How Irrigation Affects Soil Erosion Estimates of RUSLE2

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Abstract

RUSLE2 is a robust and computationally efficient conservation planning tool that estimates soil, climate, and land management effects on sheet and rill erosion and sediment delivery from hillslopes, and also estimates the size distribution and clay enrichment of sediment delivered to the channel system. In the U.S.A., RUSLE2 is supported by extensive databases maintained by the USDA-Natural Resources Conservation Service. Examples are presented of how input climate, soil and management descriptions might be built outside the U.S.A. using data from Uruguay. In addition to average annual erosion and sediment delivery, recent enhancements give RUSLE2 the ability to predict a representative runoff event sequence for a particular location, soil, management, and user-specified return period that can be coupled with a channel erosion and routing model.

Keywords: runoff, soil erosion, irrigation

Introduction

Since 2000, there has been an increase cropping intensity in Uruguay. Cropped area has increased by a factor of three, largely accounted by increasing area cropped to soybean. The growth of soybean area has come at the expense of rotations of cropland with grass/legume pastures. Current cropping systems are largely conducted with no tillage (direct seeding) and often winter cover crops are employed. Although Uruguay receives 1 to 1.5 m of rainfall annually, available soil water is not always adequate to support optimal crop growth so irrigated cropland area has also been increasing. Concern has been expressed that the wetter soil conditions under irrigation could increase the risk of soil erosion by rainfall. The purpose of this study was apply the RUSLE2 model to Uruguayan conditions to estimate the impact of irrigation on the risk of soil erosion by water.

Materials and Methods

The influence of irrigation on erosion estimated by RUSLE2 occurs through changes to the K factor and the C factor. In RUSLE2, there is no representation of any direct erosion caused by added irrigation water. Rather irrigation increases the water content of the soil, which increases the likelihood of runoff, and this is reflected through changes in the K factor. In the USLE/RUSLE/RUSLE2 family of models, soil erosion is assumed to be linearly related to the rainfall erosivity. There is no separate runoff term in the erosion equation. Rather, the likelihood of runoff and associated sediment transport is one of the factors that influences the K factor.

In RUSLE2, erosion and the state variables that control it are calculated on a daily basis. Whereas in USLE, K was taken as a constant, in RUSLE2 the default behavior is to have K vary daily based on monthly temperature and rainfall information contained in the input climate description (USDA-ARS, 2013, section 4.5). The local monthly temperature and rainfall values are compared to those from the center of the U.S.A. (Columbia, MO). Generally, the K factor is higher where and when runoff is more likely to occur due to wetter and cooler conditions. Conversely, the K factor is greatly reduced when the soil is likely to be frozen. This time varying K factor is affected by added irrigation water, resulting in a higher likelihood of runoff and therefore erosion and sediment delivery.

Added irrigation water also influences the breakdown of plant residue biomass. In RUSLE2, each sort of plant residue is characterized by a decay constant that describes that residue type's potential rate of decomposition under optimum conditions. A separate residue pool is created on each day that residue is added to the system. Each pool's decomposition is simulated with an exponential decay equation. The actual rate of decomposition on a given day may be limited by sub-optimal water or temperature conditions (USDA-ARS, 2013, section 10.3). Adding irrigation water may overcome water limitations to residue decomposition where the natural climate limits residue decomposition rates due to inadequate water. Increased decomposition will lower crop residue biomass, which will increase several of the RUSLE2 C sub-factors. Thus, irrigation could increase RUSLE2 soil loss estimates through C factor effects. However, to the extent that irrigation increases crop yield, it will also increase residue returned to the field. In RUSLE2, crop yield increases due to irrigation must be specified by the user since, unlike the residue decomposition process, RUSLE2 does not include a crop growth model that automatically increases crop yield in response to available water. If the user-specified increase in crop yield results in residue additions that exceed the increased decomposition losses caused by added irrigation water, then the net C factor in RUSLE2 may be reduced, and may offset the increased K factor associated with the wetter soil.

RUSLE2 Application to Uruguay

To illustrate the effects of irrigation on RUSLE2 erosion estimates, it is necessary to consider a RUSLE2 «profile,» which is a representative hillslope described by climate, soil, topography, and management information. Each of these are «objects» in RUSLE2 that must be specified. Below is a brief description of how these objects were described in this study.

