Effect of Slope and Rainfall Intensity on Erosion from Sodium Dispersed, Compacted Earth Microcatchments[1]

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ABSTRACT

Knowledge of erosion in microcatchment systems is needed for the design of water harvesting systems. This study was therefore conducted on the effects of microcatchment slope and length on runoff and erosion rates under natural rainfall. Two replicates of a two factor experimental plot design, including 1, 5, 10 and 15% slopes and 3 and 6 m lengths, were built on a gravelly sandy clay loam using 11.2 Mg/ha of NaCl mixed into the surface 2 to 5 cm of soil followed by compaction with a 6-Mg roller after a heavy rain. Most of the erosion was from interrill erosion. Length (m) and storm energy, *E*, (MJ/ha) had no significant effects on erosion. The effects of slope, *s*, (m/m) and maximum 30 min rainfall intensity, I_{30}, (mm/h) were significant at the 0.1% level for the 11 storms studied. These effects were significantly different from those in the USLE (Universal Soil Loss Equation), which underpredicted erosion at low slopes. The best fit equation was $A = (0.0595s^{0.998} + 0.0068)I_{30}^{1.86}$ where A is the estimate of erosion (Mg/ha). The sodium treated surface layer is estimated to last up to 20 yr under our conditions if slopes are kept to 5% or lower on these microcatchments of less than 6m length.

Additional Index Words: **Water harvesting, soil erosion, interrill erosion, length, mulch.**

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MANY WATER HARVESTING catchment surface treatments for increasing runoff have been proposed and tested (USDA, 1975; Dutt et al., 1981). However, probably only the cheapest treatments involving clearing, smoothing, compaction and/or addition of NaCl to the soil surface are economical for crop production (Cluff and Frobel, 1978). Sodium dispersed, compacted earth microcatchments installed at the University of Arizona's Oracle Agricultural Center (referred to as Page Ranch) (Dutt and McCreary, 1974) have been functioning for over 10 yr and support wine grapes and deciduous fruit trees (Mielke and Dutt, 1981).

The present study was conducted to provide information needed to design slope and downslope length of these microcatchments. Increasing slope and decreasing catchment length sometimes increase runoff (Hollick, 1974a, b; Boers and Ben-Asher, 1979). Agronomic, topographic, and climatic factors also influence the choice of catchment length and slope.

The Universal Soil Loss Equation (USLE) indicates that increased slope and length increase erosion. But, the equation, developed using data from plots generally longer than 9 m (Wischmeier and Smith, 1978), is invalid for slope lengths typical of microcatchments. Also the soil erodibility factor in the USLE does not take into account the effects of sodium dispersion or compaction (Singer, et al., 1980; Singer et al., 1982), and represents an average of soil erodibility under both rill and interrill erosion.

Microcatchment design requires equations which quantify runoff and erosion as functions of catchment slope, length, soil and climate. This paper describes erosion studies on microcatchments while a subsequent paper will deal with runoff studies on the same plots.

MATERIALS AND METHODS

Sixteen 2-m wide runoff plots were constructed using the Ap horizon of the White House gravelly sandy clay loam (fine, mixed, thermic Ustollic Haplargid) at Page Ranch, about 36 km north of Tucson, Arizona. There were two replicates of a two factor experimental design which included slopes of 1, 5, 10 and 15% and lengths of 3 and 6 m. Plot

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Table 1. Average soil loss and percent loss by particle size class for each treatment for 11 rainfall events.†

	3 m, 1%	3 m, 5%	3 m, 10%	3 m, 15%	6 m, 1%	6 m, 5%	6 m, 10%	6 m, 15%
Soil loss (Mg/ha)‡	4.1	4.9	6.6	8.0	3.3	5.0	6.9	11.7
Gravel loss, %	5.3	8.9	5.2	8.8	2.5	2.8	9.2	9.3
Sand loss, %	38.6	48.3	43.4	43.5	31.2	28.7	36.6	40.3
Silt loss, %	15.3	14.7	18.3	16.6	18.4	19.6	17.0	21.8
Clay loss, %	40.8	28.1	33.1	31.1	47.9	48.9	37.2	28.6

