVERSAL SOIL LOSS EQUATION
MODIFIED MUSGRAVE EQUATION
MODIFIED UNIVERSAL SOIL LOSS EQUATION

The new prediction equations were as follows:

Universal Soil Loss

$$\hat{Y} = .190\ R^{.65}\ K^{.08}\ L^{.99}\ S^{.49}\ C^{-.05}$$

Modified Musgrave

$$\hat{Y} = 164.4\ R^{.63}\ K^{-.02}\ L^{7.7}\ S^{.15}\ C^{.36}$$

Modified Universal Soil Loss

$$\hat{Y} = .014\ R^{.54}\ K^{-.02}\ L^{-.80}\ S^{.22}\ C^{-.004}$$

where

$\hat{Y}$ is the new predicted sediment yield in tons/acre, and

R, K, L, S, C, are the original factors computed in accordance with their respective equation.

No improvements in the equations resulted when they were screened in a computerized regression analysis that deletes the variable contributing the least to the regression model (until one variable remains).

CONCLUSIONS AND RECOMMENDATIONS

As applied in this study, the Universal Soil Loss, modified Musgrave and modified Universal Soil Loss equations are not "universal" on a per storm basis. The amount of variation in explaining sediment yield is sensitive to soil condition, plant community, antecedent moisture condition, and season. The effects of antecedent moisture and season may be "evened out" over a year, or several years, but, further research is needed to verify this assumption. Using R^2 values as an index, predictive abilities in various plant communities would seem to be, for the most part, almost random. No patterns or trends exist for use as an aid in applying the prediction equations to account for specific plant community/antecedent moisture/season interactions.

Relatively good predictions can be obtained on conditions that resemble cultivated continuous fallow (i.e., loosely consolidated) such as mine sites. These areas are somewhat similar to conditions under which the erosion prediction equations were derived.

For the most part, the factors in the three erosion prediction equations do not constitute the important parameters that explain soil loss in wildland conditions on a per storm basis, or else optimizing these factors with exponents would seemingly have accounted for the variability involved.

Recommendations in using the prediction equations are as follows: (1) from the results of this study, the land manager or researcher can find a match (from the results) to the situation in which he is interested in predicting sediment yield, and apply the prediction equation providing that the R^2 value of those situations described in this paper is significant at or above the .10 level, (2) the absolute values from the prediction equations can be adjusted to give a better estimate by solving the regression line equation for the appropriate data source (Figures 14-21) for x using the predicted sediment yield as y, (3) the equations can be applied to situations such as mine sites in which vegetation is sparse and soils are loosely consolidated and undeveloped on the surface.

Further research is definitely needed in predicting sediment yield in wildlands. Many attempts have been made with varying success, but a successful "universal wildland soil loss equation" has yet to be developed. Recommendations for further research are as follows: (1) the influence of rainfall energy on sediment yield has to be defined in terms of high intensity-short duration storms typical of western rangelands, (2) soil erodibility of various wildland soils has to be defined, (3) the effect of various rangeland plant communities on sheet and rill erosion needs to be determined along with seasonal influence, (4) the effects of slope length and slope angle, and their interactions with the above, has to be determined, and (5) development of new erosion prediction equations based on compiling the findings from infiltration and erosion studies where numerous parameters were measured for use in developing erosion prediction equations. Such studies include Meeuwig and Packer (1975), Blackburn (1973), Gifford and Busby (1974), Williams (1969), and Busby (1977).

The designed uses of the soil loss equations were mainly (Wischmeier, 1976), (1) predicting average annual soil movement from a given field slope under specified land use and management conditions, and (2) guiding the selection of conservation practices for specific sites. This study was by no means an attempt to discount use of the soil loss equations in these areas. However, a strong need exists for wildland soil loss equations and the equations evaluated in this study are the "state of the art" and are being applied to western wildlands, and thus, any findings and guidelines in their application serves a great need--a need that has yet to be satisfied.

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APPENDICES

Appendix A

Scientific Names of Plant Species

Grasses

Bluebunch wheatgrass	Agropyron spicatum (Pursch) Scribn. & Smith
Crested wheatgrass	Agropyron desertorum (Fisch.) Schult
Intermediate wheatgrass	Agropyron intermedium (Host.) Beaur.
Sandberg bluegrass	Poa secunda Presi.