Climate: RUSLE2 climates consist of monthly inputs of temperature, rainfall, and erosivity density (the ratio between the R factor and the rainfall depth), plus the depth of the 10-y 14-h precipitation depth (Dabney *et al.*, 2012). Zhu and Yu (2015) proposed that the following equation could be used to estimate monthly rainfall erosivity, E_j, from daily rainfall data:

$$\hat{E}_j = \alpha\left[1+\eta\cos\left(2\pi f\, j-\omega\right)\right]\sum_{d=1}^{N} R_d^{\beta} \tag{1}$$

where:

R_d is daily rainfall (mm), N is the number of days in month j, f=1/12, and α, β, η, and ω are parameters to be estimated. Generally, for the Southern Hemisphere, ω is set to π/6, indicating rainfall intensity would be highest in January, and to 7ð/6 in the Northern Hemisphere, indicating rainfall intensity would be highest in July. To find parameter estimates that would approximate monthly erosivity values from average monthly rainfall values, we replaced R_d with R_j and fitted the equation to monthly rainfall and erosivity pairs contained within in the official RUSLE2 database (USDA-NRCS, 2015) at selected sites in the southeastern U.S.A. Based on inspection of results, we used parameter values of α=0.4, β=1.5, η=0.5 to estimate RUSLE2 monthly erosivity values for Uruguay based on average monthly rainfall values for the period 1990 to 2009 (World Bank, 2015). These parameter values are not considered optimal and more testing could refine them, but the resulting estimated monthly erosivity values appeared reasonable for the purposes of this paper. The result was an average annual R=6060 MJ mm ha^{-1} h^{-1} for annual rainfall of 1344 mm. We also specified a latitude of -33 degrees and assigned a value of 140 mm to the 10-yr 24-hr rainfall depth, similar to events at similar northern latitude in the southeastern U.S.A.

Soil: A base K factor of 0.023 Mg h MJ^{-1} mm^{-1} was adopted as reported by Hill *et al.* (2008) for the la Estación Experimental La Estanzuela (LE, Colonia, Uruguay). This user-specified base value was allowed to vary on a daily basis referenced to Columbia, MO, U.S.A. Additionally, the soil hydrologic group was set to «A,» the clay was set to 32 %, and the sand was set to 25 %.

Topography: The LS factor was calculated for conditions equivalent to unit plot conditions (22.1 m long, 0.03 gradient), which is similar to the plot condition described in Hill *et al.* (2008).

Land management: Several crop management conditions were simulated. First, a continuous soybean disk/field cultivator tillage system is explored with and without irrigation. Rainfed yield level was set at 2.3 Mg ha^{-1} y^{-1}. Irrigation was represented as four 5.1 cm applications between 15 Dec and 4 Feb. RUSLE2 response to irrigation was estimated for two cases: (1) using the base soybean yield and (2) with a 30 % greater soybean yield of 3.0 Mg ha^{-1} y^{-1}. Second, a corn soybean rotation simulated under direct seeding (no-till) with grass cover crops between each grain crop, with and without irrigation. Planting dates, growth periods, and yields were varied in these simulations (Mario Pérez Bidegain, personal communications).

Results

The effect of adding ~20 cm of irrigation water during the December through February period on the RUSLE2 K factor is illustrated in Fig. 1. It should be noted that even without irrigation, the effective K factor in Uruguay is higher than the

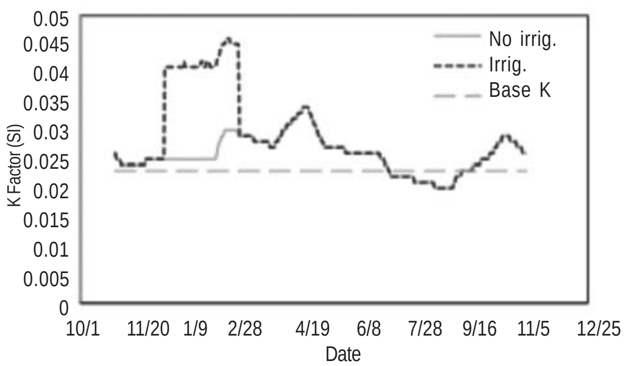

Figure 1. Daily RUSLE2 estimated K factor in Uruguay for a user-entered base K=0.023 for rainfed and irrigated conditions.

base K factor specified because Uruguay receives more rainfall than does the reference location (Columbia, MO, 987 mm). Addition of irrigation nearly doubles the K factor during the irrigation season.

