WEPP AS A TOOL FOR ENABLING A MORE COMPREHENSIVE ANALYSIS OF THE ENVIRONMENTAL IMPACTS OF SOIL EROSION

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Abstract

Cropland area in Uruguay, mostly soybeans, increased 300% during the last decade due to expansion to new areas. Although no-tillage practices are generalized among farmers, soil erosion is still a major environmental and economic issue. A predictive tool as the Water Erosion Prediction Model Project (WEPP), based on soil processes, has never been used in Uruguay. The objective of this research was to evaluate the soil erosion impact of various managements of intensive agriculture on Mollisols of Uruguay, applying the WEPP erosion model. The model was first adjusted and validated for annual erosion estimates of an Abruptic Argiudoll (Nash Sutcliffe (NS)= 0.81 and R^2 = 0.89) and a Vertic Argiudoll (NS= 0.86 and R^2= 0.90), and later applied to evaluate three Mollisols and one Vertisol with different soil managements. Treatments combined no tillage (NT) and reduced tillage (RT) with different crop rotations. Crop rotations were: continuous soybean (CS), soybean-wheat (SW), soybean-winter cover crop (S-Cover crop), corn-soybean-wheat-3/4 yr pasture (CSW-PPP/PPPP), and corn-soybean-wheat-soybean-wheat-3/4 yr pasture (CSWSW-PPP/PPPP). Soil erosion under RT system or CS was always above 7Mg.ha^{-1} (T value). Pastures inclusion under NT showed values below 7 Mg.ha^{-1}.WEPP simulated an average erosion rate below T for SW rotation with NT (100m; 3% slope) in three of the four soils studied. However, by varying the slope and the length of the hillslope, the range for which the average annual erosion remains below this level is limited (only 3% - 4%). Moreover, for those hillslopes whose average annual erosion does not exceed the T value, there is still approximately a 25% probability that this may occur any given year. Our work highlights the potential of using WEPP in the development of criteria for assessing sustainability of soil management, alternative to T value of average annual erosion units, including risk analysis.

Introduction

Cropland area in Uruguay, mostly soybeans, increased 300% during the last decade (*1*) due to expansion to new areas were soils are more vulnerable to water erosion. By the end of last century, Uruguayan agriculture was mostly managed alternating with crop-pasture rotations. This management reduced soil degradation produced by continuous crops (*2*). However, currently the wheat-soybean rotation is the most common practice in Uruguay. Soybean crops leave the soil both more susceptible to erosion (due to negative balances of nitrogen and carbon), and more exposed to erosion (because of the scarce residues of low C:N relation, which are an ineffective protection for the rain and runoff impacts) (*3*). Although no-tillage practices are generalized among farmers, soil erosion is still a major environmental and economic issue.

In this new context, it is necessary to know the potential impact continuous agriculture systems based on soybean have on soil erosion. Soil losses estimated with the Revised Universal Soil Loss Equation (RUSLE) showed that, regardless the tillage system used, continuous soybean systems presented mean annual soil loss rates higher than 7 Mg.ha^{-1}, considered a tolerance level for this soil (*4*). However, these rates were reduced when pastures were included in the cropping systems (*5*).

Environmental impact assessments require criteria for establishing thresholds. The concept of soil loss tolerance level as a threshold has evolved with time following an increase in soil knowledge and in environmental awareness. Originally, there was one single value of T considered valid for all soils in USA, with the focus on productivity (USDA 1956; in *6*). Later, a methodology was established to determine a T-value for each particular soil in USA based on its genetic, physical