Average soil composition by percent in each particle size class§

Whole soil		Particles < 2 mm		Particle size class definitions	
Gravel, %	17.1	Sand, %	46.1	Gravel	> 2 mm
Sand, %	38.3	Silt, %	26.0	Sand	0.05 to 2.0 mm
Silt, %	21.5	Silt + vfs, %	34.7	Silt	0.002 to 0.05 mm
Clay, %	23.1	Clay, %	27.9	Clay	< 0.002 mm
				Silt + vfs	0.002 to 0.1 mm

† The number of rainfall erosivity units, EI, was 262 for the 11 events and total rainfall was 15.1 cm.
‡ Soil loss is based on plot surface area, not on horizontal area.
§ For seven samples from a transect across the experimental area. Particle size analysis was done by the pipette method as given by Day (Black, 1965, p. 556–559). H_2O_2 was not used to remove organic matter and "Calgon" was replaced by 53.52 g $Na_4P_2O_7$ and 4.24 g Na_2CO_3 dissolved in 1 L of tap water.

slopes were constructed using forms similar to those used when pouring concrete slabs. Plot thickness was at least 10 cm. Granular NaCl, distributed uniformly on the surface at a rate of 11.2 Mg/ha, was raked into the top 2 to 5 cm of soil. The soil was compacted with four or more passes of a 6 Mg double steel drum roller after rains had wetted the soil. All plots had the same aspect and were protected from overland flow by vertical galvanized steel borders sunk into the surface at their top ends and sides. Galvanized steel sunk level with the plot surfaces conducted runoff from the plots' ends into troughs, sand traps and runoff reservoirs. All runoff and sediment were collected.

Runoff was measured volumetrically, and sediment was subsampled following procedures like those proposed by Brakensiek et al. (1979, p. 280–282). Details of sampling and laboratory analysis were given by Evett (1983). Rainfalls were measured using a universal weighing-type recording rain gage and two wedge-type plastic rain gages as checks. The recording gage was calibrated to read within 0.1 cm at 2.5 cm rainfall indicated on the chart and within 0.07 cm of higher indicated readings up to 15.2 cm. The remoteness of the site precluded the collection of data and samples after every individual rainstorm, especially when more than one storm passed through in a single day. Such combinations of events were defined as a single event. Data analysis was done using SPSS (Nie et al., 1975) in the 1979 update version.

RESULTS

Average soil losses for the 11 runoff events, soil losses by particle size class and the average particle size classification for the Ap horizon are shown in Table 1. Soil loss per unit area was strongly dependent on slope with losses on 15% slopes being from two to three and a half times those on 1% slopes.

Plot length had little effect on erosion for plots with 5 and 10% slopes. For plots with 15% slopes, the 6 m plots showed an erosion rate about 50% higher than that shown by the 3 m plots. At 1% slopes the 3m and 6m plots showed the reverse, with the 3m, 1% plots having 23% higher average erosion than the 6 m, 1% plots.

The higher erosion rates on 3 m, 1% and 6 m, 15% plots may have been unusually high. Quail dug holes as large as 3 cm deep and 20 cm in diameter on these plots in February and March, 1982. Also, compaction of the 6 m, 15% plots was difficult due to their steepness and length whereas the shorter 3 m, 15% plots presented no such difficulty. Hollick (1974a) reported similar problems using large rollers on steep plots. Less compaction could result in more erodible soil and the higher erosion rates exhibited by the 6 m, 15% plots.

Table 2. SI units for the USLE factors.

Symbol	Factor	SI units	Abbreviation
E	Storm energy	megajoule per hectare	or MJ ha^{-1}
EI	Storm erosivity	megajoule millimeter per hectare hour	or MJ mm per ha h
R	Annual erosivity	megajoule millimeter per hectare hour year	or MJ mm per ha h y
K	Soil erodibility	megagram hectare hour per hectare megajoule millimeter	or Mg ha h per ha MJ mm
L†	Slope length	Dimensionless	
S‡	Slope steepness	Dimensionless	
C	Cover management	Dimensionless	
P	Supporting practices	Dimensionless	

† $L = (\lambda/22.1)^m$, where λ is plot length in meters, and m is 0.3 for 1% slopes and m is 0.5 for 5, 10, and 15% slopes.
‡ $S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065$, where θ is the angle of slope in degrees.

