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DEPOSITION IN UNIFORM GRADE TERRACE CHANNELS*

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Uniform grade terraces are often credited with trapping about 80 percent of the sediment that reaches them. However, this value has been used without consideration of how it is affected by factors such as terrace grade, length, vertical interval, and channel sideslope. Data from terrace studies in the 1930's and 40's at eight locations were analyzed to determine if these factors affected deposition. The results showed that the net amount of sediment deposited in a uniform grade, open end terrace channel ranges from none for a 0.6 percent grade to 73 percent for a 0.1 percent grade for terraces typical of those of the 1930's. The amount deposited in modern terraces is estimated to be greater because today's terrace channels have shallower channel sideslopes. The data were also used to evaluate CREAMS, a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, for its ability to describe the effectiveness of terraces to control sediment yield. The results showed that CREAMS can accurately estimate average annual sediment yield from terraces when accurate estimates of the hydrologic inputs of rainfall erosivity, runoff volume, and peak runoff rate are available for individual storms.

INTRODUCTION

Terraces are an effective conservation practice for control of erosion and runoff from agricultural fields. Rill and interrill erosion are reduced because terraces break the slope into shorter slope lengths, and runoff is safely conveyed from the field at nonerosive velocities. If grade along the terrace channel is flat enough, much sediment may be deposited in the channel. This deposition helps to maintain soil productivity, reduce sediment yield from the field, and control nonpoint-source pollution from sediment.

Erosion and sediment yield from terraced fields are frequently estimated with the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). Deposition in graded terraces and outlet channels is accounted for by multiplying the estimated soil loss for the interterrace area by a supporting practices factor, P (Wischmeier and Smith 1978). Broadbase terraces are usually assumed to trap about 80 percent of the sediment reaching them (Wischmeier and Smith 1978).

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Impoundment or tile outlet terraces effectively control sediment yield by trapping about 95 percent of the sediment that reaches them (Laflen et al. 1972, Wischmeier and Smith 1978). The amount trapped depends on the characteristics of the eroded sediment, impoundment geometry, surface runoff, and retention time of runoff in the impoundment (Laflen et al. 1978).

The 30 percent value attributed to uniform grade, open end terraces is often used without consideration of how it is affected by factors such as terrace grade, length, vertical interval, and channel sideslope. Data from terrace studies conducted in the 1930's and 40's at eight locations were analyzed to determine how those factors affect deposition. The data were also used to evaluate the erosion/sediment yield component of CREAMS (Knisel 1980) for its ability to describe the effectiveness of terraces to control sediment yield.

ANALYSIS OF FIELD DATA

Extensive data on soil loss from terraces at soil erosion research stations established in the early 1930's are available in USDA Technical Bulletins listed in the Appendix. Typical studies included the effect of terrace length, grade, and vertical interval on sediment yield from terraces. Watersheds were instrumented to measure runoff rate and volume, soil loss amount, and rainfall rate and volume from individual terraces and from a system of terraces and outlet channels. An unterraced watershed was often instrumented so that soil loss from it could be compared with that from terraced watersheds.

Effect of Grade and Other Factors

The data were analyzed to identify the relationship of soil loss from a terrace (i) with terrace grade, vertical interval, and length; (ii) with cropping, management, and soil loss on the interterrace area; (iii) with runoff; and (iv) with storm erosivity. Terrace grade was the only factor where we could determine a definite relationship from the field data. Either the other factors had little measureable influence, or their effect was masked by differences between watersheds.

Soil, cropping, management, interterrace slope, and other factors varied with the station. Differences were eliminated by normalizing soil loss values at a location by dividing soil loss for a given terrace grade by that from the 0.5 percent grade terrace at the location. These normalized soil loss values are shown in Table 1 and Fig. 1. The equation

$$R = 0.253\ e^{2.64g} \qquad (1)$$

where R = normalized soil loss, and g = terrace grade in percent was fitted by linear regression.

Grade had a strong influence. The ratio of soil loss from a terrace on a 0.3 percent grade to that from a terrace on a 0.6 percent grade was 0.45. Equation (1) represents rotations, cropping, and terracing practices of the 1930's. The relationship of soil loss to grade at a specific site may differ from Eq. 1 depending on runoff, interterrace slope, crop, and other factors. At Bethany, MO, the line in Fig. 1 was steeper when the interterrace area was in corn than when it was in meadow (Zingg 1942b).