Forbs

Arrowleaf balsamroot	Balsamorhiza sagittata (Pursh.) Nutt.
Phlox	Phlox Benth.
Wooly wyethia	Wyethia mollis Gray

Woody Plants

Big sagebrush	Artemisia tridentata Nutt.
Black sagebrush	Artemisia nova (a. Nels.) Ward
Low sagebrush	Artemisia arbuscula Nutt.
Rubber rabbitbrush	Chrysothamnus nauseosus (Pall.) Britton
Single-leaf pinyon or pinyon	Pinus monophylla Torr. & Frem.
Serviceberry	Amelanchier alnifolia M. E. Jones
Snowberry	Symphoricarpos longiflorus Gray
Utah juniper or juniper	Juniperus osteosperma (Torr.) Little
Winterfat	Ceratoides lanata
Douglas rabbitbrush	Chrysothamnus viscidix larus
Shadescale saltbrush	Atriplex canfertifola

Appendix B

Tables of R^2, F, and N Values

N = number of plots

Levels of significance:

* = .10

** = .05

*** = .01

Equation 1 = Universal Soil Loss Equation

Equation 2 = Modified Musgrave Equation

Equation 3 = Modified Universal Soil Loss Equation

Table 17. R^2, F, and N values for data pooled over each individual data source

Data Source	Equation[1/]	R^2	F	N
Australia	1	.41*	162.8	234
	2	.41*	161.8	
	3	.41*	164.9	
Nevada (pool over wet and dry)	1	.01	3.8	732
	2	.02	3.0	
	3	.00	3.0	
P-J Grazing (Williams)	1	.08	35.6	416
	2	.12	57.1	
	3	.08	35.5	
Sagebrush (Idaho)	1	.04	10.8	279
	2	.07	21.6	
	3	.04	11.0	
Mine Sites (Sampled 1975)	1	.31*	63.8	142
	2	.22	38.7	
	3	.34*	73.9	
Mine Sites (Sampled 1976)	1	.23	32.1	107
	2	.23	32.4	
	3	.26	37.1	
P-J Chaining (Busby)	1	.06	48.6	683
	2	.05	32.8	
	3	.06	45.4	
Geologic Types	1	.07	10.5	147
	2	.04	5.9	
	3	.07	10.5	

Table 18. R^2, F, and N values for data collected under wet and dry antecedent moisture conditions

Source	Antecedent Moisture	Equation	R^2	F	N
Australia	Wet	1	.52*	134.3	123
		2	.50*	121.0	123
		3	.52*	131.9	123
	Dry	1	.34	56.2	108
		2	.35	57.0	108
		3	.35	57.5	108
Nevada	Wet	1	.01	5.7	425
		2	.01	3.9	425
		3	.01	2.0	425
	Dry	1	.01	4.4	425
		2	.02	9.1	425
		3	.007	3.1	425
Sagebrush (Ida)	Wet	1	.04	10.8	278
		2	.07	21.6	278
		3	.04	11.0	278
P-J Chaining	Wet	1	.09	45.5	460
		2	.13	70.5	460
		3	.09	45.4	460
Australia + Nevada (Pooled)	Wet	1	0	.14	534
		2	0	2.9	534
		3	0	1.6	534
	Dry	1	0	.31	549
		2	0	.37	549
		3	0	.94	549

Table 19. R^2, F, and N values for Australia data collected during September and November sampling periods. Data pooled over wet and dry antecedent moisture conditions, all plant communities, and mulga grove and intergrove situations.

Source	Date	Equation	R^2	F	N
Australia	September	1	.42*	102.1	140
		2	.43*	106.3	140
		3	.44*	109.1	140
	November	1	.18	19.9	91
		2	.15	16.0	91
		3	.05	5.2	91

Table 20. R^2, F, and N values for Australia plant communities pooled over September, November, wet and dry antecedent moisture conditions, and mulga grove, mulga intergrove, and mulga intermediate situations

Plant Community	Equation	R^2	F	N
Woodland[1/]	1	.02	0.31	16
	2	.04	0.6	16
	3	.08	1.3	16
Mulga perennial	1	.09	7.9	78
	2	.04	3.6	78
	3	.08	6.8	78
Mulga shortgrass	1	.15	8.2	49
	2	.009	0.4	49
	3	.20	12.0	49
Gilgai	1	.08	3.7	46
	2	.05	2.3	46
	3	.16	8.5	46
Floodplain[2/]	1	0		
	2	.02		
	3	.04		

[1/] Sampled September only

[2/] Sampled September only

Table 21. R^2, F, and N values for Australia plant community data for September and November pooled over wet and dry antecedent moisture conditions, and mulga grove, mulga integrove, and mulga intermediate.