As Table 1 shows, none of the plots lost gravel in as high a proportion as it exists in the soil. The steeper plots generally lost particle sizes in proportions that more closely followed the proportions found in the soil. All of the plots lost a higher proportion of clay than that present in the original soil, with the less steep plots generally losing a higher proportion of clay. This preferential loss of small particles formed a gravel and sand mulch on the plots.

Erosion Modeling

The first step in modeling was to test the USLE against the actual erosion data on a storm by storm basis. The USLE was developed to provide estimates of longer term average soil loss, not for modeling erosion from single storms nor on plots as short as ours. However, it was regarded as a useful starting point for modeling with the expectation that modifications would be required. The USLE is written as (Wischmeier and Smith, 1978):

$$A = RKLSCP \qquad [1]$$

where A is soil loss in megagrams per hectare for a given period, usually a year. The units for the factors R, K, L, S, C and P are given in Table 2 (Foster et al., 1981a).

When the USLE is applied to individual storms, storm erosivity, EI, is used in place of R, the average annual sum of storm erosivity units. The EI is the product of the energy value, E, (MJ/ha) for each storm and the maximum 30 min. rainfall intensity, I_{30}, (mm/h) for that storm. The EI value was calculated using all of the rainfall data for each runoff event. Calculations of R usually exclude rains of less than 12.7 mm separated from other rain periods by more than 6 h unless at least 6.4 mm of rainfall occurs in 15 min (Wischmeier and Smith, 1978). Under tilled and cropped conditions these small rainfalls might be expected to produce little or no runoff or erosion. We included all storms because of the high runoff potential and increased erodibility of our plots.

The cover and management factor, C, was taken to be 1.00 even though some gravel mulch evolved on the plot surfaces during the experiment. Longer studies might show the necessity of estimating a C value based on the different amounts and sizes of gravel mulch on plots of different slopes. The C value of 1.00 is the same as that for a construction slope with no mulch since our treatments left the soil surface completely without protection and removed the residual effect of prior vegetation (Wischmeier and Smith, 1978, p. 31, Table 9). Since no support practices existed, the support practice factor, P, was taken as 1.00.

A value for the soil erodibility factor K, was calculated from the equation:

$$K = 0.1317[2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)]10^{-2} \quad [2]$$

(Wischmeier and Smith, 1978) where a is percent organic matter, b and c are the soil structure code and profile-permeability class, respectively, from Soil Taxonomy (Soil Survey Staff, 1975), and M is defined by the equation: M = (percent silt + percent very fine sand)(100 − % clay). For the White House soil at Page Ranch, the value of a is about 0.5 (Soil Conservation Service, 1982), and b and c were taken to be 4 and 6, respectively (massive structure and very slow permeability). Using the data on particle size composition from Table 1, K was calculated to be 0.0422. This K value may be too small since soil erodibility is enhanced by the sodium salt treatment (Singer et al., 1980; Singer et al., 1982).

The USLE model was thus reduced to:

$$A_e = EI(0.0422)LS \quad [3]$$

where A_e represents the soil loss estimate (Mg/ha) and the right-hand side of the equation is the USLE estimate of soil loss. The slope steepness factor, S, and the slope length factor, L, were calculated as shown in Table 2.

A linear model of the form $A = B_0 + B_1A_e + \epsilon$ was used to see how well the USLE estimate of soil loss, A_e, followed the actual soil loss, A, (Mg/ha) from the plots. The term ϵ is an error term, and B_0 and B_1 are regression coefficients that would be zero and one respectively if the USLE perfectly estimated the soil loss. The fitted equation was:

$$A = 0.165 + 0.923A_e \quad [4]$$

with residual sum of squares = 23.5. Equation [4] explained about 78% of the variability in the data. The slope and intercept were significantly different from one and zero, respectively, at the 5% level of probability indicating that the USLE did not satisfactorily estimate soil loss from our plots.

