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RUSLE C-FACTORS FOR SLOPE PROTECTION APPLICATIONS[1]

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Abstract: Despite the fact that the Universal Soil Loss Equation (USLE) was originally developed to estimate erosion rates for agricultural lands, both the USLE and its successors (RUSLE Versions 1.06, 2.0) are increasingly applied to non-agricultural land disturbances. For these non-agricultural applications there is little consensus in the erosion-science community concerning which cover-management factor (C-factor) values should be used to account for the effects of various slope-protection materials. The purpose of this study is to derive appropriate RUSLE C-factor values from the rainfall-simulation study data collected at the Texas Department of Transportation – Texas Transportation Institute, Hydraulics and Erosion Control Laboratory (TTI) and the San Diego State University, Soil Erosion Research Laboratory (SERL), and to evaluate the utility of such values. RUSLE C-factor values were calculated for over 50 erosion-control products, straw mulch, and several vegetation types for various research conditions. The C-factor values were then compared with the few values provided by the manufacturers of erosion-control products. The C-factor values for straw mulch and the several vegetation types were compared with analogous USLE C-factor values found in *Agricultural Handbook 537* (Wischmeier and Smith, 1978) and values calculated using RUSLE2. One-way ANOVA tests and a Tukey test identified a significant difference between the C-factors calculated with the SERL methods and the USLE C-Factors and a second significant difference between the SERL method C-factors and values provided by product manufacturers. To test the spatial and temporal variability of C-factors, monthly values were calculated using RUSLE2 for 49 U.S. cities. A two-factor, without replication, ANOVA test was used to determine that the temporal and spatial variability of C-factor values is statistically significant. As a result of the lack of available C-factors for specific products, the SERL method at best provides a "quick and dirty" C-factor estimation. These values provide a soil-loss ratio useful for comparing the surface protection of similar erosion control products. The results of this study should assist USLE and RUSLE users by increasing awareness of the high variability of available C-factor values and highlight the need for product-specific C-factor values in RUSLE2.

Additional Key Words: USLE, Erosion-Control Products

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Introduction

The Universal Soil Loss Equation (USLE) was developed by the U.S. Department of Agriculture (USDA) in the late 1950's to facilitate conservation planning on agricultural lands primarily in the Midwestern U.S. The USLE remained the most useful tool for erosion prediction on disturbed lands from the early 1960's until the revision in the late 1980's. Despite the fact that the USLE was developed using agricultural-land data and was intended for agricultural use, it has been applied to a wide range of land disturbances (Meyer and Romkens, 1976), including highway construction (Farmer and Fletcher, 1977, Israelsen et al., 1980), forest lands (Dissmeyer and Foster, 1980), and mined land (Shown et al., 1982).

At a workshop of government agencies and university soil-erosion scientists in 1985, participants concluded that the wealth of scientific data and information that had accumulated since the publication of *Agriculture Handbook 537* (Wischmeier and Smith, 1978) needed to be incorporated into the USLE. This overhaul resulted in the revised and computerized version of the USLE, named the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997).

Many improvements were incorporated in RUSLE, making RUSLE better suited for uses on mined lands, construction sites, and reclaimed lands. Weather data from more locations were included in the climate database than were available during the development of the USLE. Seasonal variations in soil erodibility were incorporated into the K factor. The effects on erosion of rock-fragment covers in the soil profile and fragments are included in the K and C-factors. More accurate equations were formulated to estimate the topographic (LS) factor. To make RUSLE more versatile, a sub-factor approach was developed to calculate C-factor values, as discussed later. This approach uses variables describing the main features of a cover-management system as it influences erosion rates (Toy et al., 1999, Toy and Foster, 1998). Hence, RUSLE provides more site-specific C-factor values. Process-based equations were used to estimate erosion-control practice (P) values, accommodating a wide-variety of site-specific practices. Overall RUSLE represents a vast improvement over the USLE. Toy et al., (1999) detail particular improvements of various versions of the RUSLE models as applied to mining, construction, and reclaimed lands.

How the Universal Soil Loss Equation works:

The Universal Soil Loss Equation (USLE) is an empirically-derived equation based on more than 10,000 plot-years of field data. The equation calculates erosion from sheet and rill erosion using the six major factors that control erosion.

$$A=RKLSCP \qquad \textbf{(1)}$$

Where: A represents the computed erosion rate (soil loss), R is the rainfall-runoff erosivity factor, K is a soil-erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover-management factor, and P is a supporting-practice factor.

The RUSLE C-factor

The importance of the C-factor is described by Toy et al., (1999): “The C-factor is perhaps the most important factor in RUSLE because: (1) it represents surface conditions that often are easily managed for erosion control, and (2) the values range from virtually 0 to slightly greater than 1, strongly influencing the soil-loss rate.” As cover (vegetative or manufactured) and soil biomass increases, the C-factor value decreases. Well-protected soil has a C-factor value near zero; while nearly exposed soil has a C-factor value near one. C-factors greater than 1 are possible when site conditions are more erosive than the unit-plot conditions used to develop the C-factor (Toy et al., 1999).

The utility of RUSLE was extended by the use of a sub-factor approach to calculate site-specific C-factor values. By using this approach, RUSLE can be applied to a variety of environments, including mined land and construction sites (Toy et al., 1999). These sub-factors include: vegetation canopy, raindrop fall height, soil-surface cover and roughness, root biomass, and prior land use. When calculating a C-factor value for the Northwest Wheat and Range Region (NWRR), an additional sub-factor for soil-moisture is included (Renard et al., 1997). Table 1 summarizes the effects of the cover-management subfactors on erosion rates.