Plant Community	Equation	R^2		F		N	
		Sept.	Nov.	Sept.	Nov.	Sept.	Nov.
Woodland	1	.001	--	0.0	--	17	--
	2	.01	--	0.1	--	17	--
	3	.02	--	0.3	--	17	--
Mulga Perennial	1	.02	.29	0.8	24.5	34	60
	2	.01	.10	0.7	6.5	34	60
	3	.02	.12	0.8	8.1	34	60
Mulga Shortgrass	1	.02	.41	0.2	20.5	18	30
	2	.006	.45	0.1	23.9	18	30
	3	.005	.41	0.1	20.2	18	30
Gilgai	1	.53	.03	15.0	0.8	16	29
	2	.21	.03	4.4	0.7	16	29
	3	.66	.007	28.9	0.2	16	29
Floodplain	1	$.4x10^{-5}$	--	0.0	--	17	--
	2	.02	--	0.3	--	17	--
	3	.04	--	0.7	--	17	--

Table 22. R^2, F, and N values for Australia plant community data collected during September and November under dry antecedent moisture conditions and pooled over mulga grove, mulga intergrove, and mulga intermediate.

		R^2		F		N	
Plant Community	Equation	Sept.	Nov.	Sept.	Nov.	Sept.	Nov.
Woodland	1	.002	--	00.1	--	7	--
	2	.32	--	2.8	--	7	--
	3	.07	--	0.4	--	7	--
Mulga Perennial	1	.06	.33	0.8	13.2	14	28
	2	.08	.14	0.6	4.4	14	28
	3	.04	.29	0.6	11.2	14	28
Mulga Shortgrass	1	.02	.89*	0.1	111.7	7	14
	2	.08	.81	0.5	54.7	7	14
	3	.02	.64	0.1	23.1	7	14
Gilgai	1	.30	.31	3.0	4.9	8	12
	2	.27	.29	2.6	4.4	8	12
	3	.65	.19	12.7	2.5	8	12
Floodplain	1	.05	--	0.4	--	8	--
	2	.01	--	0.1	--	8	--
	3	.03	--	0.3	--	8	--

Table 23. R^2, F, and N values for Nevada rangeland plant community data collected under wet and dry antecedent moisture conditions and pooled over 3 inches per hour and 1.5 inches per hour application rates.

Plant Community	Equation	R^2 Dry	R^2 Wet	F Dry	F Wet	N (Wet and Dry)
Black Sagebrush/ shadescale salt-brush (SBS)	1	.03	.03	.39	0.4	15
	2	.001	.008	.14	0.1	
	3	.02	.03	.39	0.3	
Big Sagebrush (BSG)	1	.14	.02	3.6	3.7	54
	2	.001	.16	9.0	10.7	
	3	.06	.08	4.1	3.6	
Big sagebrush/ rubber rabbit brush (BSR)	1	.70	.25	28.6	4.0	13
	2	.47	.54	10.9	13.9	
	3	.72	.27	31.6	4.5	
Douglas rabbit-brush (DRB)	1	.08	.07	1.1	0.6	14
	2	.28	.07	5.2	0.6	
	3	.09	.07	1.2	0.6	
Douglas rabbit-brush/winter fat (DRW)	1	.006	.002	0.1	.03	13
	2	.03	.22	0.3	3.3	
	3	.02	.08	0.2	.30	
Utah juniper (UJP)	1	.01	.07	0.3	1.9	26
	2	.05	.11	1.2	3.0	
	3	.01	.07	0.3	1.4	
Single-leaf juniper/Utah juniper (PUJ)	1	.08	.32	4.4	25.0	54
	2	.05	.20	2.8	13.4	
	3	.06	.32	3.4	25.0	
Big sagebrush/ bluebunch wheat-grass/balsamroot (SWB)	1	.03	.05	0.8	1.0	22
	2	.05	.16	1.0	2.3	
	3	.04	.07	0.8	1.1	
Pinyon-juniper/low sagebrush/sandberg bluegrass (PJS)	1	.14	.12	1.5	1.2	10
	2	.09	.004	0.5	0.8	
	3	.13	.11	1.3	1.2	
Crested wheatgrass (CWG)	1	.006	.001	0.3	0.3	47
	2	.07	.07	0.9	1.2	
	3	.02	.01	0.3	0.8	

Table 23. Continued

Plant Community	Equation	R^2 Dry	R^2 Wet	F Dry	F Wet	N (Wet and Dry)
Big sagebrush/ sandberg blue- grass/arrowleaf balsamroot (BSA)	1	.01	0.3	0.0	0.0	22
	2	.03	.003	0.0	0.0	
	3	.04	.36	0.0	0.0	
Pinyon-juniper/ black sagebrush (PJB)	1	.30	.27	12.1	10.6	29
	2	.31	.27	12.6	10.6	
	3	.30	.27	12.1	10.6	
Big sagebrush/ snowberry (BSS)	1	.001	.002	0.0	0.0	12
	2	.003	.05	0.0	0.0	
	3	.001	.002	0.0	0.0	
Snowberry/big sagebrush/blue- bunch wheatgrass/ woody wyethia (SSW)	1	.13	.37	1.4	5.8	11
	2	.17	.18	2.0	2.1	
	3	.13	.37	1.4	5.8	