Importance of Plot Length

An analysis of variance was conducted for soil loss per unit area with plot slope and length as the factors and with EI as the covariate. Both EI and slope were significant at the 0.1% level, but plot length was not significant even at a level of 30% probability of a type one error. Interaction between plot slope and length was also insignificant, even at the 15% level. A multiple linear regression of soil loss rate against EI was subsequently performed using dummy variables for slope, length and interactions between slope and length. This analysis resulted in eight regression equations, one for each treatment. For a given plot slope, the regression coefficients for a 3 m treatment were not significantly different, at the 5% level of probability, from the coefficients for 6 m plots except for plots on the 15% slope. For plot slopes of 15% the equation slope for the 6 m plots was significantly greater than that for 3 m plots, indicating a higher erosion rate on 6 m, 15% plots, apparently caused by inadequate compaction and bird damage as mentioned above. Therefore, we conclude that slope length up to 6 m does not have an important effect on erosion for our plots at slopes of 1, 5 and 10%, and slope length is probably not important for our plots at 15% slope as well. Work by Foster et al. (1977 a, b; 1981b) indicates that slope length has little effect on erosion per unit area under conditions for which interrill erosion dominates and rill erosion is small. Therefore, it appears that interrill erosion is the dominate erosional process under our conditions.

Effect of Slope

After eliminating plot length, the erosion model was reduced to some function of slope and EI times a constant representing the combined effects of factors K, C and P. Nonlinear regression (SPSS NONLINEAR, Robinson, 1979) was used to fit several models the best of which had the form:

$$A = (B_1s^{B_2} + B_3)EI + \epsilon \quad [5]$$

where B_1, B_2 and B_3 are the regression coefficients and s is again slope (m/m). The USLE slope steepness equation was also fit to the data but the root mean square residual was identical to that for Eq. [5], indicating that Eq. [5] worked just as well.

The estimation equation resulting from fitting Eq. [5] was

$$A_e = (0.642s^{1.77} + 0.015)EI \quad [6]$$

with a residual sum of squares of 13.5, a considerable improvement over the unmodified USLE. The constant 0.015 was significantly different from zero and the exponent 1.77 was significantly different from one at the 5% level but the approximate 95% confidence interval for the coefficient 0.642 included zero. Since

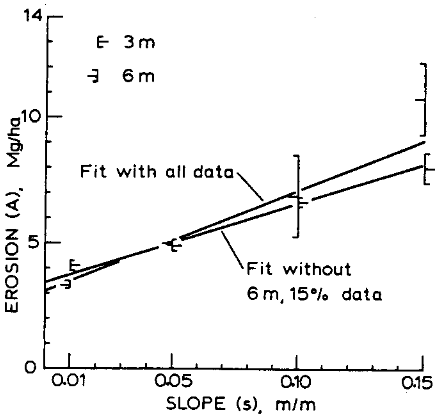

Fig. 1—Cumulative erosion versus plot slope for the 11 runoff producing events. Shown are values for each replicate and average values for each treatment. Linear regression lines are fit to all data, and to data excluding that from the 6 m, 15% treatment.

the data from the 6m, 15% treatment were questioned earlier we again used Eq. [5], but excluded data from the 6 m, 15% plots, resulting in:

$$A_e = (0.108s^{0.963} + 0.013)EI \qquad [7]$$

The residual sum of squares was 5.7, a reduction of 58% resulting from exclusion of only one eighth of the data. The coefficients 0.108 and 0.013 were significantly different from zero at the 5% level. Figure 1 illustrates how the data from the 6 m, 15% treatment does not fit the overall trend. Since we had good reason to believe that the 6 m, 15% plots were not representative of properly constructed microcatchments of our type, we eliminated data from those plots in all subsequent analyses.