Fraction Of Soil Loss Deposited In Terrace Channel

The field data were analyzed to determine the fraction of sediment reaching a terrace channel that is deposited in the channel. Table 2 summarizes the data from unterraced watersheds at locations where soil loss could be compared with that from watersheds with 0.25 percent grade terraces, the recommended grade at the time. Soils were similar, and cropping was the same for

Table 1. Soil Loss from Single Terrace Watersheds for Uniform Terrace Grades

Location	Period of record	Grade	Total soil loss for period	Ratio of soil loss to that from a terrace on a 0.5% grade
		(%)	(kg/m^2)	
Guthrie,[a] Oklahoma	1931-38	0.50	16.7	1.00
		0.33	10.7	0.64
		0.17	5.7	0.34
		Level, open end	2.5	0.15
Clarinda,[b] Iowa	1933-40	0.50	14.3	1.00
		0.33	8.7	0.61
		0.17	3.2	0.22
Bethany,[c] Missouri	1932-40	0.67	54.9	2.35
		0.50	23.4	1.00
		0.33	22.0	0.94
		0.17	10.9	0.47
		Level, open end	7.7	0.33
Statesville,[d] North Carolina	1931-38	0.75	10.7	0.97
		0.50[e]	11.0	1.00
		0.50	3.2	1.00
		0.25	1.2	0.38
Tyler,[f] Texas	1931-38	0.50	2.8	1.00
		0.25	1.1	0.39
		Level, open end	1.0	0.36
Zanesville,[g] Ohio	1934-37	0.50	11.7	1.00
		0.25	6.8	0.58
		Level, open end	3.6	0.31

[a] Scour reported on a 0.5% grade terrace.

[b] No mention of scour for grades studied.

[c] Grade of 0.67% did not allow scour but was conducive to damaging sediment deposits in sodded outlet channel.

[d] Appreciable scouring occurred with 0.75% grade. Also, scouring was noted on 0.5% grade.

[e] Two separate 0.50% grade terraces were located in different fields having different soils and slopes. The 0.75% grade terrace was in one field and the 0.25% grade terrace was in the other field.

[f] Scour was not mentioned, but authors commented that a grade greater than 0.25% was too steep.

[g] Authors commented that 0.5% grade was noticeably too steep, allowing considerable scouring.

Table 2. Comparison of Soil Loss from Terraced and Unterraced Watersheds

Location and length of record	Watershed characteristics	Slope length	Slope steepness s	USLE LS	Soil loss		Sediment delivery ratio[b]
					Measured	Adjusted[a]	
	(Terrace grades are 0.25% unless noted).	(m)	(%)		(kg/m^2)	(kg/m^2)	
Guthrie, Oklahoma 1930-38	Unterraced; contoured	107	5.0	1.00	182.3	182.3	
	Multiple, level, open end terraces; R = 0.52[c]	21	3.0	0.26	9.6	71.4	0.39
Clarinda, Iowa 1934-41	Unterraced; corn/small grain rotation, farming parallel to field boundry	67	7.7	1.50	10.7	7.6	
	Multiple terraces, contoured; corn/small grain rotation; grassed outlet channel; P = 0.6	17	3.3	0.36	1.4	2.7	0.36
	Unterraced; contoured; corn/small grain/meadow rotation	96	5.2	0.98	2.9	3.0	
	Unterraced; contoured corn/small grain/meadow rotation	72	8.4	1.64	1.8	1.1	
	Multiple terraces; contoured; corn/small grain/meadow rotation; grassed outlet channel	15	10.0	0.95	0.2	0.2	0.11[d]
Bethany, Missouri 1935-42	Unterraced; contoured; grassed waterways	37	9.0	1.30	5.3	4.1	
	Multiple terraces, contoured, grassed outlet channel	17	7.0	0.62	1.1	1.7	0.42
Tyler, Texas 1933-41	Unterraced; contoured	51	7.5	1.17	11.6	9.9	
	Single terrace; contoured; soil loss measured at outlet of terrace	19	6.0	0.53	1.2	2.3	0.23
Zanesville, Ohio	Unterraced; contoured	76	14.0	3.63	37.5	10.3	
	Single terraced; contoured; soil loss measured at outlet of terrace	21	10.0	1.15	7.6	6.6	0.64
LaCrosse, Wisconsin 1933-36	Unterraced; contoured	91	15.0	4.43	54.6	12.3	
	Single terrace; contoured; soil loss measured at outlet of terrace[e]	21	10.0	1.15	8.4	7.3	0.59
1937-43	Unterraced; contoured; filter strip over lower 1/3; P = 0.5	91	15.0	4.43	8.5	3.8	
	Single terrace contoured; soil loss measured at outlet of terrace[e]	21	10.0	1.15	2.0	1.8	0.46