Each subfactor value is multiplied together to yield a soil-loss ratio (SLR) (Renard et al., 1997). The equation for calculating the soil-loss ratio is given below:

$$SLR = PLU * CC * SC * SR * SMR \qquad \textbf{(2)}$$

A SLR is calculated for each time period during which the subfactors values remain constant, The SLR for each time period is then weighted based on the fraction of rainfall and erosivity (EI) that occurs during that time period. The weighted factors are combined into an overall C-factor value.

Table 1. Cover-Management Subfactors and Effects (Toy et al., 1999 and Renard et al., 1997).

C-Subfactor	Effect of Subfactor
Canopy Cover (CC)	Intercepts raindrop energy, reduces rainsplash (detachment) erosion
Raindrop Fall Height	Increase in raindrop energy as fall height from canopy increases. Increased height results in more rainsplash (detachment) erosion.
Surface Cover(SC)	Dissipates raindrop energy and reduces runoff velocities.
Roughness (SR)	Ponds runoff, increases infiltration, reduces runoff velocity and volume, and traps sediment
Root Biomass	Binds soil particles to reduces soil-loss rates.
Prior Land Use (PLU)	Reflects soil disturbance and incorporation of biomass. Disturbance disrupts soil structure, increases soil-loss rates. Incorporation of biomass results in reduced soil-loss rates.
Soil-Moisture (SMR)	Reduces infiltration and results in increased surface runoff and soil-loss.

C-factor values are equal to the reduction in soil loss for a specific-erosion control system when compared to the bare soil (control) condition. The designer of an erosion-control plan requires C-factor values representing various conditions from unvegetated, to fully vegetated, (including protection by mulches or Rolled Erosion Control Products (RECP), in order to determine an appropriate C-factor value to represent the planned site condition (Sprague, 1999).

Purpose of Research

The purpose of this study was to derive RUSLE C-factor values from the rainfall-simulation data collected by the Texas Department of Transportation–Texas Transportation Institute, Hydraulics and Erosion Control Laboratory (TTI) using computational methods developed at the San Diego State University, Soil Erosion Research Laboratory (SERL).

The utility of these C-factor values was then evaluated by means of comparisons with C-factor values computed by the RUSLE program and the values provided by erosion-control product manufacturers. Additionally, the spatial and temporal variability of C-factor values was examined.

Derivation of C-Factor Values

TTI has used rainfall simulation to test more than 50 erosion-control products, as well as straw mulch, and several vegetation covers (Landphair et al., 2001). These tests were conducted on both sandy and clayey soils (USDA classification) on both 2:1 and 3:1 slope steepnesses. The data from these tests were used with the methodology developed by SERL (2001) to calculating RUSLE C-factors. The SERL method calculates USLE C-factor values by holding R, K, LS, and P constant and assigning a C-factor value of 1.0 to the baseline, bare soil condition. C-factor values are then calculated by comparing the sediment yield of the bare soil condition to the sediment yield of the slope protected by the erosion-control product. For example:

$A_{\text{Bare soil}} = 46.32\text{ kg}$ **(3)**

Hold R, K, LS, and P constant and set $C_{\text{Bare soil}}$ to 1.0

$46.32\text{ kg} = 1.0\ C_{\text{Bare soil}}$

$A_{\text{protected soil}} = 0.20\text{ kg}$

Solve for $C_{\text{protected soil}}$ by: $0.20\text{ kg} / 46.32\text{kg} = 0.004$

$C_{\text{protected soil}} = 0.004$

Table 2 presents the sediment-loss data (in kilograms per 10 square meters) from the TTI rainfall simulation tests and the corresponding C-factor values calculated using the SERL methodology.