The Storm Erosivity Factor

Examination of a plot of the residuals (actual soil loss minus predicted soil loss) for Eq. [7] revealed no consistent trends related to plot length and slope indicating that the effect of these variables was adequately modeled. However, there was a strong trend associated with *EI*.

Energy of rainfall in southeastern Arizona is higher than would be predicted by the USLE energy-intensity relationship (Wischmeier and Smith, 1978; Tracy, 1983). In addition, since erosion on sodium affected soils has been shown to be unrelated to erosion as predicted by the USLE (Singer et al., 1980, 1982), it was thought that the effect of *EI* under our conditions might be other than as presented in the USLE.

An analysis of variance for erosion versus slope as a factor, and E and I_{30} as covariates revealed that both slope and I_{30} affected erosion significantly at the 0.1% level of probability but that *E* was not significant even at a 50% probability of type I error. The regression coefficient for *E* was quite small at −0.014, also indicating no relationship between erosion and *E*.

Eliminating *E*, we fit several nonlinear regression models the best of which gave:

$$A_e = (0.0595\, s^{0.998} + 0.0068)I_{30}{}^{1.86} \qquad [8]$$

with a residual sum of squares of 3.7, somewhat improved over that of Eq. [7]. Equation [8] explained

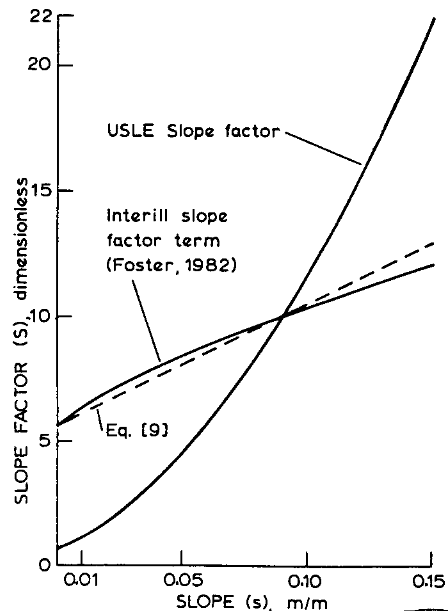

Fig. 2—Comparison of our slope factor, Eq. [9] ($S = 4.72\, s^{0.986} + 0.560$), with the USLE slope factor ($S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.65$), and with the interrill slope factor term of Foster (1982) ($S = 2.96\, [\sin\theta]^{0.79} + 0.56$).

about 94% of the variability in the data. Approximate 95% confidence intervals for the coefficients 0.0595 and 0.0068 were 0.0176 to 0.1015 and 0.0045 to 0.0091, respectively. for the exponents 0.998 and 1.86 the intervals were 0.64 to 1.36 and 1.75 to 1.97, respectively.

Normalization of the slope associated terms from Eq. [8] to give a slope factor, *S*, of unity at 9% slope results in a slope factor term:

$$S = 4.88\, s^{0.998} + 0.56 \qquad [9]$$

which is plotted in Fig. 2 along with the USLE slope factor. Our slope factor shows much less effect of slope on erosion than does the USLE. For an increase in slope from 1 to 15% the USLE slope factor shows more than 18-fold increase in erosion whereas our slope factor predicts only a 2-fold increase in erosion. Meyer et al. (1975) reported that for no-mulch conditions soil loss from 61 cm by 61 cm soil pans increased only about two to three times as slope increased from 1 to 15%. Foster (1982) used the data of Meyer et al. (1975) and Lattanzi et al. (1974) to develop the interrill slope factor term plotted in Fig. 2. Our essentially linear slope factor agrees closely with that of Foster (1982), again implying that the dominant erosional process was interrill erosion on our plots, excepting the 6 m, 15% treatment.

The absence of an effect of storm energy on erosion taken together with the presence of a sand and gravel mulch and the large exponent of I_{30} in Eq. [8] all lead us to suspect that erosion is occurring only when runoff rate is large enough to move the particles in the mulch, thus exposing the underlying plot surface to erosive forces.

