Cover-Management Enhancements for Rusle2 in the Pacific Northwest USA

***D. K. McCool*[1], *G. R. Foster*[2], *A. H. Ingersoll*[3], *R. C. McClellan*[4] and *R. W. Rickman*[5]**

[1] USDA-ARS, Pullman, WA 99164-6120 USA
E-mail: dkmccool@wsu.edu
[2] USDA-ARS, retired, National Sedimentation Laboratory, Oxford, MS USA
[3] USDA-NRCS, Mongmong, GU USA
[4] USDA-NRCS, retired, Spokane, WA USA
[5] USDA-ARS, retired, Pendleton, OR USA

Abstract: The Natural Resources Conservation Service (NRCS) of the US Department of Agriculture is charged with the responsibility of assisting land owners develop conservation plans to protect their cropland from erosion and prevent excessive sediment delivery to streams and reservoirs. Erosion prediction technology, such as the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997), is the tool used universally to develop these plans. The NRCS is implementing RUSLE2, the most recent version of RUSLE, for farm planning use in 2002. Technology in this new version of RUSLE is significantly improved from previous versions. New relationships have been added, retained ones improved, it is more process based, and computations are done on a daily basis. This change in technology provided the need and impetus to examine and improve the cover and management relationships for the Northwestern Wheat and Range Region (NWRR) (Austin, 1981) of the Pacific Northwest USA. Analysis of a large crop yield and total biomass data set collected during a 10-year period in the NWRR provided relationships between residue production and crop yield for a number of crops. Recent data provided new relationships for root mass values for small grains. These new relationships, as well as previously reported findings, were used in validating RUSLE2 for the NWRR using 13 years of runoff plot data from the Palouse Conservation Field Station (PCFS) near Pullman, Washington, USA. Validating RUSLE2 for the NWRR is especially important to ensure that RUSLE2 works well in a region where erosion uniquely occurs during low intensity rainfall on saturated, thawing soil where the soil is easily eroded. RUSLE2 must perform well to develop cost-effective conservation plans to prevent both on-site and off-site damages.

Keywords: water erosion, prediction, management, soil loss, surface cover, RUSLE

1 Experimental setup

The runoff plots of the study were located at the Palouse Conservation Field Station (PCFS) 3 km northwest of Pullman, WA. Data reported in this paper was collected from the fall of 1978 through the spring of 1991. Thirty-year (1961—1990) average annual precipitation at the site is 540 mm; about 250 mm of this falls during the primary erosion season, December through March. Instrumentation at the plot site included recording and standard rain gages. Temperature and other climate data were collected at the PCFS weather station, 0.3 km from the plots. Frost tubes (McCool and Molnau, 1984) were used to determine frost depth.

Bordered runoff plots were placed on a south-facing hill slope of 15% to 26% steepness. Soil at the site is a Palouse silt loam (fine silty, mixed Mesic-Pachic, Ultic, Haploxeroll). The plots were 3.66 m wide and ranged from 12.0 m to 45.9 m in length. At least one plot of each treatment was 22.1 m long. Runoff was collected at the lower end of each plot and flowed by gravity into a large tank. The contents of the tank were agitated using a pump, and an aliquot was collected from a splitting tee when the tank was emptied by the pump; the aliquot was then stirred and samples were collected for determining sediment concentration.