Figure 2 illustrates how RUSLE2 estimates the C factor, the K Factor, the standing above ground biomass, the surface residue biomass, and the runoff and erosion for a representative series of runoff events calculated according to procedures described by Dabney *et al*. (2011, 2012) for rainfed conditions. The sum of the estimated erosion events resulted in an estimated annual soil loss of 19 Mg ha^{-1} y^{-1}. Addition of irrigation without any increase in crop yield increased the annual erosion estimate to 21 Mg ha^{-1} y^{-1}. Increasing the soybean yield to 130 % of the base yield with irrigation resul-

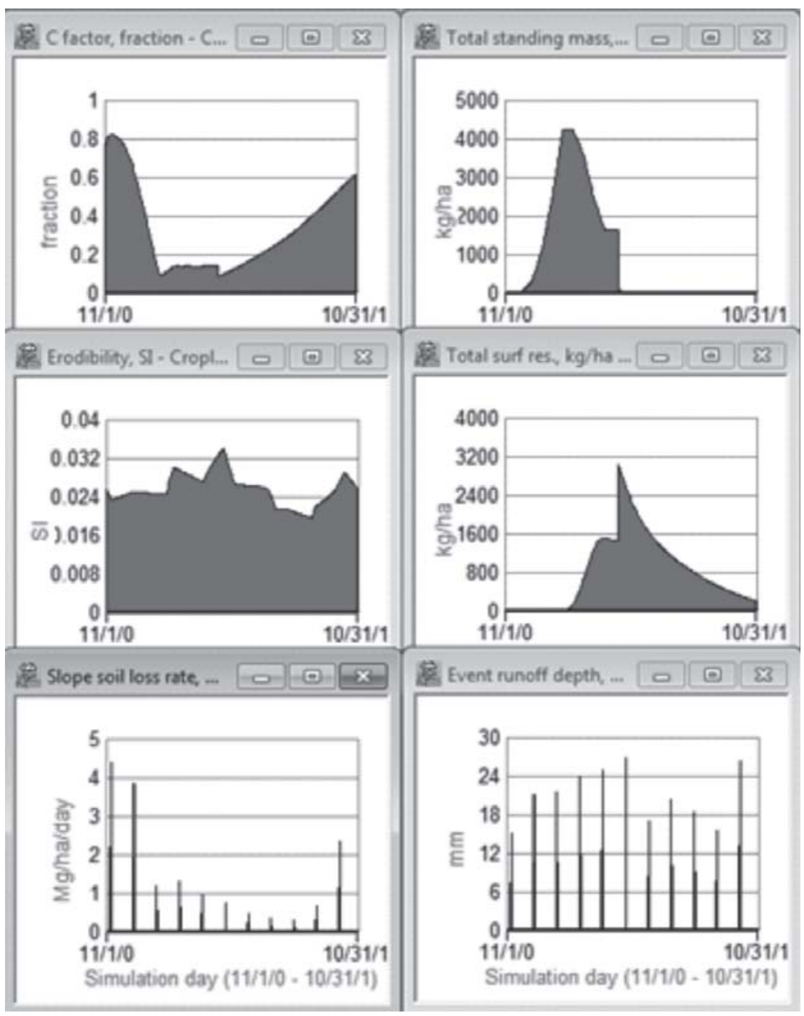

Figure 2. Plots generated by the RUSLE2 graphical user interface display daily estimated C and K factors, above ground and surface residue biomass, and representative event runoff and erosion for disk-till soybean grown on a 22.1 m 0.03 gradient plot with base K = 0.023 in Uruguay.

Table 1. RUSLE2 individual event runoff and erosion estimated on December 11 for runoff events with varying return periods for disk-tillage soybean grown on 22.1 m long, 3 % slope plots in Uruguay on a soil with K=0.023.