Erosion Prediction

Estimation of average annual erosion using Eq. [8] was prevented by a lack of long term data for I_{30} at

Table 3. Projected average annual erosion rates and depths of soil loss for microcatchments 6 m or less in length.

	Slope			
Line	1%	5%	10%	15%‡
1 Projected soil loss (Mg/ha) per year:	14	19	24	30
2 Projected depth of soil eroded per year (mm)†:	0.95	1.3	1.6	2.0
3 Estimated soil loss (Mg/ha) for *EI* = 262 (11 rains):	3.8	5.1	6.6	8.0
4 Actual average soil loss (Mg/ha) for 11 rains:	3.7	5.0	6.8	8.0
5 USLE estimate of soil loss (Mg/ha) averaged for 3 and 6 lengths and for *EI* = 224:	0.7	1.9	4.9	9.2

† Depths were calculated assuming a bulk density of 1.5 Mg/m^3.
‡ For lengths of 3 m or less only.

the site. However, the average annual R value in southern Arizona and New Mexico can be estimated from (Simanton and Renard, 1982):

$$R = 102.4(P_6)^{1.62} \quad [9]$$

where R is in SI units and P_6 is the 2-yr frequency 6-hr duration rainfall in cm from the NOAA Atlas 2 (Miller et al., 1973). For Page Ranch P_6 is 4.01 cm and the estimated R value is 971.

Equation [7] and the estimate of R obtained from Eq. [9] were used to tentatively project the average annual erosion rates and the projected average annual depths of erosion given in the first two lines of Table 3. Verification of these erosion rates over the long term will require further study. Line 4 shows the actual soil loss averaged for each slope. Comparison of line 4 to line 3 shows that Eq. [7] does a good job of estimating soil loss. If the USLE rule for exclusion of small rainfalls is applied, the sum of calculated *EI* is 224, reduced from 262 for the 11 storms by the exclusion of six storms and the reduction of *EI* values for two of the five remaining storms. The USLE severely underestimated erosion rate for the lower slopes as shown on Line 5, Table 3.

Projected erosion would be severe on plots with 15% slopes and most of the sodium dispersed surface layer could be lost in 12 yr. The same soil loss could take about 20 yr on plots with slopes of 5%. For the sake of longevity microcatchment slopes should probably be kept at 5% or lower.

REFERENCES

Black, C.A. et al. 1965. (ed.) Methods of soil analysis, Part 1. Agronomy 9:556–559.

Boers, M. and J. Ben-Asher. 1979. Harvesting water in the desert. *In* Annual Rep. 1979, Int. Inst. Land Reclamation & Improvement, Wageningen, The Netherlands.

Brakensiek, D.L., H.B. Osborn and W.J. Rawls. 1979. Field manual for research in agricultural hydrology. Agric. Handb. 224. Science and Education Administration, USDA, U.S. Government Printing Office, Washington, D.C.

Cluff, C.B., and R.K. Frobel. 1978. Water harvesting catchment and reservoir construction methods. Water resources contribution 2. Water Resources Research Center. College of Earth Sciences, Univ. of Arizona, Tucson, AZ.

Dutt, G.R., C.F. Hutchinson, and M.A. Garduno. 1981. Foreword. *In* Rainfall collection for agriculture in arid and semiarid regions. Commonwealth Agricultural Bureaux. United Kingdom.

Dutt, G.R. and T.W. McCreary. 1974. Multipurpose salt treated water harvesting system. *In* Proceedings of the water harvesting symposium. ARS W-22. Agricultural Research Service, USDA, 1975.

Evett, S.R. 1983. Erosion and runoff from sodium dispersed, compacted earth water harvesting catchments. M.S. Thesis, Univ. Arizona, Tucson. University Microfilms International, Ann Arbor, MI.

Foster, G.R. 1982. Chapter 8 - Modeling the erosion process. p. 320. *In* C.T. Hann, H.P. Johnson and D.L. Brakensiek (eds.). Hydrologic modeling of small watersheds. Am. Soc. Agric. Eng.

Foster, G.R., L.D. Meyer and C.A. Onstad. 1977a. An erosion equation derived from basic erosion principles. Trans. Am. Soc. Agric. Eng. 20:678–682.