Table 24. R^2, F, and N values for Nevada rangeland plant community data collected under wet antecedent moisture conditions and application rates of 3 inches per hour and 1.5 inches per hour

		R^2		F		N	
Plant Communities	Equation	1.5 in/hr	3.0 in/hr	1.5 in/hr	3.0 in/hr	1.5 in/hr	3.0 in/hr
Black sagebrush/ shadescale salt- brush (SBS)	1	.060	.004	0.4	0.0	7	7
	2	.08	.28	0.5	2.3		
	3	.05	.005	0.3	0.0		
Big sagebrush (BSG)	1	.36	0	13.5	0.0	25	28
	2	.25	0	8.4	0.0		
	3	.31	0	11.0	0.0		
Big sagebrush/ rubber rabbitbrush (BSR)	1	.003	.19	0.0	1.4	5	7
	2	.05	.70	0.2	14.1		
	3	.05	.20	0.2	1.5		
Douglas rabbit- brush (DRB)	1	.59	.14	7.0	1.0	6	7
	2	.52	.76	5.5	19.4		
	3	.61	.15	7.9	1.0		
Douglas rabbit- brush/winterfat (DRW)	1	.47	.22	5.3	1.1	7	5
	2	.35	.15	3.2	0.7		
	3	.45	.01	4.9	0.0		
Utah juniper(UJP)	1	.07	.09	0.9	1.0	13	12
	2	.18	.05	2.7	0.6		
	3	.16	.08	2.2	1.0		
Single-leaf juniper/ Utah juniper (PUJ)	1	.19	.42	7.1	15.0	31	22
	2	.19	.33	7.2	10.6		
	3	.14	.49	4.8	19.7		
Pinyon-juniper/low sagebrush/sandberg bluegrass (PJS)	1	.04	.08	0.2	0.2	5	4
	2	.01	.56	0.0	3.8		
	3	.03	.07	0.1	0.2		
Crested wheatgrass (CWG)	1	.08	.007	1.4	0.2	17	29
	2	.23	.02	4.7	0.7		
	3	.11	0	2.0	0.0		
Big sagebrush/sand- berg bluegrass/ arrowleaf balsam- root (BSA)	1	.03	.02	0.1	0.4	4	17
	2	.09	.003	0.3	0.1		
	3	.03	.38	0.1	9.9		

Table 24. Continued

Plant Communities	Equation	R^2 1.5 in/hr	R^2 3.0 in/hr	F 1.5 in/hr	F 3.0 in/hr	N 1.5 in/hr	N 3.0 in/hr
Pinyon-juniper/	1	--	.27				
blacksagebrush	2	--	.27				
(PJB)	3	--	.27				
Big sagebrush/	1	.04	.12	0.2	0.6	5	5
snowberry (BSS)	2	.01	.012	0.1	0.1		
	3	.04	.12	0.2	0.6		
Snowberry/big	1	.008	.68	0.0	8.4	5	5
sagebrush/blue-	2	.008	.50	0.0	4.0		
bunch wheatgrass/	3	.008	.68	0.0	8.4		
wooly wyethia (SSW)							

Table. 25. R^2, F, and N values for Nevada rangeland plant community data collected under dry antecedent moisture conditions and application rates of 3 inches per hour and 1.5 inches per hour.