Scenario	Irrigation	Yield (Mg ha^{-1})	Return Period	Runoff (mm)	Erosion (Mg ha^{-1})
1	no	2.3	unspecified	21	3.8
2	no	2.3	1	55	3.8
3	no	2.3	10	99	7.7
4	no	2.3	100	150	12
5	yes	3.0	100	150	12

ted in an annual average erosion estimate of 18 Mg ha^{-1} y^{-1}, lower than the base rainfed estimate, but still much too high to be sustainable.

The user can use RUSLE2 to explore the risk of extreme events by specifying a return period for any single event in the runoff event sequence. Table 1 illustrates the effect of varying the return period on estimated individual event runoff and soil loss for extreme events occurring on 11 December, a date when the RUSLE2 C factor was equal to 0.71. The results show that both runoff and soil loss increase with extreme events. However, as implemented in RUSLE2, irrigation had only a slight effect on runoff and erosion of associated with an extreme event. This may be because the extreme event overwhelms the impact of antecedent conditions or because RUSLE2 does not account for all forms of erosion. For example, RUSLE2 erosion estimates do not account for soil loss associated with concentrated flow and ephemeral gullies, which are likely to be important during extreme events. Dabney *et al.* (2015) have discussed technology that can extend RUSLE2 erosion estimates to include ephemeral gully estimates.

To estimate the likely effect of irrigation on land managed with direct drilling and cover crops, two corn-soybean cropping systems described in Table 2 were compared on the

Table 2. Management descriptions (operations and vegetations) of direct seeded corn soybean rotations under rainfed and irrigated conditions.

Date, m/d/y	Operation	Vegetation	Yield Mg ha^{-1}	Resid. added Mg ha^{-1}	Cover added %
Rainfed					
1/1/00	no operation				
5/15/00	harvest killing crop			3.91	73
5/25/00	begin growth	grass cover	4.6		
11/1/00	kill vegetation				
11/10/00	drill, double disk	soybean	2.6		
5/15/01	harvest killing crop			1.39	51
6/1/01	begin growth	grass cover	4.6		
11/25/01	kill vegetation				
12/10/01	planter, double disk opnr	corn	6.0		
Irrigated					
1/1/00	no operation				
3/20/00	harvest killing crop			5.64	85
4/1/00	begin growth	grass cover	4.6		
11/1/00	kill vegetation				
11/10/00	drill, double disk	soybean	3.3		
4/15/01	harvest killing crop			1.72	59
5/1/01	begin growth	grass cover	4.6		
8/25/01	kill vegetation				
9/10/01	planter, double disk opnr	corn	8.0		