Table 2. RUSLE C-factors for erosion control products calculated from TTI data

	1:2 Sand		1:2 Clay		1:3 Sand		1:3 Clay	
Product Name	**Sed Loss***	**C Factor**	**Sed Loss***	**C Factor**	**Sed Loss***	**C Factor**	**Sed Loss***	**C Factor**
Airtrol®	37.89	0.753	0.24	0.117	12.39	0.455	0.24	0.194
Airtrol®	13.42	0.267	NA	NA	9.26	0.340	NA	NA
Airtrol®	NA	NA	NA	NA	13.02	0.479	NA	NA
Airtrol® Plus	30	0.596	0.4	0.194	NA	NA	NA	NA
Airtrol® Plus	NA	NA	1.04	0.505	NA	NA	NA	NA
Anti-Wash® /Geojute®	30.3	0.602	0.27	0.131	NA	NA	NA	NA
BioD-Mesh® 60	NA	NA	NA	NA	13.03	0.479	0.26	0.210
Conwed 3000 BFM	27.31	0.543	0.31	0.150	12.68	0.466	0.3	0.242
Curlex®	29.8	0.592	0.19	0.092	4.41	0.162	0.15	0.121
Curlex®	21.81	0.433	NA	NA	4.12	0.151	0.12	0.097
Curlex®	9.12	0.181	NA	NA	2.94	0.108	NA	NA
Curlex®	NA	NA	NA	NA	7.84	0.288	NA	NA
Curlex®-LT	NA	NA	NA	NA	8.47	0.311	0.28	0.226
Curlex®-LT	NA	NA	NA	NA	NA	NA	0.18	0.145
EarthBound	27.85	0.553	0.31	0.150	11.06	0.406	0.33	0.266
EcoAegis®	NA	NA	0.37	0.180	12.26	0.451	0.31	0.250
EcoAegis®	29.98	0.596	0.36	0.175	11.93	0.438	NA	NA
Econo-Jute	30.79	0.612	NA	NA	11.74	0.431	0.29	0.234
ECS Excelsior BlanketStandard	NA	NA	NA	NA	10.01	0.368	0.25	0.202
ECS High Velocity Straw Mat	25.14	0.499	0.2	0.097	NA	NA	NA	NA
ECS Standard Straw	23.61	0.469	0.31	0.150	NA	NA	NA	NA
ECS Straw Blanket Standard	NA	NA	NA	NA	8.06	0.296	0.29	0.234
EnviroGuard Plus	27.42	0.545	0.38	0.184	12.04	0.442	0.32	0.258
EnviroGuard Plus	19.63	0.390	0.26	0.126	8.61	0.316	NA	NA
Formula 480 Liquid Clay	26.24	0.521	0.31	0.150	NA	NA	NA	NA
Futerra®	23.76	0.472	0.29	0.141	11.19	0.411	0.27	0.218
Geocoir® /DeKoWe® 700	10.39	0.206	NA	NA	NA	NA	NA	NA
Geocoir® /DeKoWe® 700	24.59	0.488	0.22	0.107	NA	NA	NA	NA
Geogro	27.33	0.543	0.42	0.204	13.39	0.492	0.38	0.306
Geogro	NA	NA	2.29	1.112	15.35	0.564	0.43	0.347
Geojute® Plus	0.69	0.335	8.16	0.162	NA	NA	NA	NA
Geojute® Plus 1	27.03	0.537	0.39	0.189	NA	NA	NA	NA
Geojute® Plus 1	26.11	0.519	0.32	0.155	NA	NA	NA	NA
Grass Mat	32.17	0.639	0.39	0.189	14.53	0.534	0.34	0.274
Greenfix WSO72	24.89	0.494	0.28	0.136	NA	NA	NA	NA
Greenstreak® PEC-MAT®	31.14	0.619	0.25	0.121	16.4	0.603	0.2	0.161
K-Mat	28.94	0.575	0.37	0.180	12.14	0.446	0.32	0.258
KoirMat® 400	27.05	0.537	0.25	0.121	NA	NA	NA	NA
Landlok BonTerra CS2	NA	NA	0.28	0.136	NA	NA	NA	NA
Landlok BonTerra EcoNet ENCS2	NA	NA	0.25	0.121	7.98	0.293	0.15	0.121
Landlok® 407GT	18.77	0.373	0.24	0.117	NA	NA	NA	NA
Landlok® BonTerra® CS2®	19.98	0.397	0.3	0.146	NA	NA	NA	NA
Landlok® BonTerra® CS2®	NA	NA	0.35	0.170	NA	NA	NA	NA
Landlok® BonTerra® S1®	NA	NA	NA	NA	6.29	0.231	0.25	0.202
Landlok® BonTerra® S2®	15.3	0.304	0.32	0.155	NA	NA	NA	NA

Table 2. (continued)	1:2 Sand		1:2 Clay		1:3 Sand		1:3 Clay	
Product Name	**Sed Loss***	**C Factor**	**Sed Loss***	**C Factor**	**Product Name**	**Sed Loss***	**C Factor**	**Sed Loss***
Landlok® BonTerra® S2®	25.23	0.501	NA	NA	NA	NA	NA	NA
Landlok® BonTerra®ENCS2™	24.43	0.485	NA	NA	NA	NA	NA	NA
Landlok® FRS 3112	14.25	0.283	0.28	0.136	NA	NA	NA	NA
Landlok® FRS 3112	16.94	0.337	NA	NA	NA	NA	NA	NA
Landlok® TRM 435	23.38	0.464	0.18	0.087	NA	NA	NA	NA
Miramat® 1000	11.82	0.235	0.42	0.204	NA	NA	NA	NA
Miramat® TM8®	22.73	0.452	0.32	0.155	NA	NA	NA	NA
North American Green S150	23.92	0.475	0.23	0.112	NA	NA	NA	NA
North American Green S75	27.01	0.537	0.31	0.150	8.1	0.298	0.27	0.218
North American Green SC150	20.82	0.414	0.21	0.102	NA	NA	NA	NA
North American Green® S150 BN	25.4	0.505	0.32	0.155	NA	NA	NA	NA
North American Green® S75	26.42	0.525	NA	NA	NA	NA	NA	NA
North American Green® S75 BN	NA	NA	NA	NA	11.44	0.420	0.31	0.250
Pennzsuppress	27.53	0.547	0.33	0.160	NA	NA	NA	NA
POZ-O-CAP®	NA	NA	NA	NA	NA	NA	0.36	0.290
POZ-O-CAP®	NA	NA	NA	NA	13.44	0.494	0.42	0.339
Seed-Guard®	23.4	0.465	0.42	0.204	NA	NA	NA	NA
Soil Guard®	8.04	0.160	0.27	0.131	NA	NA	NA	NA
SuperGro®	8.97	0.178	0.33	0.160	3	0.110	0.08	0.065
SuperGro®	23.17	0.460	NA	NA	9.74	0.358	0.31	0.250
Tensar® Erosion Blanket TB1000	16.82	0.334	0.33	0.160	NA	NA	NA	NA
Terra-Control®	NA	NA	NA	NA	10.48	0.385	0.22	0.177
Terra-Control®	NA	NA	NA	NA	13.15	0.483	0.35	0.282
verdyol® ERO-MAT®	NA	NA	NA	NA	9.08	0.334	0.15	0.121
verdyol® Excelsior High Velocity	16.73	0.332	0.39	0.189	NA	NA	NA	NA
verdyol® Excelsior High Velocity	26.98	0.536	0.31	0.150	NA	NA	NA	NA
verdyol® Excelsior Standard	NA	NA	NA	NA	7.41	0.272	0.32	0.258
Xcel Regular	NA	NA	NA	NA	4.71	0.173	0.32	0.258
Xcel Superior	15.68	0.311	0.32	0.155	NA	NA	NA	NA
CONTROL	50.34	1.000	2.06	1.000	27.21	1.000	1.24	1.000