Plant Community	Equation	R^2 1.5 in/hr	R^2 3.0 in/hr	F 1.5 in/hr	F 3.0 in/hr	N 1.5 in/hr	N 3.0 in/hr
Black sagebrush/ shadescale salt- brush (SBS)	1	.01	.26	0.1	2.2	7	7
	2	.001	.04	0.0	0.2		
	3	.004	.25	0.0	2.0		
Big sagebrush (BSG)	1	.00	.30	0.0	11.7	25	28
	2	.01	.15	0.3	4.6		
	3	.01	.30	0.2	11.3		
Big sagebrush/ rubber rabbit- brush (BSR)	1	.09	.65	0.4	11.0	5	7
	2	.22	.27	1.2	2.3		
	3	.23	.64	1.2	10.7		
Douglas rabbitbrush (DRB)	1	.58	.05	6.9	0.3	6	7
	2	.44	.12	4.0	0.8		
	3	.56	.58	6.3	6.2		
Douglas rabbit- brush/winterfat (DRW)	1	.31	.01	2.7	0.1	7	5
	2	.01	.22	0.1	1.4		
	3	.31	.01	2.7	0.0		
Utah Juniper (UJP)	1	.13	.03	1.8	0.4	13	12
	2	.19	.01	2.8	0.1		
	3	.21	.03	3.1	0.4		
Single-leaf juniper/ Utah juniper (PUJ)	1	.21	.02	8.4	0.4	31	22
	2	.20	.02	7.3	0.4		
	3	.14	.02	4.7	0.5		
Pinyon-juniper/low sagebrush/sandberg bluegrass (PJS)	1	.00	.45	2.5	0.0	5	4
	2	.01	.03	0.1	0.0		
	3	.00	.42	2.1	0.0		
Crested wheatgrass (CWG)	1	.21	.00	4.2	0.0	17	29
	2	.42	.04	11.6	1.0		
	3	.25	.01	5.4	0.3		

Table 25. Continued.

Plant Community	Equation	R^2 1.5 in/hr	R^2 3.0 in/hr	F 1.5 in/hr	F 3.0 in/hr	N 1.5 in/hr	N 3.0 in/hr
Big sagebrush/ sandberg bluegrass/ arrowleaf balsam-root (BSA)	1	.06	.01	0.2	0.3	4	17
	2	.14	.06	0.5	1.0		
	3	.07	.04	0.2	0.6		
Big sagebrush/snow-berry (BSS)	1	.02	.05	0.1	0.2	5	5
	3	.02	.05	0.1	0.2		
Snowberry/big sage-brush/bluebunch wheatgrass/wooly wyethia (SSW)	1	.01	.16	0.1	0.7	5	5
	2	.01	.53	0.1	4.6		
	3	.01	.17	0.1	0.8		

Table 26. R^2, F, and N values for untreated pinyon-juniper community data collected in central and southern Utah

Site	Equation	R^2	F	N
Pinnacle Bench (PB)	1	.002	0.0	8
	2	.00	0.0	
	3	.002	0.0	
Coal Creek (CC)	1	.95	20.2	3
	2	.87	7.0	
	3	.95	19.4	
Wood Hill (WH)	1	.05	0.3	7
	2	.03	0.2	
	3	.05	0.3	
Huntington (HN)	1	.50	1.0	3
	2	.48	0.9	
	3	.49	1.0	
Boulter (BR)	1	.01	0.0	4
	2	.06	0.2	
	3	.01	0.0	
Government Creek (GC)	1	.007	0.1	16
	2	.001	0.2	
	3	.007	0.1	
Fry Canyon (FC)	1	.08	0.4	5
	2	.02	0.1	
	3	.08	0.4	
Brush Basin (BB)	1	.00	0.0	8
	2	.09	0.7	
	3	.00	0.0	
Arca #149 (149)	1	.13	1.6	12
	2	.03	0.4	
	3	.13	1.6	
Alkali Ridge (AR)	1	.02	0.1	7
	2	.02	0.1	
	3	.02	0.1	

Table 26. Continued

Site	Equation	R^2	F	N
Indian Peaks (IP)	1	.02	0.6	27
	2	.03	0.8	
	3	.01	0.3	
Jockeys (JY)	1	.00	0.0	21
	2	.00	0.0	
	3	.00	0.0	
Beaver (BR)	1	.03	0.3	10
	2	.02	0.2	
	3	.02	0.2	
Arrow Head Mine (AM)	1	.14	0.8	6
	2	.22	1.4	
	3	.15	0.8	
All Sites Pooled (AP)	1	.09	16.2	156
	2	.12	21.7	
	3	.09	16.1	

Table 27. R^2, F, and N values for untreated pinyon-juniper and untreated big sagebrush data pooled over all areas

Source	Equation	R^2	F	N
P-J (Grazing + P-J (Chaining)	1	.07	15.5	205
	2	.07	16.9	
	3	.07	15.8	
P-J (Chaining)	1	.12	7.6	56
	2	.07	4.3	
	3	.12	7.9	
Big sagebrush (Ida) + Big sagebrush (Nev)	1	.05	4.2	78
	2	.00	0.3	
	3	.03	2.2	
Big sagebrush (Ida)[1/]	1	.05	1.2	23
	2	.12	3.0	
	3	.07	1.6	