Each plot area was assigned one of the following six crop management treatments: continuous bare fallow, tilled (CBF); winter wheat following winter wheat, tilled (WW/WW); winter wheat following summer fallow, with no-till seeded winter wheat killed in the spring before fallow (WW/SF); winter wheat following spring peas, with the wheat stubble fall tilled with a straight point chisel and winter wheat no-till seeded into pea stubble (WW/P A); winter wheat following spring peas, with the wheat stubble fall plowed before spring peas and winter wheat no-till seeded into pea stubble (WW/P B); winter wheat following spring peas, with wheat stubble fall tilled with a twisted point chisel before spring peas, and winter wheat seeded into tilled pea stubble (WW/P C). Final operations for the seeded plots were done on contour for most years of the study. Plots left rough-tilled over winter were always tilled on contour, and the furrow slice was always turned upslope with the moldboard plow. The no-till seeded treatments were not in continuous no-till, as tillage was used for other crops in the rotation. Borders on the CBF plots were removed for a short time in the fall to till the plots. For all other treatments, plot borders were installed in mid-October after fall tillage or seeding winter wheat and removed in April after the end of the main erosion season. Thus no data was collected from these plots between early April and mid-October, a period of low erosion hazard in the region.

2 Data collection

Runoff volume was determined from a volume/depth relationship for each collection tank. In general, runoff measurements and sediment samples were taken daily, at which time the tanks were emptied. This routine was followed even if an event lasted for more than one day; total runoff for extended events consisted of the sum of several days' measurements. Daily or event soil loss was calculated by multiplying runoff volume by sediment concentration. The event total soil loss was divided by plot area to give soil loss per unit area. These values were totaled for each winter erosion season to give annual winter soil loss per unit area for each plot. The annual totals for all plots with a given treatment were averaged to give an annual treatment value. These annual treatment values were then averaged across the years of the study to give the treatment average soil loss in Table 1.

Surface cover was estimated by comparison with photos showing known quantities of residue mass per unit area or percentage residue cover. Surface cover values for each treatment are given in Table 1. Canopy cover was also determined by comparison with photos showing known percentage cover. Because of the narrow alleys between treatments and the use of contour seeding, it was necessary to seed all winter wheat plots at the same time. Thus, there was no early seeding into summer fallow and no associated early growth. Winter wheat cover during the winter was generally well under 10%; individual treatment crop cover data are not shown.

In the early stages of the project, surface roughness was estimated by counting or estimating the number of surface clods of a given size in a square meter. Later in the project, photos showing specific random roughness (standard deviation about the mean elevation) values were used to rank the random roughness on the plots (Renard *et al.*, 1997). Random roughness values, a mean of fall and spring observations, are given in Table 1.

In the early stages of the project, ridge height was determined by use of a ruler and straight edge. Later, ridge heights were determined using a 1.83-m wide profile meter that was set up across and up and down the plots in the fall, and again in the spring, to document plot conditions. See Table 1 for ridge height values.

3 Analytical procedure

The bulk of this analysis centers on calibration and validation of the C and P factor values. However, values of LS and R are also involved. The value of the rainfall and runoff erosivity factor, R, for Pullman, based on EI (product of storm energy and maximum 30-minute intensity), is less than 255 (MJ mm)/(ha • h • y). However, based on soil loss observed on the CBF plot, a value of seven times or more is more appropriate. The LS value for the PCFS plots is approximately 1.6. With nomograph K of 0.042 (t • ha • h)/(ha MJ mm) for the Palouse silt loam on the site, an equivalent R (Req) value of 1925 (MJ mm)/(ha • h • y) would be obtained.

Table 1 RUSLE2 Verification For Pacific Northwest USA Using Palouse Conservation Field Station Plot Data