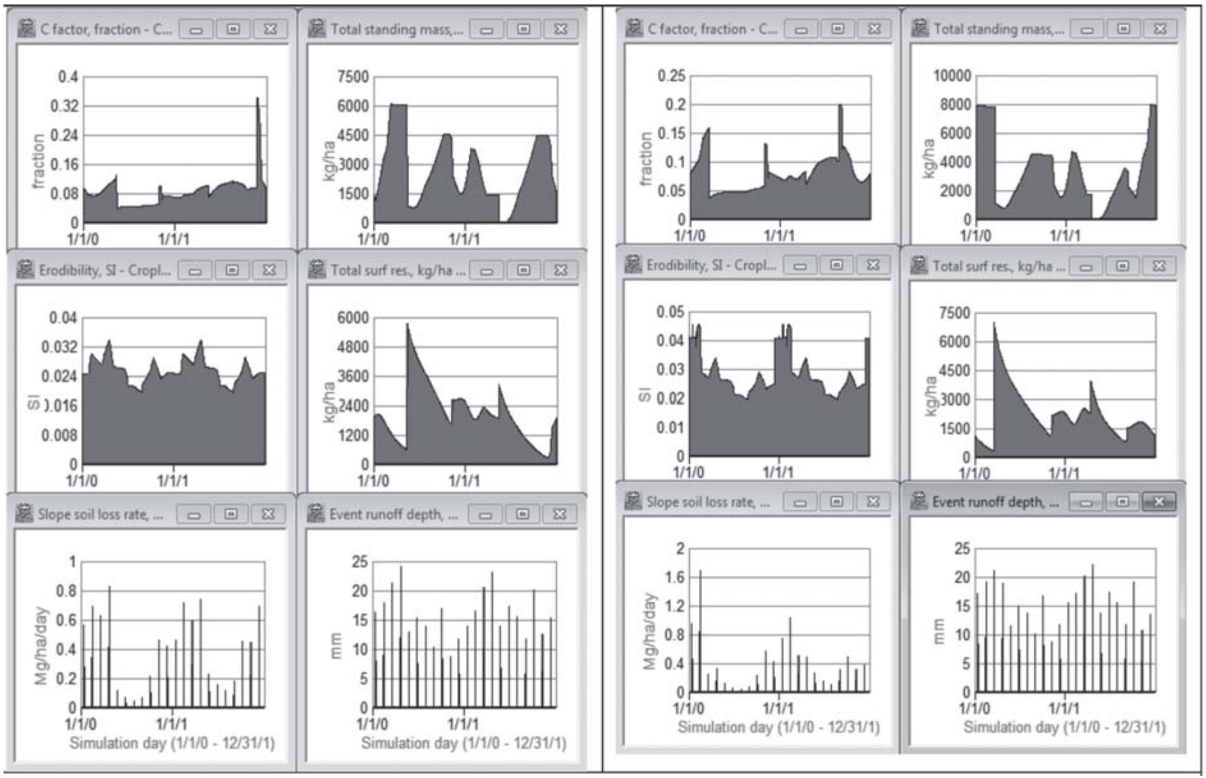

Figure 3. Daily RUSLE2 estimated C and K factors, above ground and surface residue biomass, and representative event runoff and erosion for direct seeded soybean-corn rotations described in Table 2 (A) rainfed and (B) irrigated on a 22.1 m 0.03 gradient plot with base K = 0.023 in Uruguay.

same hillslope described above. In this case, in order to have RUSLE2 generated plots begin on January 1, a null operation on that date was added to each management description.

Figure 3 illustrates the RUSLE2 estimated runoff and soil loss for the land management systems described in Table 2. In this case irrigation increased estimated average annual soil loss about 10%, from 4.5 to 4.9 Mg ha^{-1} y^{-1}. The largest soil loss events occurred during the irrigated corn growing season (mid-February of the first year) when surface residue cover was close to a minimum value. Under both rainfed and irrigated conditions, RUSLE2 sheet and rill erosion estimates were much lower than under the disk-tillage continuous soybean simulation, but are still significantly higher that would be expected from well-managed pasture (Dabney *et al.* 2012).

Discussion

RUSLE2 is a conservation planning tool whose primary objective is to lead to sound conservation planning decisions. The increased RUSLE2 K factor estimated by RUSLE2 in Uruguay is consistent with the observations by Hill et al. (2008) that erosion was increased when antecedent soil water content was higher. In this case, no water balance was conducted. Rather, the added irrigation water was disaggregated into daily values whose effect on the K factor was estimated. When used for conservation planning, the exact amount and timing of future rainfall and irrigation events is not known so simplified procedures are justified.

An option exists with RUSLE2 to use historical rainfall event data rather than the representative

runoff storm sequence approach illustrated herein. This alternative uses a «rain-data» object that accepts as input: rain event date, event depth, event erosivity, rainfall duration, maximum 30-minute intensity, rainfall start time and rainfall end time. If multiple rainfall events occur within a single day, RUSLE2 combines all the events on a day into a composite event. When this option is selected, estimated erosion will vary from year to year and not just season to season. In this retrospective case, accuracy of predicted daily runoff would be improved by a daily water balance accounting.

While an increased risk of erosion associated with wetter soil is estimated by RUSLE2, the increased yield associated with irrigation compensates for this through increased canopy and crop residue cover. For the Uruguayan conditions studied, these two influences largely offset so RUSLE2 predicts only minor impacts of irrigation on water erosion. A more comprehensive analysis would consider the effects of extreme events on ephemeral gully erosion. Certainly, field validation of erosion estimates is needed.

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