and chemical properties (Logan 1977; in *4*), which was later adapted for our country (*4*). More recently, it has been suggested that the soil function concept should be incorporated and that T does not only depend on the type of soil, but also on the objectives of evaluation, being these productivity, rate of soil loss compensation by soil formation or off-site effect control *(7,8, and 9*).
Despite this evolution, all T-values proposed still refer to annual means. For a wider approach, to meet aims beyond productivity, annual means or even annual probabilities are not enough. For instance, the effects of extreme events, which can be highly erosive in one single day, are concealed by means. And these are the events that may produce irreversible processes, as gullies. When turning the focus to water ecosystems, it occurs that balances of parameters need to be maintained within a range at a daily step. Hence, RUSLE mean annual erosion estimations result insufficient to give answers to such detail. The model developed by the Water Erosion Prediction Project (WEPP), is based on soil processes at a daily step, and offers outputs, not only as annual means, but as probability of occurrence, and extreme events return periods (*10*). Although it has never been used in Uruguay it has a potential for evaluating soil managements with a wider approach. The objective of this research was to evaluate the soil erosion impact of various managements of intensive agriculture on Mollisols of Uruguay, applying the WEPP erosion model.

Materials y methods

The data used to adjust and validate the WEPP model was obtained from a research project conducted by the National Agricultural Research Institute of Uruguay. The study sites corresponded to an Abruptic Argiudoll (33º 12'S 54º 22'W) and a Vertic Argiudoll (34º 25' S 58º 0' W). Run off plots were installed in each experimental site. Table 1 shows the soil parameters used in WEPP model.

Table 1. Soil parameters given by default by the WEPP model and their adjusted values.

		Kb		τC	
Soil	Slope (%)	default	adjusted	default	adjusted
Abruptic Argiudoll	3.5	3.55	2.19	3.4	2.3
Vertic Argiudoll	3.0	3.55	6.00	3.5	3.0

Kb: baseline effective hydraulic conductivity; τC: critical shear stress; after adjustments made by Jorge (11).

For this study we used the WEPP hillslope model, version 2010.1. It was adjusted and validated for annual erosion estimates of an Abruptic Argiudoll and a Vertic Argiudoll (Table 1). The measured erosion data belonged to the Experimental Stations of the National Agriculture Research Institute (INIA) standard USLE natural runoff plots.

Measured and modeled soil loss was compared on an annual basis. Goodness of fit between measured and simulated erosion was assessed using the coefficient of determination (R^2) and the Nash-Sutcliffe (NS) coefficient (*12*).

The validated model was applied to evaluate three Mollisols and one Vertisol: Vertic Argiudoll (VA), Pachic Argiudoll (PA), Typic Hapludert (TH) and Typic Argiudoll (TA), with different soil managements. Treatments combined no tillage (NT) and reduced tillage (RT) with different crop rotations.

Crop rotations were: continuous soybean (CS), soybean-wheat (SW), soybean-winter cover crop (S-Cover crop), corn-soybean-wheat-3/4 yr pasture (CSW-PPP/PPPP), and corn-soybean-wheat-soybean-wheat-3/4 yr pasture (CSWSW-PPP/PPPP). Slope files were generated combining slope lengths from 10 to 300m and slopes from 3% to 7%. Rill and interrill erosion, Kb and TC were calculated by the model (*13*). In the case of VA and TA, Kb was calculated considering the subsuperficial horizons conductivities as in Jorge et al. (14).

The climate generator CLIGEN 4.3 was used to generate 100 years of simulated climate for INIA- La Estanzuela Experimental Station (34º 25' S 58º 0' W). The selected soils can be found within a radio of 120km from La Estanzuela Experimental Station. Simulated mean annual soil erosion was contrasted with soil loss tolerance level (T) established at 7Mg.ha^{-1}.yr-1 for all soils (*4*). Additionally, the probability of annual soil erosion exceeding T was calculated.

Results and Discussion

The adjusted model showed high levels of goodness-of-fit at an annual time scale for the annual erosion estimates of the Abruptic Argiudoll (Nash Sutcliffe (NS)= 0.81 and R^2 = 0.89) and the Vertic Argiudoll (NS= 0.86 and R^2= 0.90).