Treatment	Crop Yield	Residue Production	Surface Cover After Final Operation		Winter Average Random Roughness		Ridge Height After Final Operation		Winter Average Soil Loss	
			Observed	RUSLE2	Observed	RUSLE2	Observed	RUSLE2	Observed	RUSLE2
	kg/ha	kg/ha	%	%	mm	mm	mm	mm	t/ha	t/ha
CBF	0	0	3	0	6.4	4.1	0.0	0.0	130	134
WW/WW	3,307	6,053	38	41	11.9	11.7	38.1	38.1	1.10	0.85
WW/SF	4,909	8,462							9.20	5.60
Yr 1 WW after SF			12	13	8.6	9.9	35.6	35.6	18.22	10.80
Yr 2 WW			90	89	6.4	7.4	no data	25.4	0.12	0.14
WW/P A	3,363/953	4,752/3,620							0.70	0.72
Yr 1 WW after Peas			51	50	8.9	10.2	63.5	63.5	1.05	1.30
Yr 2 Fall Till			61	58	25.4	20.6	142.2	137.2	0.27	.10
WW/P B	4,001/953	6,613/3,239							1.21	1.68
Yr 1 WW after Peas			53	51	7.1	8.4	34.3	35.6	2.35	2.69
Yr 2 Fall Till			18	19	35.6	35.6	139.7	139.7	0.04	.47
WW/P C	3,845/930	6,445/3,363							1.77	3.36
Yr 1 WW after Peas			19	20	12.2	10.7	40.6	38.1	3.38	6.72
Yr 2 Fall Till			48	55	25.4	25.2	132.1	132.1	0.16	0.11

Treatment Summary:

CBF Continuous bare fallow, tilled.

WW/WW Winter wheat following winter wheat, tilled.

WW/SF Winter wheat following summer fallow, with no till seeded winter wheat killed before fallow.

WW/P A Winter wheat following spring peas, with wheat stubble fall tilled with a straight point chisel before spring peas and winter wheat no till seeded into pea stubble. Two-year rotation.

WW/P B Winter wheat following spring peas, with wheat stubble fall plowed before spring peas and winter wheat no till seeded into pea stubble. Two-year rotation.

WW/P C Winter wheat following spring peas, with wheat stubble fall tilled with a twisted point chisel before spring peas and winter wheat seeded into tilled pea stubble. Two-year rotation.

The LS relationship for rill erosion in the area (McCool *et al.*, 1993) is

$LS = (\lambda/22.13)^{0.5} (10.8\sin\theta + 0.03)$ $\theta < 5.143$ degrees

$LS = (\lambda/22.13)^{0.5} (\sin\theta/\sin 5.143)^{0.6}$ $\theta \geq 5.143$ degrees

where LS = Length-Steepness Factor

λ = Slope Length, meters

θ = Angle of Slope, degrees

With the use of a fixed erodibility, K, based on the soil erodiblility nomograph (Wischmeier *et al.*, 1971), all interaction of the climate and erodibility is included in the Req relationship and its distribution through time.

The soil loss ratio, SLR, is the ratio of soil loss with a given treatment to that from continuous tilled bare fallow. The SLR is calculated as the product of seven subfactors $SLR = BG \times SC \times CC \times GC \times SR \times RF \times SM$.

where SLR = Soil Loss Ratio

BG = Below Ground Biomass Subfactor

SC = Soil Consolidation Subfactor

CC = Crop Canopy Subfactor

GC = Ground Cover Subfactor

SR = Surface Roughness Subfactor

RF = Ridge Subfactor

SM = Soil Moisture Subfactor

The Soil Consolidation Subfactor accounts for how soil becomes less erodible after a mechanical soil disturbance. The Below Ground Biomass Subfactor accounts for how live and dead roots and buried residue affect soil loss. The Crop Canopy Subfactor accounts for the effect of crop canopy, The Ground Cover Subfactor accounts for the effects of crop residue and rock fragments on the surface. The Surface Roughness Subfactor accounts for the effects of random roughness, the Ridge Subfactor accounts for the effect of ridge height on soil loss, and the Soil Moisture Subfactor accounts for the effect of antecedent water prior to the erosion season. Only two factors have been calibrated specifically to the NWRR, SC and SM. A relationship for SC as a function of surface cover developed for the PCFS runoff plots (McCool *et al.*, 1997) is

$$SC = e^{(-0.046M)}$$

where M = percent surface cover.

The SM Subfactor was developed from observations on runoff plots on farm fields near Rockford, WA. The SM Subfactor ranges from 0 to 1.0. A field at wilting point to a depth of 2 m in the fall is assigned a value of 0, which would increase as the soil profile fills with water during the winter, and a value of 1.0 is assigned for a soil profile at field capacity, fall or spring.