[1/] Data from August 6, 1968 sampling period only

Table 28. R^2, F, and N values for data collected on different geologic types

Geologic Type	Equation	R^2	F	N
Masuk (M)	1	.75	30.4	12
	2	.88*	71.6	
	3	.75	30.4	
Blue Gate (BG)	1	.55	42.0	36
	2	.57	44.6	
	3	.55	42.0	
Tunuk (T)	1	.52	17.3	18
	2	.42	11.5	
	3	.52	17.3	
Mancos Undivided (MUD)	1	.22	4.5	19
	2	.13	2.5	
	3	.22	4.5	
Mancos shale, pooled (MSP)1/	1	.44*	66.2	84
	2	.41	56.5	
	3	.45*	66.2	
Cedar mountain (CM)	1	.21	2.6	12
	2	.23	3.0	
	3	.21	2.6	
Alluvial deposits (AD)	1	.45	8.3	12
	2	.55	12.4	
	3	.45	8.3	
Gravel Caps (GC)	1	.35	5.5	12
	2	.30	4.3	
	3	.35	5.5	
Black Hawk (BH)	1	.28	0.4	3
	2	.98	39.0	3
	3	.28	0.4	
Price River (PR)	1	.39	2.6	6
	2	.34	2.0	
	3	.39	2.6	

Table 28. Continued.

Geologic Type	Equation	R^2	F	N
North Horn (NH)	1	.00	0.0	6
	2	.00	0.0	
	3	.00	0.0	
Cotton (C)	1	.07	0.3	6
	2	.21	1.1	
	3	.07	0.3	
Green River (GR)	1	.61	6.4	6
	2	.88	25.6	
	3	.62	6.4	

1/ Pooled over the Masuk, Tununk, Blue Gate, and Mancos Undivided.

Table 29. R^2, F, and N values for data collected on mine sites and pooled pooled over all tailings and spoils sites

Situation	Equation	R^2	F	N
All sites pooled over 1975 and 1976 sampling periods	1	.03	8.2	250
	2	.06	16.5	
	3	.03	8.9	
All sites sampled in 1975	1	.31*	63.8	142
	2	.22	38.7	
	3	.34*	73.4	
All sites sampled in 1976	1	.23	32.1	107
	2	.23	32.4	
	3	.26	37.1	
All tailings pooled over 1975 and 1976 sampling periods	1	.10	2.0	19
	2	.03	0.6	
	3	.09	1.8	
All tailings sampled in 1975	1	.82*	64.7	15
	2	.57	18.4	
	3	.83*	68.2	
All tailings sampled in 1976	1	.44	1.6	3
	2	.43	1.5	
	3	.44	1.6	
All spoils pooled over 1975 and 1976 sampling periods	1	.03	7.1	230
	2	.06	15.4	
	3	.03	7.9	
All spoils sampled in 1975	1	.28	48.7	126
	2	.19	28.5	
	3	.30	53.5	
All spoils sampled in 1976	1	.23	31.2	31.2
	2	.24	32.2	
	3	.26	36.1	

Table 30. R^2, F, and N values for data collected on individual mine sites sampled in 1975

Mining Site[1/]	Equation	R^2	F	N
Castle Gate-tailings (CAST)	1	.00	0.0	4
(revegetated)	2	.30	1.3	
	3	.00	0.0	
Castle Gate (CAS)	1	.58	4.2	4
	2	.57	4.0	
	3	.63	5.1	
Stauffer, S. E. (STS)	1	.41	2.0	4
(not regraded)	2	.38	1.8	
	3	.62	4.8	
Stauffer, N. W. (STNR)	1	.85	17.4	4
(regraded)	2	.80	12.4	
	3	.87	20.1	
Stauffer, S. W. (STSR)	1	.20	0.8	4
(regraded)	2	.28	1.1	
	3	.31	1.3	
Five Mile Pass (FMPS)	1	.29	1.2	4
(slope)	2	.82	13.4	
	3	.30	1.3	
Five Mile Pass (FMPF)	1	.33	1.5	4
(flat)	2	.42	2.2	
	3	.41	2.1	
Spar Mountain (SPR)	1	.37	1.2	3
	2	.07	0.2	
	3	.43	1.5	
Brush Beryllium (BRUS)	1	.01	0.0	4
(slope)	2	.04	0.1	
	3	.02	0.1	
Brush Beryllium (BRUF)	1	.88	22.7	4
(flat)	2	.92	36.1	
	3	.97*	108.8	