For a mean annual precipitation of 1164 mm, the mean annual erosion simulated with WEPP model ranged from 2 to 67 Mg.ha^{-1}.yr-1. The VA soil showed higher erosion rates than the others soils for those crop rotations with RT, or CS. However, under NT the TA soli showed the highest soil erosion estimates. The VA soil had a claypan which increased runoff rates, though rapid saturation. Its effect on enhancing erosion was therefore higher on those treatments which left the soil more exposed to it.

The second soil, TA, besides having a claypan, had lower clay and organic matter contents in the A horizon. These features decreased its shear stress, favoring soil erosion even in NT treatments. The PA soil had the highest soil organic matter content and clay in the A horizon, which favored soil resistance to water erosion. The highest erosion rate for continuous soybean with no tillage was estimated for TH (Table 2). For TA, simulations with WEPP ordered crop rotations similarly to the order established by USLE/RUSLE simulations. The WEPP estimated values were also similar, although slightly lower, with the exception of SW RT (*5*). Soil erosion under RT system or CS was always above 7Mg.ha^{-1} (T value), while pastures inclusion under NT showed values below 7 Mg.ha^{-1} (Table 2).

The SW rotation with NT is the most common in Uruguay. The WEPP model simulated an average erosion rate below T for this rotation on a 100m and 3% slope, in three of the four soils studied (Table 2). However, by varying the slope and the length of the hillslope, the range for which the average annual erosion remains below this level is limited (only 3% - 4%) (Fig.1). Moreover, for those hillslopes, whose average annual erosion does not exceed the T value, there is still approximately a 25% probability that this may occur any given year (Table 3).

This probability was obtained from the output of 100 possible years modeled by the climate generator. In this way, annual variability, which is lost when analyzing only in terms of annual means, can be introduced in the evaluation. Furthermore, analyzing event by event, there are cases where daily erosion can even surpass T, with a return period of 20 years for TA 300m 3% slope.

If the annual mean T is taken as a sustainability index, focusing on productivity, only those rotations with NT and 3 or more years of pastures would be sustainable, although slope length and percentage should be considered for site specific evaluation. For environmental impact assessments, responding to a wider approach, probabilities of annual erosion exceeding a threshold could provide complementary information for risk analysis.

Table 2. Simulated erosion for Vertic Argiudoll (VA), Pachic Argiudoll (PA), Typic Hapludert (TH) and Typic Argiudoll (TA) with different rotations (hillslope 100m; 3%)

	Simulated soil erosion (Mg.ha^{-1})			
Soil[1]	VA	PA	TH	TA
Rotation[2]				
CS RT	**66.81**	**52.1**	**64.38**	**42.70**
SW RT	**30.21**	**21.36**	**28.11**	**21.05**
CS NT	**29.79**	**28.50**	**35.59**	**24.89**
S-Cover crop. RT	**29.77**	**20.56**	**27.94**	**20.95**
CSWSW - PPP RT	**13.71**	**9.81**	**12.65**	**9.52**
CSWSW - PPPP RT	**13.01**	**9.05**	**12.24**	**8.83**
CSW-PPP RT	**11.8**	**8.67**	**11.48**	**8.09**
CSW-PPPP RT	**9.77**	6.82	**9.09**	6.76
SW NT	5.65	3.25	5.19	**8.07**
S-Cover crop. NT	4.48	2.40	3.67	6.97
CSWSW - PPP NT	4.12	2.54	3.86	4.87
CSWSW - PPPP NT	3.85	2.44	3.68	4.67
CSW-PPP NT	3.68	2.33	3.50	4.48
CSW-PPPP NT	3.42	2.10	3.15	3.91

[1]Soil Taxonomy (Durán et al., 1999); [2] C=corn; S=soybean; W=wheat; P=pastures; RT=Reduced Tillage; NT=No Tillage. **Bold numbers** indicate erosion rates above T (Soil Loss Tolerance Level T=7Mg.ha^{-1}) (*4*).