Vegetation files were developed that matched the average observed yield and biomass production from the crops grown on the cropping treatments on the plots. Specific operation files were developed by trial and error to match the residue cover, surface roughness, and ridge height observed on the crop treatments. Because of the near-perfect contouring on the plots, duplicating observed ridge height was important.

After the databases were developed that would match observed plot conditions, RUSLE2 was then run with appropriate Req, K, and LS values in order to obtain an erosion prediction for each year of each rotation. The data are presented in Table 1.

4 Results and discussion

RUSLE2 output values for surface cover, random roughness, ridge height after the final operation in the fall and soil loss are given in Table 1. RUSLE2 operations include flattening, burial and surfacing of the above ground biomass. The plant material must be flattened before it can be incorporated. Most adjustments of the core database to match the observed surface cover after the final operation in the fall were made in the burial coefficient. Close correspondence between observed and RUSLE2 surface cover was obtained by trial and error.

Obtaining exact correspondence between observed and RUSLE2 winter average random roughness was not given the same attention as surface cover. Soil loss is less sensitive to random roughness than to surface cover.

Because of the near-perfect contouring on the plots for most years of the study, ridge height is quite important in controlling the observed amount of soil loss, and this effect is also quite important in RUSLE2. Ridge height input values were adjusted to match the observed data. Because of the large amount of residue on Yr 2 of the WW/SF rotation, no ridge height data were collected. A ridge height of 25.4 mm was assumed. This is a slightly smaller value than when the drill was used on other treatments with less surface cover.

Because the Req value was calculated from the CBF plot data, RUSLE2 would be expected to exactly duplicate the observed erosion value for that treatment. The difference, 134 versus 130 t/ha, is primarily due to round off error in the various values entered to calculate soil loss. RUSLE2 calculations for winter wheat seeded into tilled ground are low for WW/WW and Yr 1 of the WW/SF treatment, but high for Yr 1 of the WW/P C treatment. RUSLE2 estimates for no-till seeded winter wheat into winter wheat or pea stubble, Yr 2 of WW/SF and Yr 1 of WW/P A and WW/P B, are reasonably close to observed values. RUSLE2 erosion estimates for rough primary tillage with a straight point or twisted point chisel, Yr 2 of WW/P A and WW/P C, are reasonably close to observed values. However, the calculated erosion value for the moldboard plow, Yr 2 of WW/P B, is more than 10 times the observed value. This likely reflects the value of turning the furrow upslope on perfect contour that is not captured in the model.

5 Summary

RUSLE2 has been validated for the NWRR using erosion plot data from the PCFS near Pullman, WA. Results are generally acceptable given the wide range of conditions included on the plots. Additional enhancements to the model will improve the predictions. RUSLE2 can be downloaded from the internet at http://www.rusle2.org.

References

Austin, M. E. 1981. Land resource regions and major land resource areas of the United States. USDA Agriculture Handbook No. 296. p. 156.

McCool, D.K., G.O. George, M. Freckleton, C.L. Douglas, Jr., R.I. Papendick. 1993. Topographic effect on erosion from cropland in the Northwestern Wheat Region. Trans. of the ASAE 36(4):1067-1071.

McCool, D. K., M. Molnau. 1984. Measurement of frost depth. In: Western Snow Conference Proceedings, Sun Valley, ID, p. 33-41.

McCool, D.K., K.E. Saxton, J.D. Williams. 1997. Surface cover effects on soil loss from temporally frozen cropland in the Pacific Northwest. p. 235-241. In Proc. International Symposium on Physics, Chemistry, and Ecology of Seasonally Frozen Soils, Fairbanks, AK, June 10-12, 1997.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder (Coordinators). 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703, pp. 404.

Wischmeier, W. H., C. B. Johnson, B. V. Cross. 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil and Water Conserv. 26:189-193.