Table 30. Continued

Mining Site[1/]	Equation	R^2	F	N
Keystone Wallace (HYW) (untreated)	1	.84	16.2	4
	2	.80	12.3	
	3	.82	13.7	
Keystone Wallace (KYWR) (revegetated)	1	.85	16.6	4
	2	.86	18.5	
	3	.86	17.9	
Milford Bowana (BOW)	1	.60	4.4	4
	2	.25	1.0	
	3	.27	1.1	
Milford, OID Hickory (OLD)	1	.68	6.5	4
	2	.37	1.8	
	3	.69	6.8	
Rattlesnake Mine (RAT)	1	.40	2.0	4
	2	.44	2.4	
	3	.41	2.1	
Fry Canyon (FRY)	1	.90	27.7	
	2	.91	30.9	
	3	.98*	140.0	
White Canyon (WHTF) (flat)	1	.94	50.5	4
	2	.94	51.0	
	3	.94	50.0	
White Canyon (WHTS) (slope)	1	.78	10.8	
	2	.91	28.7	
	3	.84	15.2	
American Fork, Dutchman (DUT)	1	.74	8.5	4
	2	.29	1.2	
	3	.76	9.3	
Alta, Upper Emma (ALU)	1	.55	3.7	4
	2	.63	5.0	
	3	.54	3.6	
Alta, Parking Lot (ALP)	1	.76	9.5	4
	2	.76	9.6	
	3	.78	10.8	

Table 30. Continued

Mining Site[1/]	Equation	R^2	F	N
Alta, Bel Vega (ALB)	1	.53	3.4	4
	2	.33	1.5	
	3	.51	3.1	
American Fork, Pacific (AFP)	1	.96*	73.8	4
	2	.78	11.2	
	3	.38	1.9	
American Fork, Pacific-tailings (AFPT)	1	.07	0.3	4
	2	.08	0.3	
	3	.08	0.2	
Provo, Stubbs Clay (STU)	1	.37	1.7	4
	2	.38	1.8	
	3	.42	2.2	
Mill Creek (MLC)	1	.88	21.1	4
	2	.79	11.5	
	3	.83	14.7	
Kimberly, North Pond (KMN)	1	.02	0.1	4
	2	.03	0.1	
	3	.13	0.5	
Box Creek (BOX)	1	.91	29.9	4
	2	.97*	92.4	
	3	.90	28.3	
Box Creek - Stockpile (BOXS)	1	.53	3.4	4
	2	.66	6.0	
	3	.56	3.8	
Hiawatha (HIA)	1	.00	0.0	4
	2	.02	0.1	
	3	.00	0.0	
Old Frisco-tailings (FRST)	1	.43	2.2	4
	2	.55	3.7	
	3	.42	2.2	
Old Frisco (FRS)	1	.95*	60.8	4
	2	.78	10.9	
	3	.95	53.3	

[1/] All sites are spoils unless otherwise indicated.

Table 31. R^2, F, and N values for data collected on individual mine sites sampled in 1976

Mining Site	Equation	R^2	F	N
Bullion Canyon (BUL)	1	.76	9.4	4
	2	.68	6.3	
	3	.75	9.2	
Milford (MIL)	1	.33	1.5	4
	2	.92	33.7	
	3	.33	1.5	
King David (KND	1	.90	26.4	4
	2	.95*	54.8	
	3	.93	40.5	
Geneva, Iron Mt. (GEN)	1	.81	12.7	4
	2	.74	8.5	
	3	.78	10.8	
Marysville (MAR)	1	.89	15.7	4
	2	.75	6.1	
	3	.89	16.6	
Dog Valley (DOG)	1	.21	1.1	4
	2	.33	2.0	
	3	.24	1.3	
Utah International (UTIR) (revegetated)	1	.96*	70.0	4
	2	.69	6.8	
	3	.93	37.7	
Utah International (UTI)	1	.07	0.2	4
	2	.10	0.3	
	3	.07	0.2	
Cedar Coal and Ash (CCA)	1	.99***	797.7	4
	2	.99***	758.4	
	3	.99***	829.1	
Five Mile Pass (FML)	1	.69	6.6	4
	2	.67	6.0	
	3	.71	7.4	
Mercur (MCR) (tailings)	1	.86	18.6	4
	2	.86	18.4	
	3	.86	18.1	