[a] Adjusted soil loss is measured soil loss divided by LS and P factor values to adjust sheet and rill erosion to a common base for terraced and unterraced watersheds.

[b] Sediment delivery ratio is the ratio of adjusted soil losses from the terraced and unterraced watersheds and represents deposition in terrace channels, outlet channel, or both. Same as USLE P subfactor for sediment yield from terraces.

[c] A watershed with a level terrace was the only one suitable for comparison. Sediment yield from a 0.25% grade terrace is 1/0.52 that from an open end, level terrace according to Eq. 4.

[d] An average of the soil loss from the two corn/small grain/meadow rotation unterraced watersheds was used to compute sediment delivery ratio.

[e] No uniform 0.25% grade terrace available. A variable 0 to 0.5% grade terrace was used. Data from other locations showed that the two give similar soil losses.

watersheds at a location. The average ratio of measured soil loss from the terraced watersheds to that from corresponding unterraced watersheds for data in Table 2 is 0.15. That is, without consideration of reduction of slope length, gully erosion, or any other factor, the average sediment yield from terraced watersheds was 15 percent of that for unterraced watersheds. Terraces on these watersheds reduced sediment yield by eliminating gully erosion that was severe on some of the unterraced watersheds, reducing rill and interrill erosion by dividing total slope length into increments, and causing some eroded sediment that reached the terrace channels to be deposited rather than leave the field.

To estimate sediment yield from fields, the USLE may be written as:

$$A = R\,K\,L\,S\,C\,P \qquad (2)$$

where A = sediment yield (mass/unit area/unit time), R = factor for rainfall-runoff erosivity, K = factor for soil erodibility, L = factor for slope length, S = factor for slope steepness, C = factor for cover-management, and P = factor for supporting practices which can include the effect of gully erosion ($P > 1$) or deposition in terrace channels ($P < 1$) as well as the effect of contouring and filter strips.

The composite P factor for sediment yield from terraces is the product of several subfactors such as contouring and deposition in a terrace channel. The P subfactor for deposition in a terrace channel is essentially a sediment