*****Sediment Loss is expressed as “kilograms per 10 square meters

The Utility of C-Factor Values

The methods used to calculate the C-factors values in Tables 2 are quite different from the methods originally used to compute C-factor values during and following the development of USLE. In addition, the RUSLE program utilizes the sub-factor approach in calculating C-factor values as described earlier. One way to evaluate the utility of the C-factor values in Table 2 is by comparing these values with those values developed for the USLE and values computed by the RUSLE program. First, it was necessary to construct comparable data sets using the best available information. C-factor values were calculated using the SERL methodology for straw mulch and several vegetative covers based on data from other TTI studies that used testing protocol similar to the TTI (2001) tests. C-factor values developed for the USLE were taken from *Agricultural Handbook 537* (Wischmeier and Smith, 1978). C-factor values were calculated using the RUSLE programs with the same inputs as used in the TTI tests. Finally, the C-factor values calculated using the SERL method were compared with the few available C-factor values provided by erosion-control product manufacturers.

TTI Project 9-1504 and the TTI project published in Caltrans (2000) were selected for this study because the cover-management practices tested were analogous to those for which USLE C-factor values are available. These projects employed a testing methodology similar to that used in TTI (2001). TTI Project 9-1504 compares the erosion-control properties of turf sod, native grasses, forbes, and wild flowers on 2:1 clayey and 3:1 sandy slopes. The vegetation on each plot was allowed to grow for two years and then was subjected to the same rainfall simulations that TTI uses to test erosion-control blanket on slopes. Sediment loss was recorded after each storm. The sediment-loss from each trial was then divided by the sediment-loss from the appropriate control slope (TTI, 2001). These values are then used to calculate the SERL-method C-factors in Table 3.

The TTI data published in Caltrans (2000) measured the erosion-control effectiveness of crimped and tacked straw applied at a rate of 4000 lbs/acre on 2:1 and 3:1 slopes with both sandy and clayey soils. Each slope was subjected to ten-minutes of simulated rainfall at one- and two-year event intensities.

The USLE C-factor values that were most comparable with the TTI test of straw on 3:1 slopes are found in Table 9 of Agricultural Handbook (AH) 537 (Wischmeier and Smith, 1978). C-factor values were developed for straw or hay, tied down by anchoring and tacking equipment, applied at 4000 lbs/acre, on slopes up to 150 feet long with steepnesses between 11% and 15%. The USLE C-factor values that were most comparable with the TTI test of straw on 2:1 slopes also are found in Table 9. C-factor values were developed for straw or hay, tied down by anchoring and tacking equipment, applied at 4000 lbs/acre, on slopes up to 75 feet long with a steepness between 21% and 25%. TTI Project 9-1504 tested bermudagrass, native grasses, wildflowers, native forbs/grasses, and crownvetch on 2:1 clayey and 3:1 sandy slopes but these covers do not have analogs in AH 537. The USLE values for an established meadow combination of alfalfa, lespedeza, and second year sericea were used for proxy comparisons

(Table 5B, *Agricultural Handbook 537,* Wischmeier and Smith, 1978). The USLE C-factor values are included in Table 3.

The RUSLE2 program was used to generate monthly C-factor values for straw and vegetation types similar to those tested in TTI Project 9-1504. The inputs to this program included: site location Bryan, TX, slope length of 30 feet, slope angles of 15% and 23%, clay and sandy soils, blade fill and add 4000 lbs/acre of straw mulch, or vegetation types similar to those tested by TTI. The average annual C-factor values are calculated from the monthly values and listed in Table 3. In some cases, the exact cover-management practice or vegetation type was not available in the USLE literature or in the RUSLE2 database files. In these situations, similar vegetation was selected. The last column in Table 3 lists the substituted vegetation.

Comparison of C-Factor Values

A one-way ANOVA test was used to evaluate the differences between the C-factor values calculated from the TTI data using the SERL methodology, the USLE C-factor values found in *Agricultural Handbook 537* (Wischmeier and Smith, 1978), and C-factor values calculated using the RUSLE2 program. The results in Table 4 indicate that the null hypothesis, that there are no significant differences among the three sets of C-factor values, should be rejected. The ANOVA test identified a significant difference between the C-factors values calculated using the SERL methods and the USLE C-factor values found in AH 537 and C-factor values calculated with RUSLE2, but did not indicate which specific pair or pairs were significantly different. A Tukey test (see Table 5) isolated the difference of means between the C-factors calculated with the SERL methods and the USLE C-Factors as the source of the significant difference identified by the ANOVA test. The Tukey test results in Table 5 also indicate that there are no significant differences between Pair One (USLE C-Factors and the RUSLE2 C-Factors) or Pair Two (calculated SERL C-Factors and the RUSLE2 C-Factors).