Table 31. Continued

Mining Site	Equation	R^2	F	N
Chief #1 (CHFF) (flat)	1	.71	7.2	4
	2	.69	6.6	
	3	.75	8.9	
Chief #1 (CHF)	1	.28	1.2	4
	2	.46	2.5	
	3	.28	1.4	
Scofield (SCOF) (flat)	1	.87	19.4	4
	2	.73	8.3	
	3	.75	9.0	
Scofield (SCO)	1	.58	4.1	4
	2	.47	2.7	
	3	.57	3.9	
Joe's Valley (JOE)	1	.85	16.4	4
	2	.62	5.0	
	3	.85	16.4	
Henifer (HEN)	1	.81	13.0	4
	2	.74	8.6	
	3	.81	12.5	
Rock Candy Mountain (RCM)	1	.32	1.4	4
	2	.06	0.2	
	3	.41	2.1	
Geneva (GEN)	1	.95	56.3	4
	2	.99***	875.4	
	3	.94	43.5	
Upper Marysvale (UPM)	1	.41	2.0	4
	2	.72	7.8	
	3	.37	1.8	
Upper Marysvale (UPMF) (flat)	1	.21	1.8	4
	2	.15	0.6	
	3	.36	1.7	
Firefly (FRF)	1	.07	0.3	4
	2	.71	7.3	
	3	.06	0.2	

Table 31. Continued

Mining Site	Equation	R^2	F	N
Vanadium Queen (VAN)	1	.21	0.8	4
	2	.58	4.1	
	3	.15	0.5	
Natural Bridge (NAT)	1	.11	0.4	4
	2	.50	3.0	
	3	.13	0.5	
Keefer Wallace (KEW)	1	.41	2.1	4
	2	.42	2.2	
	3	.42	2.2	
Keefer Wallace (KEWF) (flat)	1	.86	18.8	4
	2	.66	5.8	
	3	.81	12.7	

Table 32. R^2, F, and N values for data collected on plowed big sagebrush site

Date	Equation	R^2	F	N
(Data pooled over entire year)				
1969	1	.16	10.3	55
	2	.14	8.9	
	3	.16	10.3	
1970	1	.28	25.7	66
	2	.36	36.2	
	3	.28	25.6	
1971	1	.00	0.0	62
	2	.09	14.0	
	3	.00	0.0	
1972	1	.07	4.8	68
	2	.02	1.3	
	3	.06	4.7	
(Sampling periods within each year)				
8/6/68[1/]	1	.05	1.2	23
	2	.11	3.0	
	3	.06	1.6	
4/12/69	1	.38	7.2	13
	2	.51	12.6	
	3	.37	7.1	
6/18/69	1	.11	2.1	19
	2	.10	2.0	
	3	.11	2.1	
8/11/69	1	.20	5.1	21
	2	.17	4.2	
	3	.20	5.1	
6/20/70	1	.45	18.1	23
	2	.39	14.1	
	3	.45	18.0	

Table 32. Continued

Date	Equation	R^2	F	N
8/27/70	1	.46	17.5	22
	2	.50	21.0	
	3	.46	17.6	
10/3/70	1	.36	10.6	19
	2	.15	3.2	
	3	.37	10.6	
5/21/71	1	.01	0.1	19
	2	.07	1.5	
	3	.01	0.1	
8/16/71	1	.01	0.1	18
	2	.18	3.8	
	3	.01	0.1	
9/20/71	1	.00	0.0	23
	2	.11	2.7	
	3	.00	0.0	
5/29/72	1	.04	1.0	20
	2	.04	0.8	
	3	.05	0.9	
7/25/72	1	.03	0.8	23
	2	.02	1.5	
	3	.04	0.9	
9/11/72	1	.04	0.9	23
	2	.02	0.5	
	3	.03	0.7	

1/ Sampling date prior to plowing.

Table 33. R^2, F, and N values for data collected on grazed and treated pinyon-juniper site

Condition	Equation	R^2	F	N
Unchained Woodland				
GNE[1/]	1	.12	7.6	56
	2	.07	4.3	
	3	.13	7.9	
67[2/]	1	.13	7.7	54
	2	.04	7.0	
	3	.03	2.1	
69[3/]	1	.36	27.0	49
	2	.17	9.7	
	3	.16	9.4	
71[4/]	1	.07	4.1	53
	2	.08	5.0	
	3	.09	5.4	
Windrowed				
GNE	1	.20	15.5	64
	2	.07	4.9	
	3	.08	5.8	
67	1	.00	0.0	72
	2	.00	0.0	
	3	.00	0.0	
71	1	.15	11.4	68
	2	.14	10.5	
	3	.16	12.5	
Debris in Place				
GNE	1	.03	1.9	62
	2	.01	0.1	
	3	.01	0.7	
67	1	.19	16.1	70
	2	.21	18.8	
	3	.20	17.7	

Table 33. Continued

Condition	Equation	R^2	F	N
69	1	.16	12.7	70
	2	.16	13.1	
	3	.15	11.8	
71	1	.07	5.2	74
	2	.07	5.9	
	3	.09	7.2	

1/ GNE - Grazing not excluded

2/ 67 - grazing excluded in 1967

3/ 69 - grazing excluded in 1969

4/ 71 - grazing excluded in 1971