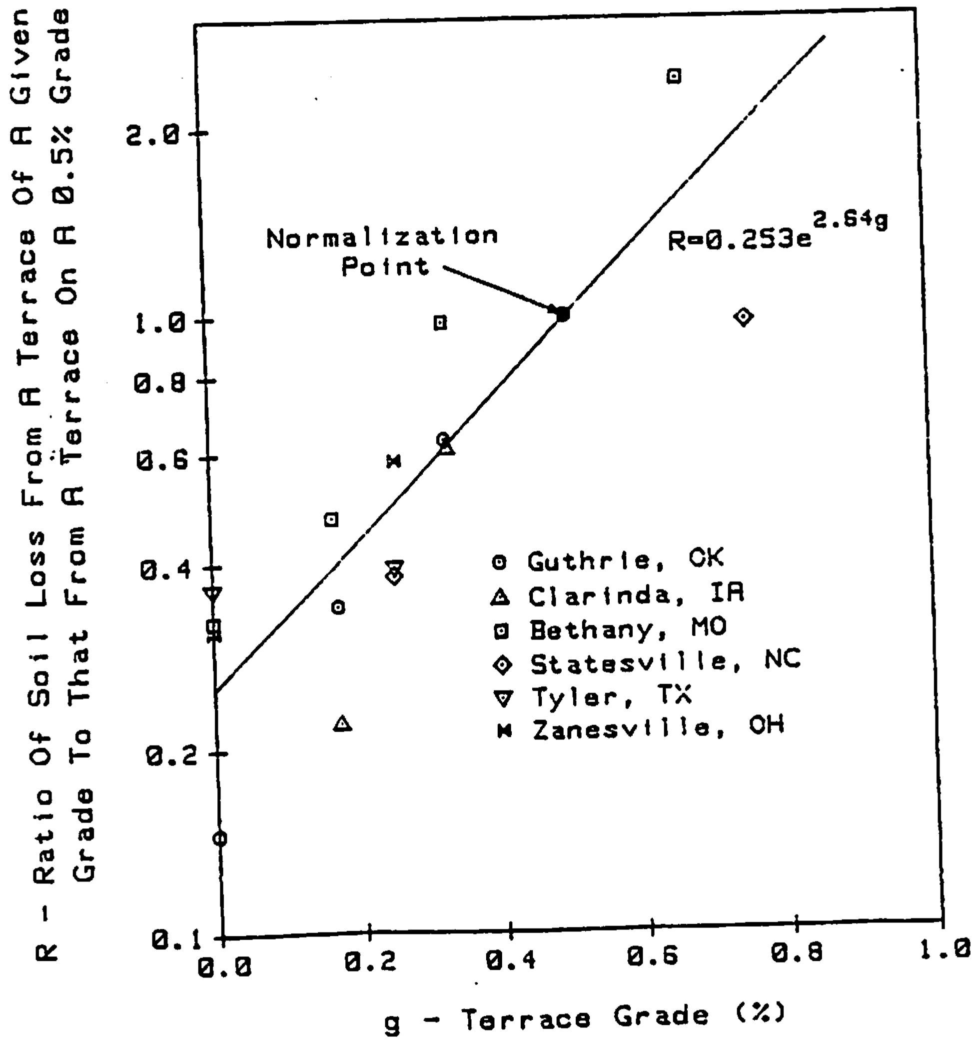

Fig. 1. Relationship of Normalized Soil Loss to Terrace Grade.

delivery ratio, the ratio of sediment yield from the watershed to soil loss from the interterrace area. The P subfactor for deposition in terrace channels, P_T, can be computed from field data by:

$$P_T = (A_T / L_T S_T P_{OT}) / (A_U / L_U S_U P_{CU}) \quad (3)$$

where the subscripts T and U denotes variables for the terraced and unterraced watersheds respectively. The factors P_{OT} and P_{CU} are composite P factors for effects of supporting practices other than deposition in terrace channels.

Each measured sediment yield value was adjusted according to Eq. 3 using standard USLE values (Wischmeier and Smith 1978). Gully erosion was not considered in the adjustment. The LS factor was estimated from slope length and steepness determined from watershed maps. Sediment yield from terraces on a 0.25 percent grade was chosen for comparison with sediment yield from the unterraced watershed. Equation 1 was used to adjust for terrace grade at Guthrie, OK.

Slope length on the unterraced watersheds was typically about 75 m. After terracing, slope length was about 20 m which according to the USLE LS factor reduced soil loss by 48 percent due to reduction of slope length alone. That is, the amount of sediment reaching the terrace channel was about 52 percent of sheet-rill erosion on the unterraced watersheds.

The average sediment delivery ratio (P subfactor for deposition in terrace and outlet channels) computed according to Eq. 3 for the data was 0.40. This applies to a uniform 0.25 percent grade terrace typical of those of the 1930's when channel sideslopes were steeper than those currently used. The 0.40 value is twice the 0.20 value frequently used with the USLE to estimate sediment yield from terraces (Wischmeier and Smith 1978). However, this value varies with terrace grade, as described earlier, and with channel sideslope discussed in a later section on Applicability of CREAMS. It also depends on the amount of deposition in the outlet channel, which varies with grade, cover, runoff, sediment load reaching the channel, and sediment size and density.

Equation 1 can be rewritten in absolute terms to give R = 0.4 for a grade of g = 0.25%. The new equation is

$$P_T = 0.207\ e^{2.64g} \quad (4)$$

where P_T = ratio of sediment delivered to the outlet of a uniform grade, open end terrace channel to that which reaches the channel. This is an average annual value for 1930's style terraces. Values for specific storms may differ greatly from those given by Eq. 4.