Table 3. C-factor comparison of values calculated from TTI data, AH 537 USLE values, and RUSLE2 values

Plot	Slope	Soil	Treatment	Sed Loss*	Control*	Calc C	USLE C	RUSLE2 C	USLE C Source	RUSLE2 C Description
CL1	1:2	Clay	4000** Straw Crimped	0.580	2.06	0.28	0.14	0.173	Table 9, AH 537	4000** Straw
CL2	1:2	Clay	4000** Straw Crimped	2.730	2.06	1.33	0.14	0.173	Table 9, AH 537	4000** Straw
CL3	1:2	Clay	4000** Straw Crimped	0.440	2.06	0.21	0.14	0.173	Table 9, AH 537	4000** Straw
CL4	1:2	Clay	4000** Straw Crimped	1.080	2.06	0.52	0.14	0.173	Table 9, AH 537	4000** Straw
SA1	1:2	Sand	4000** Straw Crimped	2.660	50.34	0.05	0.14	0.139	Table 9, AH 537	4000** Straw
SA2	1:2	Sand	4000** Straw Crimped	2.080	50.34	0.04	0.14	0.139	Table 9, AH 537	4000** Straw
SA3	1:2	Sand	4000** Straw Crimped	32.660	50.34	0.65	0.14	0.139	Table 9, AH 537	4000** Straw
SA4	1:2	Sand	4000** Straw Crimped	29.350	50.34	0.58	0.14	0.139	Table 9, AH 537	4000** Straw
C1	1:3	Clay	4000** Straw Crimped	0.110	1.24	0.09	0.07	0.178	Table 9, AH 537	4000** Straw
C2	1:3	Clay	4000** Straw Crimped	0.080	1.24	0.06	0.07	0.178	Table 9, AH 537	4000** Straw
C3	1:3	Clay	4000** Straw Crimped	0.520	1.24	0.42	0.07	0.178	Table 9, AH 537	4000** Straw
C4	1:3	Clay	4000** Straw Crimped	0.430	1.24	0.35	0.07	0.178	Table 9, AH 537	4000** Straw
S1	1:3	Sand	4000** Straw Crimped	1.320	27.21	0.05	0.07	0.145	Table 9, AH 537	4000** Straw
S2	1:3	Sand	4000** Straw Crimped	1.090	27.21	0.04	0.07	0.145	Table 9, AH 537	4000** Straw
S3	1:3	Sand	4000** Straw Crimped	22.450	27.21	0.83	0.07	0.145	Table 9, AH 537	4000** Straw
S4	1:3	Sand	4000** Straw Crimped	18.220	27.21	0.67	0.07	0.145	Table 9, AH 537	4000** Straw
S16	1:3	Sand	Bermuda only	1.214	27.21	0.04	0.02	0.042	alfalfa, lespedeza, sericea†	Bahaigrass
S16	1:3	Sand	Bermuda only	1.158	27.21	0.04	0.02	0.042	alfalfa, lespedeza, sericea†	Bahaigrass
S17	1:3	Sand	Native grasses	1.252	27.21	0.05	0.02	0.072	alfalfa, lespedeza, sericea†	Range Grass
S17	1:3	Sand	Native grasses	1.200	27.21	0.04	0.02	0.072	alfalfa, lespedeza, sericea†	Range Grass
S18	1:3	Sand	wildflower mix	2.547	27.21	0.09	0.02	0.183	alfalfa, lespedeza, sericea†	Sunflowers
S18	1:3	Sand	wildflower mix	1.660	27.21	0.06	0.02	0.183	alfalfa, lespedeza, sericea†	Sunflowers
S19	1:3	Sand	native forbes/grasses	1.301	27.21	0.05	0.02	0.072	alfalfa, lespedeza, sericea†	Range Grass
S19	1:3	Sand	native forbes/grasses	1.395	27.21	0.05	0.02	0.072	alfalfa, lespedeza, sericea†	Range Grass
S20	1:3	Sand	Crownvetch	1.255	27.21	0.05	0.02	0.083	alfalfa, lespedeza, sericea†	Hairy Vetch
S20	1:3	Sand	Crownvetch	1.391	27.21	0.05	0.02	0.083	alfalfa, lespedeza, sericea†	Hairy Vetch
CL12	1:2	Clay	Crownvetch	0.028	2.06	0.01	0.02	0.083	alfalfa, lespedeza, sericea†	Hairy Vetch
CL12	1:2	Clay	Crownvetch	0.024	2.06	0.01	0.02	0.083	alfalfa, lespedeza, sericea†	Hairy Vetch
CL13	1:2	Clay	native forbes/grasses	0.035	2.06	0.02	0.02	0.075	alfalfa, lespedeza, sericea†	Range Grass
CL13	1:2	Clay	native forbes/grasses	0.031	2.06	0.02	0.02	0.075	alfalfa, lespedeza, sericea†	Range Grass
CL14	1:2	Clay	wildflower mix	0.040	2.06	0.02	0.02	0.183	alfalfa, lespedeza, sericea†	Sunflowers
CL14	1:2	Clay	wildflower mix	0.038	2.06	0.02	0.02	0.183	alfalfa, lespedeza, sericea†	Sunflowers
CL15	1:2	Clay	Native grasses	0.033	2.06	0.02	0.02	0.075	alfalfa, lespedeza, sericea†	Range Grass
CL15	1:2	Clay	Native grasses	0.032	2.06	0.02	0.02	0.075	alfalfa, lespedeza, sericea†	Range Grass
CL16	1:2	Clay	Bermuda only	0.030	2.06	0.01	0.02	0.043	alfalfa, lespedeza, sericea†	Bahaigrass
CL16	1:2	Clay	Bermuda only	0.035	2.06	0.02	0.02	0.043	alfalfa, lespedeza, sericea†	Bahaigrass

*kg/10 m^2

† Table 5B AH 537

**lbs /acre

Table 4. Single Factor ANOVA: Comparing Calculated TTI C-Factors, USLE C-Factors, and RUSLE2 C-Factors

Alpha = 0.05

SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
Calculated TTI-SERL C-Factors	36	6.860	0.191	0.088		
USLE C-Factors	36	2.080	0.058	0.002		
RUSLE2 C-Factors	36	4.363	0.121	0.003		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.318	2	0.159	5.108	0.007637	3.082846
Within Groups	3.263	105	0.031			
Total	3.581	107				