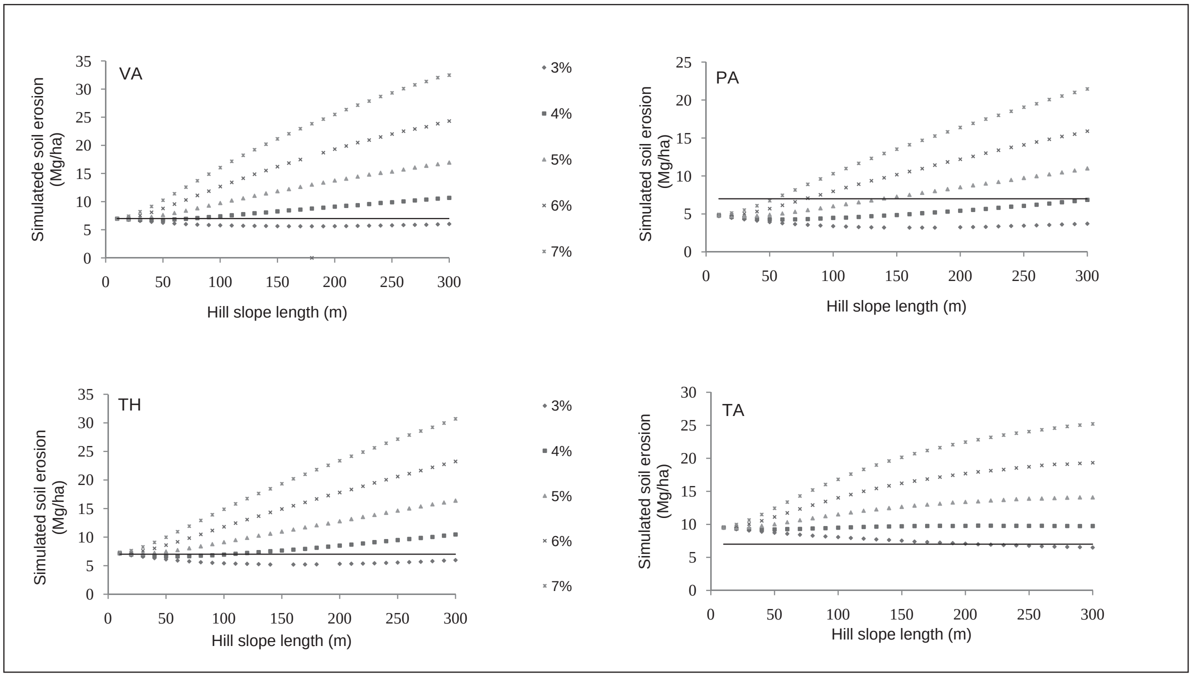

Fig.1. Simulated mean annual soil erosion for wheat-soybean rotation vs. slope length, for Vertic Argiudoll (VA), Pachic Argiudoll (PA), Typic Hapludert (TH) and Typic Argiudoll (TA), with slopes 3% to 7%. Horizontal line represents T=7Mg. ha-1.yr-1, maximum tolerable soil loss) (4).

Table 3. Probability of WEPP simulated annual erosion to exceed the soil loss tolerance level (T) at a wheat-soybean rotation

Soil*	Slope* (%)	Slope length* (m)		
		100	200	300
VA	3%	0.28	0.26	0.31
	4%	0.50	-	-
PA	3%	0.05	0.06	0.14
	4%	0.13	0.25	0.36
	5%	0.33	-	-
	6%	0.54	-	-
TH	3%	0.22	0.25	0.28
	4%	0.43	-	-
TA	3%	-	-	0.38

VA: Vertic Argiudoll, PA:Pachic Argiudoll, TH:Typic Hapludert, and TA: Typic Argiudoll.
*Combination of soils, slope length and slope percentage whose mean annual erosion does not exceed T (*4*)