Deposition may occur everywhere along a low gradient terrace. As grade increases, deposition ends in the lower reaches of the terrace channel, and continues at a reduced rate in the upper reach. On steep grades deposition does not occur, and the channel may erode if the soil is susceptible to erosion by flow. The grade where net deposition is zero is the grade at which P_T = 1. This grade from Eq. 4 is 0.60 percent which generally agrees with field observations given in footnotes to Table 1. The observations recorded as footnotes in Table 2 did not include the length of channel over which erosion and/or deposition occurred. Scour could have occurred over a very short distance near the terrace outlet while deposition occurred over a major portion of the terrace channel. Zingg (1942b) estimated from the Bethany, MO data that grade could be as steep as 1.0 percent before net deposition ends. The grade at which scour begins depends on runoff, cover, and soil conditions in the terrace channel. Erosion occurs at a flatter grade at seedbed time for tilled crops than it does for meadow, where the consolidated soil has a higher critical shear stress (Foster et al. 1980b). Also, if sediment load exceeds transport capacity in the terrace channel, deposition will occur even though the soil may be susceptible to erosion. Field observations noted in Table 1 probably indicated the most susceptible condition.

Zingg (1942a) used profile measurements at Bethany, MO to estimate that 90 percent of the sediment reaching a terrace channel is deposited. Our analysis of similar measurements for Statesville, NC, Guthrie, OK, and Tyler, TX indicated that 64 percent of the sediment reaching a terrace channel on a 0.25 percent grade is deposited, which agrees with values in Table 2. Errors in estimating erosion and deposition from profile measurements are judged to be as great as errors in Table 2.

APPLICABILITY OF CREAMS

Models like CREAMS (Knisel 1980) are used in analyses of nonpoint-source pollution from agricultural land to evaluate terraces and other conservation practices for controlling sediment yield from individual storms. Data from the erosion research stations were also used to evaluate CREAMS for this purpose.

Overview Of CREAMS Erosion/Sediment Yield Model

The CREAMS erosion/sediment yield model (Foster et al. 1980a) estimates erosion and sediment yield from field-sized areas on a storm-by-storm basis. Hydrologic inputs are storm rainfall erosivity, EI—a product of rainfall energy and maximum 30-min intensity; volume of runoff; and peak runoff rate.

Terraced watersheds are represented in CREAMS by a typical interterrace profile and a typical channel for a series of terrace channels that supply a main outlet channel. Natural waterways in unterraced fields can also be represented.

Separate relationships describe detachment by raindrop impact (interrill erosion) and by runoff (rill erosion) on areas of overland flow or on interterrace areas. Erosion in waterways and channels is described by an excess shear stress equation. Sediment transport capacity is computed with the Yalin equation (Yalin 1963) modified for nonuniform sediment mixtures of primary particles and aggregates (Foster et al. 1980a). When sediment load exceeds transport capacity, deposition is computed at a rate directly proportional to fall velocity and the difference between transport capacity and sediment load. Enrichment of fines during deposition is estimated.

Validation Of CREAMS For Terraces

Observed data from Guthrie, OK; Hays, KS; Clarinda, IA; and Bethany, MO were used to assess the validity of CREAMS. Measured data included rainfall and runoff amounts, maximum 30-min rainfall intensity, peak runoff rate, soil loss, and a description of watershed conditions for each storm. Observed hydrologic values were used as input instead of values from the hydrologic component of CREAMS. This allowed an evaluation of the erosion/sediment yield component of CREAMS without having to consider errors in hydrologic inputs. Parameter values were selected from the CREAMS User's Manual (Foster et al. 1980b) to obtain the results shown in Table 3 without calibration of the model.