Table 5. Tukey Test: Pairwise comparison isolating the significance between Calculated TTI C-Factors, USLE C-Factors, and RUSLE2 C-Factors

Difference of Means	
Pair 1 USLE C-Factors and RUSLE2 C-Factors	0.063
Pair 2 USLE C-Factors and the Calculated TTI-SERL C-Factors	0.133
Pair 3 Calculated TTI-SERL C-Factors and the RUSLE2 C-Factors	0.070
Qt	3.4
MS within group	0.031
S	36
D minimum	0.1

C-Factor Values Provided by Product Manufacturers

North American Green and Profile Products provide C-factor values for their erosion control products. These values are provided in Table 6 along with the C-factor values calculated using the SERL method. The sources of these values are the manufacturer’s websites (North American Green, December 2003. http://www.nagreen.com; Profile Products, December 2003. http://www.profileproducts.com/futerra/index.html).

Table 6. Comparison of Calculated C-factors with C-factors supplied by the product manufacturer.

Product Name	**Slope**	**Soil**	**Sed Loss**	**C-Factor Calculated with SDSU/SERL Method**	**C-Factor Supplied by manufacturer**
NAG SC150	1 to 2	Clay	0.21	**0.102**	0.145
NAG SC150	1 to 2	Sand	20.82	**0.414**	0.145
NAG S75	1 to 3	Sand	8.10	**0.298**	0.11
NAG S75 BN	1 to 3	Clay	0.31	**0.250**	0.19
NAG S75	1 to 3	Clay	0.27	**0.218**	0.11
NAG S75 BN	1 to 3	Sand	11.44	**0.420**	0.11
Futerra®	1 to 2	Sand	23.76	**0.472**	0.016
Futerra®	1 to 2	Clay	0.29	**0.141**	0.016
Futerra®	1 to 3	Sand	11.19	**0.411**	0.016
Futerra®	1 to 3	Clay	0.27	**0.218**	0.016
Conwed 3000 BFM	1 to 2	Sand	27.31	**0.543**	0.004
Conwed 3000 BFM	1 to 2	Clay	0.31	**0.150**	0.004
Conwed 3000 BFM	1 to 3	Clay	0.30	**0.242**	0.0003*
Conwed 3000 BFM	1 to 3	Sand	12.68	**0.466**	0.0003*

*Note-2.5:1 slope

A one-way ANOVA test was used to evaluate the differences between the C-factor values calculated from the TTI data using the SERL methodology and C-factor values provided by erosion-control product manufacturers. The results shown in Table 7 indicate that the null hypothesis, that there is no significant difference between the two data sets, should be rejected. The C-factors values calculated using the SERL methods are significantly different from C-factor values provided by the manufacturers.

Table 7. Single Factor ANOVA: Comparing Calculated TTI C-Factors and C-Factors Provided by the Product Manufacturer

Alpha = 0.05

SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
SDSU/SERL Method C-factors	14	4.344	0.310	0.020		
Manufacturer C-factors	14	0.883	0.063	0.005		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.428	1	0.428	34.719	3.25E-06	4.2252
Within Groups	0.320	26	0.012			
Total	0.748	27				

The results of the statistical analyses comparing the C-factor values calculated using the SERL method with values from: (1) the USLE (AH 537), (2) values calculated using the RUSLE2 program, and (3) values provided by the erosion-control product manufacturers suggest that it is inappropriate to use the SERL method to calculate C-factor values for the estimating erosion rates to be used in reclamation or erosion-control planning. However, from a practical perspective, there may be little alternative in many cases. Often, this method may constitute the best available technology.

Even though the statistical analyses suggest that the calculated values may be unreliable, there may be reasonable explanations for differences between the SERL values, the values from the USLE, the values from RUSLE program, and those provided by the manufacturers. One possible explanation for the differences is the variation in slope angles and soil-types used in the tests to measure erosion and to derive the C-factor values compared in the ANOVA analyses. Another possible source of error rests in the selection of analogous vegetation. Unfortunately, it was not possible to find in the available test data and in the published literature exactly comparable experimental conditions.

Further, there is "great" to "moderate" uncertainty associated with many of the calculated and USLE C-factor values, as indicated in Table 8. Given the expected accuracy of these values and the fact that many of the calculated values are within a few percent of the USLE values; the SERL methodology may be more useful than indicated by the statistical analysis. The values provided by the erosion-control manufacturers also may be questionable; several are in the category of "great" uncertainty.

In the absence of available C-factor values for specific products, the SERL method provides a "quick and dirty" method for C-factor value estimation. These values provide a soil-loss ratio useful for comparing the surface protection resulting from similar erosion-control products. Users are cautioned, however, that these values may introduce large errors into their erosion calculations. The final decision of whether to use these values or not depends on the error tolerance of the RUSLE user. Future scientific research is needed to calculate specific C-factors for erosion-control products and evaluate their performance for 1-month, 3-month, 6-month, 1-year, and 2-year periods.