Conclusions

The criterion used in Uruguay hereto to evaluate sustainability of crop rotations and soil management in terms of soil erosion has been the soil tolerance value (T) as a threshold for acceptable mean annual erosion. WEPP model simulations showed that continuous soybean systems and crop rotation systems including soybean with reduced tillage, would produce erosion rates that exceed T. However, pastures inclusion in these systems, under no tillage, would reduce the erosion rates to values lower than T. This confirms the estimations previously done with RUSLE for a 100 m and 3% slope. Because these results are highly dependent on slope and hillslope length, when increasing these factors, average annual erosion may exceed T. Moreover, annual estimations indicate that even when mean annual erosion is below T, there is still a probability for some years to exceed this threshold. Our work highlights the potential of using WEPP in the development of criteria for assessing sustainability of soil management, alternative to T value of average annual erosion units, including risk analysis.

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References

1. DIEA. 2011. Anuario Estadístico Agropecuario. MGAP.
2. García Préchac, F. and Durán, A. 1998. Propuesta de estimación del impacto de la erosión sobre la productividad del suelo en Uruguay. Agrociencia. II(1):26-36.
3. Terra J. and García Préchac, F. 2001. Siembra directa y rotaciones forrajeras en las Lomadas del Este: Síntesis 1995-2000. INIA, Serie Técnica Nº 125. 100pp.
4. Puentes, R. and Szogi, A. 1983. Manual para la utilización de la ecuación universal de pérdida de suelo en el Uruguay. Normas Técnicas en Conservación de Suelos Nº1. Dir. Suelos. MAP.
5. Clérici, C and García Préchac, F. 2001. Aplicaciones del modelo USLE/RUSLE para estimar pérdidas de suelo por erosión en Uruguay y la región sur de la cuenca del Río de la Plata. Agrociencia. (Revista Científica de la Facultad de Agronomía - UDELAR). Montevideo, Uruguay. 5(1):92-103.
6. Johnson, L.C. 1987. Soil loss tolerance: Fact or myth? Journal of Soil and Water Conservation 42(3):55-160.
7. Verheijen, F.G.A., Jones R.J.A. and Smith, C.J.

2009. Tolerable versus actual soil erosion rates in Europe.Earth-Science Reviews. 94:23-38.
8. Li, L., Du, S., W., L and Liu, G. 2009. An overview of soil loss tolerance. Catena. 78:93-99.
9. Bui, E.N., Hancock, G.J. and Wilkinson S.N. 2011. 'Tolerable' hillslope soil erosion rates in Australia: Linking science and policy. Agriculture, Ecosystems and Environment. 144:136–149.
10. Flanagan, D.C., and M.A. Nearing. 1995. Water Erosion Prediction Project: Hillslope profile and watershed model documentation. Report 10. US. Department of Agriculture (USDA) -Agricultural Research Service, NSERL, West Lafayette, IN.
11. Jorge, G. 2012. Evaluación del impacto de la intensificación del uso del suelo sobre la erosión hídrica en sistemas agrícolas del Uruguay: Aplicación del modelo WEPP. Master's Thesis. Facultad de Ciencias. Universidad de la República. Uruguay. 121pp.
12. Nash, J.E., and Sutcliffe, J.V. 1970. River flow forecasting through conceptual models part I -- A discussion of principles. J. Hydrol. 10:282-290.
13. Alberts, E.E. Earing, M. A., Weltz, M. A., Risse, L. M., Pierson, F. B. Zhang, X. C., Laflen, J. M. and Simanton, J. R. 1995. Chapter 7. Soil component. In: In: Water Erosion Prediction Project: Hillslope profile and watershed model documentation. Report 10. US. Department of Agriculture (USDA)-Agricultural Research Service, NSERL, West Lafayette, IN.
14. Jorge, G., Vázquez N., Pérez-Bidegain, M. and Terra, J. 2011. Mejora de la estimación de la erosión de los suelos en Uruguay: Aplicación del Modelo WEPP en suelos con diferenciación textural. Publicación de la X Escuela Latinoamericana de Física de Suelos-ELAFIS. (in press).