Based on these results, we judged that the erosion/sediment yield component of CREAMS can satisfactorily show the influence on erosion and sediment yield of terraces and grassed outlet channels without calibration. This conclusion assumes that estimates of runoff volume and peak rate are available that accurately describe the effect of conservation practices on runoff. For example, if the hydrologic model being used to estimate runoff volume and peak rate is not sufficiently sensitive to terrace grade, the

Table 3. Total Observed and Computed Sediment Yield for Terraced and Unterraced Watersheds

Location and length of record	Watershed Characteristics	Area	No. of runoff producing storms	Sediment Yield	
				Observed	Computed with CREAMS
		(ha)		(kg/m^2)	(kg/m^2)
Guthrie, Oklahoma 1931-38	Single terrace, variable grade, 0.33% at outlet to 0 at upper end	2.42	58	12.2	6.4
	Single terrace, variable grade, 0.5% at outlet to 0 at upper end	2.29	63	13.8	11.9
	Single terrace, uniform 0.5% grade	1.15	53	12.1	10.6
	Single terrace, uniform 0.17% grade	1.04	43	4.6	4.8
Hays, Kansas 1931-38	Single terrace, uniform 0.33% grade	0.42	33	3.42	3.82
	Single terrace, uniform 0.33% grade	0.34	32	2.10	1.63
	Single terrace, uniform 0.33% grade	0.35	32	4.65	5.47
	Single terrace, level, open end	1.14	34	0.38	0.44
	Single terrace, level, open end	1.19	36	0.33	0.47
Clarinda, Iowa 1934-38	Unterraced, corn/small grain rotation, parallel to field boundary farming	0.80	30	1.94	1.92
	Multiple terraces, corn/small grain rotation, contoured, grassed outlet channel	0.80	25	0.53	0.35
	Unterraced, corn/small grain/meadow rotation, contoured	1.32	21	1.17	0.81
	Unterraced, corn/small grain/meadow rotation, contoured	1.32	28	0.63	1.04
	Multiple terraces, corn/small grain/meadow rotation, contoured, grassed outlet channel	1.26	14	0.09	0.04
Bethany, Missouri 1934-42	Unterraced, contoured, grassed-waterways	3.04	86	7.1	4.9
	Multiple terraces, contoured, grassed outlet channel	3.25	86	2.1	2.4
	Unterraced, gullied	1.76	137	53.8	31.4

erosion/sediment yield component of CREAMS will not be as sensitive to terrace grade as it should be.

Sensitivity Analysis

Having shown that CREAMS gives reasonable estimates, a sensitivity analysis was conducted with CREAMS to study the influence of individual factors on sediment yield from terrace systems. The procedure was to compute sediment yield for a given set of base parameter values. Next, sediment yield was computed for a new value of a given factor, which was varied independently about its base value. The results are given in Table 4 where the comment with each line denotes the variable that was changed. Since only one variable was changed at a time, interactions were not studied. The results are a better description of relative effects of terrace variables than of absolute effects. Hydrologic inputs were computed with the daily rainfall option of CREAMS (Smith and Williams 1980).

Interpretation Of Results

The sensitivity analysis, like field data, showed that of the factors studied, terrace grade (S1 in Table 4) had the greatest effect on sediment yield from terraces. When grade is flat, much sediment is deposited; when grade is steep, scour potentially occurs in the terrace channel. Sensitivity to grade is increased when the effect of grade on runoff volume (Q in Table 4) and peak runoff rate (which field data showed to be significant) is considered. At Bethany, MO total runoff for the period of record from the 0.67 percent grade terrace was 1.47 times that from a 0.17 percent grade terrace, while the average peak runoff rate for the 0.67 percent grade terrace was 4.6 times that from the 0.17 percent grade terrace.

The effect of terrace length (L1 in Table 4) was not great. An increase of length from 150 m to 450 m increased sediment yield and the USLE P factor-sediment delivery ratio by 15 percent. An increase in interterrace horizontal interval (L0 in Table 4) by a factor of four increased sediment yield by 53 percent, but the sediment delivery ratio did not change.