Table 8. C-factor error (Yoder et. al. 1998)

C-Factor	**Expected Accuracy**	**Comment**
< 0.01	Great uncertainty	Data have extreme variability
0.01 – 0.05	Moderate	RUSLE soil loss estimates are most strongly affected by this factor, and RUSLE data includes a wide variety of surface conditions. Users need to be very careful in specifying factors which affect surface cover.
0.05 – 0.4	Best	
0.4 - 0.7	Good	
0.7 - 1.0+	Good	

Temporal and Spatial C-Factor Variation

In the past, single C-factor values often have been selected and used at various locations throughout the United States and throughout the year in USLE and RUSLE erosion calculations. The final issue addressed in this research is the spatial and temporal variability of C-factor values. In other words, can a single C-factor value be used to represent the surface protection provided by a specific material at all geographic locations and during all times of the year? To address this question, RUSLE2 was used to calculate monthly C-factors values for 49 U.S. cities using identical sets of program inputs. The following inputs were used for this experiment:

Soil- Sandy-Clay-Loam (low-med OM)
Slope Length- 72.6 feet
Slope Steepness- 9.0%
Slope Management- 1st day of month Blade and Fill Material, Op Depth 2.0
in Op Speed 2.0 mph, 2nd day of month, Add Mulch, 2000 lbs/acre
Contouring- Up and Down Slope

The above criteria remained held constant while the location and month are varied. The calculated monthly C-factors for each of the 49 U.S. cities are presented in Table 9.

This experiment resulted in a surprising range of C-factor values. Spatially, the values ranged from 0.16 in an arid environment such as Reno, NV and Phoenix, AZ to 0.40 in a humid environment such as Baton Rouge, LA. Temporally, the greatest range of values was in Salem, OR, with C-factor values ranging from 0.17 in September and October to 0.31 in April.

Table 9. Monthly C-Factor values for straw mulch in 49 U.S. Cities.

St	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AL	Montgomery	0.30	0.31	0.32	0.33	0.33	0.32	0.31	0.31	0.30	0.30	0.29	0.29
AZ	Phoenix	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.17
AR	Little Rock	0.29	0.29	0.29	0.30	0.30	0.30	0.29	0.29	0.29	0.28	0.27	0.28
CA	Fresno	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.18	0.18	0.18	0.18	0.18
CO	Denver	0.20	0.20	0.20	0.19	0.19	0.19	0.20	0.21	0.22	0.21	0.21	0.20
CT	Hartford	0.23	0.27	0.25	0.26	0.26	0.25	0.24	0.23	0.22	0.22	0.22	0.22
DE	Wilmington	0.26	0.26	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.25
DC	Washington DC	0.26	0.27	0.27	0.27	0.27	0.26	0.26	0.27	0.27	0.27	0.26	0.26
FL	Tallahassee	0.34	0.34	0.35	0.36	0.34	0.33	0.34	0.36	0.37	0.36	0.35	0.34
GA	Atlanta	0.28	0.29	0.30	0.31	0.31	0.30	0.30	0.30	0.29	0.28	0.27	0.27
ID	Boise	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.17
IL	Chicago	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.25	0.25	0.24	0.23	0.23
IN	Indianapolis	0.24	0.25	0.25	0.28	0.25	0.24	0.24	0.25	0.25	0.24	0.23	0.24
IA	Des Moines	0.23	0.24	0.24	0.25	0.23	0.23	0.24	0.25	0.25	0.24	0.23	0.23
KS	Topeka	0.25	0.26	0.25	0.27	0.24	0.25	0.26	0.27	0.27	0.27	0.26	0.25
KY	Louisville	0.26	0.26	0.27	0.31	0.27	0.26	0.27	0.27	0.27	0.26	0.25	0.25
LA	Baton Rouge	0.34	0.35	0.37	0.40	0.37	0.36	0.35	0.36	0.35	0.34	0.33	0.33
ME	Augusta	0.22	0.22	0.23	0.27	0.24	0.23	0.22	0.21	0.20	0.20	0.20	0.21
MD	Baltimore	0.26	0.26	0.27	0.30	0.27	0.26	0.26	0.26	0.26	0.25	0.25	0.25
MA	Boston	0.23	0.24	0.25	0.29	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.22
MI	Detroit	0.22	0.23	0.23	0.25	0.23	0.22	0.22	0.23	0.23	0.23	0.22	0.22
MN	Minneapolis	0.22	0.23	0.23	0.24	0.22	0.22	0.23	0.24	0.24	0.23	0.22	0.22
MS	Jackson	0.30	0.31	0.32	0.38	0.33	0.32	0.31	0.31	0.30	0.29	0.28	0.29
MO	St. Louis	0.25	0.25	0.26	0.29	0.25	0.25	0.25	0.26	0.26	0.25	0.24	0.25
MT	Helena	0.18	0.18	0.18	0.20	0.18	0.18	0.18	0.18	0.19	0.18	0.18	0.18
NE	Lincoln	0.24	0.24	0.24	0.25	0.23	0.23	0.24	0.25	0.23	0.25	0.24	0.24
NV	Reno	0.16	0.17	0.17	0.24	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
NH	Concord	0.22	0.23	0.23	0.26	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.21
NJ	Newark	0.25	0.26	0.27	0.30	0.27	0.26	0.25	0.25	0.25	0.24	0.24	0.25
NM	Santa Fe	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.20	0.21	0.20	0.20	0.19
NY	Albany	0.22	0.23	0.23	0.27	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21
NC	Raleigh	0.29	0.29	0.30	0.33	0.29	0.28	0.28	0.30	0.30	0.29	0.29	0.28
ND	Bismarck	0.19	0.19	0.19	0.20	0.19	0.19	0.20	0.21	0.21	0.20	0.19	0.19
OH	Columbus	0.24	0.25	0.25	0.27	0.24	0.24	0.24	0.25	0.25	0.24	0.24	0.24
OK	Oklahoma City	0.27	0.27	0.27	0.29	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.27
OR	Salem	0.21	0.23	0.24	0.31	0.26	0.21	0.20	0.19	0.17	0.17	0.18	0.18
PA	Philadelphia	0.26	0.27	0.28	0.31	0.28	0.27	0.26	0.27	0.26	0.26	0.25	0.25
RI	Providence	0.23	0.24	0.25	0.29	0.26	0.25	0.23	0.23	0.22	0.21	0.22	0.22
SC	Columbia	0.31	0.31	0.32	0.35	0.30	0.30	0.31	0.32	0.33	0.33	0.32	0.31
SD	Pierre	0.20	0.20	0.20	0.21	0.19	0.19	0.20	0.21	0.21	0.21	0.20	0.20
TN	Nashville	0.27	0.28	0.28	0.33	0.28	0.28	0.28	0.28	0.27	0.26	0.25	0.26
TX	Austin	0.28	0.27	0.27	0.29	0.27	0.28	0.29	0.30	0.31	0.31	0.30	0.29
UT	Salt Lake City	0.19	0.19	0.19	0.25	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19
VT	Bennington	0.21	0.22	0.22	0.26	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20
VA	Richmond	0.28	0.28	0.28	0.31	0.27	0.27	0.27	0.29	0.29	0.28	0.28	0.27
WA	Olympia	0.22	0.23	0.23	0.30	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.20
WV	Charleston	0.26	0.26	0.27	0.30	0.26	0.26	0.26	0.27	0.27	0.26	0.25	0.26
WI	Madison	0.22	0.23	0.23	0.25	0.23	0.22	0.22	0.23	0.23	0.23	0.22	0.22
WY	Cheyenne	0.19	0.19	0.19	0.20	0.19	0.19	0.19	0.21	0.21	0.20	0.20	0.19