Foster, G.R., L.D. Meyer, and C.A. Onstad. 1977b. A runoff erosivity factor and variable slope length exponents for soil loss estimates. Trans. Am. Soc. Agric. Eng. 20:683–687.

Foster, G.R., D.K. McCool, K.G. Renard, and W.C. Moldenhauer. 1981a. Conversion of the Universal Soil Loss Equation to SI metric units. J. Soil Water Conserv. (36)6:355–359.

Foster, G.R., J.R. Simanton, K.G. Renard, L.J Lane, and H.B. Osborn. 1981b. Discussion of "Application of the Universal Soil Loss Equation to rangeland on a per-storm basis" by Trieste and Gifford in J. Range Manage. 33:66–70, 1980. J. Range Manage. 34:161–165.

Hollick, M. 1974a. The development of improvements for farm dam catchments. Final report to the water research foundation of Australia for project 71-215. Dep. of Civil Engineering, Univ. of Western Australia.

Hollick, M. 1974b. The design of roaded catchments for maximum runoff. *In* Proceedings of the water harvesting symposium. ARS W-22. Agricultural Research Service, U.S. Dept. Agric. 1975.

Lattanzi, A.R., L.D. Meyer, and M.F. Baumgardner. 1974. Influences of mulch rate and slope steepness on interrill erosion. Soil Sci. Soc. Amer. Proc. 38(6):946–950.

Meyer, L.D., G.R. Foster, and M.J.M. Romkens. 1975. Source of soil eroded by water from upland slopes. p. 177–189. *In* Present and Prospective Technology for Predicting Sediment Yields and Sources. ARS-S-40. Agricultural Research Service, USDA.

Mielke, E.A., and G.R. Dutt. 1981. Deciduous tree and vine fruit production using water harvesting techniques. *In* Rainfall collection for agriculture in arid and semiarid regions. Commonwealth Agricultural Bureaux. United Kingdom.

Miller, J.F., R.H.J. Frederick and R.J. Tracey. 1973. Precipitation frequency atlas of the western United States, VIII: Arizona. NOAA Atlas 2. National Weather Service, NOAA, Silver Springs, MD.

Nie, N.H., D.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. SPSS, Statistical package for the social sciences, 2nd edition. McGraw-Hill Book Co., New York.

Robinson, B. 1979. SPSS subprogram NONLINEAR - nonlinear regression. Manual 433. Vogelback Computing Center, Northwestern University, Evanston, IL.

Simanton, J.R. and K.G. Renard. 1982. The USLE rainfall factor for southwestern U.S. rangelands. *In* Proceedings of the workshop on estimating erosion and sediment yield on rangelands. Agricultural Research Service (Western Region), USDA, Oakland, CA. Agric. Reviews and Manuals, ARM–W–26/June 1982.

Singer, M.J., J. Blackard and P. Janitzky. 1980. Dithionite iron and soil cation content as factors in soil erodibility. p. 259–267. *In* M. DeBoodt and D. Gabriels (ed.) Assessment of erosion, John Wiley and Sons, New York.

Singer, M.J., P. Janitzky, and J. Blackard. 1982. The influence of exchangeable sodium percentage on soil erodibility. Soil Sci. Soc. Am. J. 46:117–121.

Soil Conservation Service. 1982. Unpublished report to the Office of International Agricultural Programs, College of Agriculture, University of Arizona, Tucson, AZ, from Soil Conservation Service staff, Casa Grande, AZ.

Soil Survey Staff. 1975. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Agric. Handb. 436. Soil Conservation Service, USDA.

Tracy, F.C. 1983. Rainfall characteristics for southeastern Arizona. M.S. Thesis, Univ. Arizona, Tucson.

U.S.D.A. 1975. Proceedings of the water harvesting symposium. Phoenix, AZ, March 26–28, 1974. Agricultural Research Service, USDA ARS W–22.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses - A guide to conservation planning. Agric. Handb. 537. USDA, U.S. Government Printing Office, Washington, D.C.