The USLE P subfactor for sediment yield or sediment delivery ratio is one minus the fraction of sediment reaching a terrace channel that is deposited. The fraction of sediment that is deposited depends on transport capacity of runoff in the channel relative to the incoming sediment load. No deposition occurs unless transport capacity is less than sediment load. If sediment load is reduced by reducing the slope of the interterrace area (S0 in Table 4) without reducing transport capacity in the terrace channel, reduction in sediment yield may not be great. The computed sediment yield from an interterrace area on a 9 percent slope was 6.9 kg/m^2, and sediment yield from the terrace was 2.4 kg/m^2 which gives a sediment delivery ratio of 0.35. Sediment yield from the interterrace area for a 3 percent slope was 1.7 kg/m^2 and sediment yield from the terraces and outlet channel was 1.2 kg/m^2 which gives a sediment delivery ratio of 0.71. Although soil loss from the 3 percent slope was one-fourth that from the 9 percent slope, sediment yield was only cut in half, which doubled the sediment delivery ratio.

Runoff may vary greatly for a given storm erosivity (EI in Table 4) depending on antecedent conditions. Conversely, particular runoff amounts and rates can be caused by a variety of storm erosivities. Sediment yield from the interterrace area is often highly related to storm erosivity while sediment yield from the terrace is highly related to runoff if deposition is occurring. Sediment delivery ratio was calculated to decrease for given runoff characteristics when storm erosivity increases.

Transport capacity of flow depends on channel geometry. Computed deposition increased and sediment delivery ratio decreased as sideslope (SS in Table 4) flattened from 5:1 to 40:1 (horizontal to vertical). Equation 4 is assumed

Table 4. Calculated Sediment Yield (kg/m^2) for Sensitivity Analysis of CREAMS Erosion/Sediment Yield Component. Variables Tested: Terrace Grade (S1), Runoff Volume (Q), Terrace Length (L1), Interterrace Horizontal Interval (L0), Slope of Interterrace Area (S0), Storm Erosivity (EI), Sideslope of Terrace Channel (SS), Mannings's n in Outlet Channel (N2), Outlet Channel Length (L2), and Curve Number for Management Practice (CN).

Sediment yield from interterrace interval	Sediment yield from terrace channel	Sediment delivery ratio at end of terrace channel[a]	Sediment yield from outlet channel	Sediment delivery ratio at end of outlet channel[a]	Comments
(kg/m^2)	(kg/m^2)		(kg/m^2)		
3.99	1.67	0.42	1.67	0.42	Base values[b]
3.99	1.56	.39	1.56	.39	S1 = 0.1%
1.98	0.70	.35	0.70	.35	S1 = .1%; Q = 0.4 Q base
3.51	1.32	.37	1.32	.37	S1 = .1%; Q = .8 Q base
2.55	0.93	.36	0.93	.36	S1 = .2%; Q = .5 Q base
3.99	1.92	.48	1.92	.48	S1 = .4%
2.94	1.24	.42	1.24	.42	S1 = .4%; Q = .6 Q base
4.46	2.26	.51	2.26	.51	S1 = .4%; Q = 1.2 Q base
3.99	2.19	.55	2.19	.55	S1 = .5%
3.03	1.42	.47	1.42	.47	S1 = .5%; Q = .63 Q base
4.63	2.75	.59	2.75	.59	S1 = .5%; Q = 1.23 Q base
3.99	3.17	.79	3.17	.79	S1 = .8%
3.24	2.25	.69	2.25	.69	S1 = .8%; Q = 0.7 Q base
4.97	4.57	.92	4.58	.92	S1 = .8%; Q = 1.4 Q base
4.15	1.63	.39	1.63	.39	L1 = 152
3.99	1.80	.45	1.80	.45	L1 = 450 m
3.15	1.36	.43	1.36	.43	LO = 12 m
5.09	2.08	.41	2.08	.41	LO = 49 m
1.70	1.15	.68	1.15	.68	SO = 3%
6.89	2.39	.35	2.45	.36	SO = 9%
2.74	1.38	.50	1.38	.50	EI = 0.5 EI base
2.58	2.17	.37	2.17	.37	EI = 2.0 EI base
3.99	1.39	.35	1.39	.35	SS = 10:1
3.99	1.18	.30	1.18	.30	SS = 20:1
3.99	1.02	.26	1.02	.26	SS = 40:1
3.99	1.67	.42	2.49	.63	N2 = 0.05
3.99	1.67	.42	1.33	.33	N2 = .2
4.14	1.47	.42	1.74	.42	L2 = 152 m
3.79	1.57	.41	1.58	.42	L2 = 610 m
1.31	0.55	.42	.55	.43	CN = 70, Chisel plow

[a] Sediment delivery ratio is the ratio of sediment yield at the end of the terrace channel or outlet channel to that from interterrace area.