A two-factor, without replication, ANOVA analysis was used to test the null hypothesis that there is no spatial or temporal difference in the calculated C-factor values. The results in Table 10 indicate that this null hypothesis should be rejected at the one-percent significance level. Several conclusions are drawn from this analysis. First, C-factor values vary significantly at different geographic locations. Second, C-factor values vary significantly throughout the year. Lastly, it is inappropriate to select a single C-factor value for all geographic locations, during all times of the year. While there may be occasions and circumstances where single C-factor values provide satisfactory erosion estimates, the above analysis does not support this practice.

Based on this study, the risk of introducing error into the RUSLE erosion estimates by using the same C-factor value at a particular location for different times of year (maximum range of 0.14) seems to be slightly lower than using the same C-factor value at different locations (maximum range of 0.24).

The results of this study indicate that geographic variation may result in erosion calculation errors as large as 24%, while temporal variation may result in errors up to 14%. These results also suggest that it may be possible to "regionalize" C-factor values without introducing unreasonable error into the estimates. For example, Denver, CO and Cheyenne, WY have maximum C-factor difference of 0.01, which produces a one-percent error in the erosion calculation. Further study is required to define these regions.

Overall, it is best to calculate site- and time-specific C-factors using the RUSLE program. When this is not possible, RUSLE users must make well-informed and conscious decisions regarding how much calculation error is acceptable for a particular purpose and select C-factor values based on that tolerance threshold. It is imperative that RUSLE users understand the possible consequences associated with improper C-factor value selection.

Table 10. Spatial and Temporal C-Factor ANOVA Results

ANOVA	**Alpha = 0.01**					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Spatial (Rows)	1.152816	48	0.024017	166.9618	**8.552E-287**	1.575181
Temporal (Columns)	0.052490	11	0.004772	33.1730	**1.6731E-53**	2.281396
Error	0.075951	528	0.000144			
Total	1.281258	587				

Conclusions

There is little consensus in the erosion-science community concerning which values for the cover-management factor (C-factor) should be used when the USLE or Revised Universal Soil Loss Equation (RUSLE1.06) is applied to non-agricultural lands, such as mined lands and construction sites. Based on this study, the C-factor values calculated from the TTI data by the SERL method are significantly different than the USLE values found in AH 537 (Wischmeier and Smith, 1978) and the values calculated with the RUSLE2 program. Despite these findings, in many real-world situations the SERL methods and the resulting values may constitute the best available technology. Given the highly variable nature of low magnitude C-factor values and the fact that many of the calculated values are within a few percent of the USLE/RUSLE2 values, the SERL methodology may be more useful than implied by the statistical analysis. The values presented by the erosion-control manufacturers appear questionable because several fall within the category of "great" uncertainty and are of uncertain derivation.

Due to the paucity of research-derived C-factor values for specific erosion-control products, the SERL method provide "quick and dirty" C-factor values. At worst, these values provide a soil-loss ratio useful for comparing the surface protection of similar erosion-control products. RUSLE users must be cautioned that improper C-factor value selection may introduce large errors into their erosion calculations. The final decision of whether to use these values or not depends on the error tolerance of the RUSLE user. RUSLE2 (Version- December 2, 2003) offers only a few choices under the Management tab for erosion-control blankets (Roll Material, Roll Material Quick Decay, Roll Material Slow Decay, Roll Material ws05 Single Net Straw 0.5 lbs/sq yd). Based on the variable erosion-control success of the products tested by TTI, there is a distinct need for additional options within RUSLE2 in order to select specific erosion-control products.

The spatial and temporal variation in C-factor values is statistically significant. It is inappropriate to assign a single C-factor value to represent the surface protection provided by a specific erosion-control product at all geographic locations, during all times of the year. There may be occasions and circumstances where such assignments cannot be avoided but the RUSLE user must recognize the probability of introducing substantial errors into the erosion calculations. Use of a C-factor value from another, hopefully nearby, location within the region seems to be one way to minimize introduced error. Site-specific C-factors provide the best calculation of erosion rates. Further research is needed to unbiasedly calculate C-factors for specific erosion control products.

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