[b] Base Values: 20 ha watershed located in central Georgia in continuous, conventionally tilled corn. Silt loam soil (erodibility = 0.040 kg h/m^2 N). 24 m and 6%—interterrace horizontal interval and slope respectively. 305 m, 0.2% uniform, and 5:1—terrace length, grade, and sideslope repsectively. 0.1, 305 m, 6% uniform, and 20:1—outlet channel Manning's n, length, grade, and sideslope respectively. Rainfall erosivity, runoff volume, peak runoff rate generated by daily rainfall option of CREAMS hydrology component (Smith and Williams 1980).

to apply to terrace channels with a sideslope of 5:1. Incorporating the results of the sensitivity analysis on sideslope without considering the effect of sideslope on runoff volume or peak rate gives:

$$P_T = 0.3e^{2.64g}\, s^{-0.24} \qquad (5)$$

where s = channel sideslope (horizontal to vertical). According to Eq. 5, the fraction of the sediment deposited in a uniform grade, open end terrace channel with 20:1 sideslopes on a 0.6 percent grade is 0.29 which is one minus the sediment delivery ratio. Values of P_T greater than 1 indicate a potential for net erosion, a case where deposition may occur in an upper reach of the terrace channel and scour in a lower reach.

The results for grassed outlet channels were as expected. On a 6 percent grade, neither deposition nor erosion was computed for a Manning's n (N2 in Table 4) of 0.1 which represents a moderately dense grass stand. When n was decreased to 0.05, a sparse cover, erosion in the outlet channel was calculated, which is indicated in Table 4 by a sediment yield at the outlet channel end larger than that at the ends of the terraces. Conversely, when n was increased to 0.20 to represent a heavy, dense cover, deposition was calculated. These results are not general. Had the outlet channel been on a 4 percent slope, deposition might have been calculated at a lower grass density. Length of the outlet channel (L2 in Table 4) had little effect until the channel became so long and discharge so high that it began to erode near the outlet. Little or no deposition was calculated for the outlet channel because it was steep.

Terraces alone may not adequately control soil loss on the interterrace area. Additional practices like conservation tillage may be needed. A change from conventional tillage to chisel plow tillage (CN in Table 4) had little effect on the sediment delivery ratio.

Modern terraces are often constructed with irregular grades. If grade is flat enough near the terrace outlet to cause much deposition, sediment yield from the terrace may be closely related to the grade of the terrace channel near the outlet. Also, deposition may be great at intermediate upstream points along a terrace of an irregular grade which may influence sediment yield. In this analysis, we did not consider such nonuniformities.

CONCLUSIONS

1. The ratio of sediment reaching a terrace channel that is delivered to the channel outlet depends strongly on terrace grade. Soil loss from a 0.3 percent uniform grade terrace was 45 percent of that from a 0.6 percent uniform grade terrace typical of those of the 1930's. Other factors, like terrace length and vertical interterrace interval, have much less effect. For a given horizontal interterrace interval, the delivery ratio seems to increase by a factor of 2 when interterrace slope is reduced from 9 to 3 percent for continuous, conventionally-tilled corn in a high rainfall-runoff area.

2. The ratio of sediment reaching a terrace channel that is delivered to the outlet was estimated to be 0.4 for a 0.25 percent uniform grade terrace with row crop/small grain/meadow rotations for terraces of the 1930's. At a 0.6 percent grade, net deposition seemed to be insignificant for these terraces. The delivery ratio for modern terraces on a 0.6 percent grade is estimated to be 0.5 to 0.7.

3. Conclusions (1) and (2) are for uniform grade, open end terraces and do not apply to variable or irregular grade, closed end, or tile outlet terraces.

4. The erosion/sediment yield component of CREAMS, a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, can be used without calibration to evaluate the effectiveness of terraces and grassed waterways for controlling sediment yield from farm fields. However, accuracy depends on having runoff estimates from a hydrologic model with proper sensitivity to factors like terrace grade.

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APPENDIX — DATA SOURCES

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