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RESEARCH PAPER

Soil erosion by water estimated for 99 Uruguayan basins

Leonidas Carrasco-Letelier[1], and Andrés Beretta-Blanco[2,3]

[1]Instituto Nacional de Investigación Agropecuaria (INIA), Estación experimental Alberto Boerger INIA La Estanzuela, Programa de Producción y Sostenibilidad Ambiental. Colonia, Uruguay.

[2] Instituto Nacional de Investigación Agropecuaria (INIA), Estación experimental Alberto Boerger INIA La Estanzuela, Laboratorio de aguas y suelos. Colonia, Uruguay.

[3] Universidad de la República, Facultad de Agronomía, Departamento de Suelos y Aguas. Garzón 780, 12900, Montevideo, Uruguay.

Abstract

L. Carrasco-Letelier, and A. Beretta-Blanco. 2017. Soil erosion by water estimated for 99 Uruguayan basins. Cien. Inv. Agr. 44(2): 184-194. Soil erosion can be accelerated by agricultural intensification, and the soil loss can alter the quality of water bodies. Sustainable agricultural production therefore requires the management of erosion and potential water pollution. In Uruguay, where there is heavy use of soil for agriculture, there is a need to continually develop and update erosion management policies. In this framework, we estimated the erosion in 99 drainage basins by analyzing and managing the information required (K, L, S, C and R-factors) in the universal soil loss equation (USLE) and the revised universal soil loss equation (RUSLE) in a geographical information system (GIS). The studied drainage basins encompass 73% of the area of Uruguay. The results include the following values: the K-factor range from 0.0073 to 0.088 (t ha h)(ha MJ mm)$^{-1}$, the R-factor range from 3,547 to 9,342 (MJ mm)(ha h yr)$^{-1}$, the C-factor range from 0 to 0.155, the slope gradients are less than 4.3% in 78% of the soils, and the multiplicative products of L and S are less than 0.73 in 75% of the cases. The drainage basin characteristics allowed the identification of 4 homogeneous regions based on their erosion behavior. The northern-western-southern basins cluster and Sierras del Este basins clusters indicate the possibility of managing their erosion through control of vegetation cover, which is represented by the C-factor. In general, this forecast of soil erosion by water (92.9% of the soil polygons and 99.9% of the drainage basins) indicates a mean soil loss of less than 7 t (ha yr)$^{-1}$ corresponding to the land cover surveyed in 2011.

Keywords: Erosion, GIS, RUSLE, USLE, watersheds.

Introduction

During the agricultural expansion in Uruguay in the late 1950s (the first phase of modernization, Arbeletche *et al.*, 2012), there was a significant loss of soil due to soil erosion by water (Durán and García-Prechac, 2007). This loss led to the prioritization of soil survey research during the following five decades (CNFR, 2011) and calibration of the USLE/RUSLE. Research was focused on runoff plots at three sites (Clericí and García-Préchac, 2001; Durán and García-Prechac, 2007). Because 30% of the agricultural land in Uruguay

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Corresponding author: lcarrasco@inia.org.uy

was associated with reduction of productivity (García-Préchac and Durán, 1998) and exhibited substantial soil erosion by water in 2000 (CNFR, 2011), a software program created by the Ministry of Agriculture, Erosion 6, (García-Préchac *et al.*, 2013) has been enforced since 2012 to avoid a soil erosion loss higher than acceptable values.

Over the past 10 yr, Uruguay has developed important land use changes, one of the most important being the expansion and intensification of its agriculture production of grains (soybeans, wheat, sorghum), from 278,000 ha in 2004 to 1.334 million ha in 2015, and the expansion of commercial forest cultures from 30,000 ha to more than one million of ha in 2014 (DIEA, 2015). These land cover changes had the potential of promoting fresh water pollution with run-off sediments. Potential environmental impacts seemed to be under control until 2013. That year, phosphorous contamination in the Santa Lucía River – unique source of tap water of Montevideo City – caused a cyanobacteria algae bloom. Situations became more complex when Carrasco-Letelier *et al.* (2014) identified similar conditions in other basins. In this framework, it is now understood that freshwater protection actions have been insufficient and that there are not enough tools for the identification and the forecast of potential water pollution situations at basin scale.

There are several international studies focused in the estimation of soil erosion by water at regional scale in which the USLE was used through a geographic information system (GIS) (Kouli *et al.*, 2008; Farhan *et al.*, 2013; Panagos *et al.*, 2015; Medeiros *et al.*, 2016) for the identification of important environmental situations.

Based on these experiences, we hypothesize that it is possible to apply the calibrated USLE/RUSLE model for Uruguay with a geographical information system (GIS) for the identification and prioritization of land use and basin with a potential fresh water pollution process. To test this hypothesis, we developed a GIS in which we incorporate each factor of USLE/RUSLE model as a geo-referenced information layer. By multiplicative operation of these geo-referenced information, the mean annual soil erosion by water per land use and the mean annual soil erosion of basin by area-weight, can be obtained.

Materials and Methods

Study area and the basins

The study area consisted of basins that were surveyed as part of the "National System for Identification of Agriculture Land Use with High Impact on Freshwater Quality" project of the INIA Uruguay (Project INIA SA27) (Carrasco-Letelier *et al.*, 2014). These basins were delineated by applying the r.watershed tool (Jasiewicz and Metz, 2011) in the software program GRASS GIS (GRASS Development Team, 2012) to the digital terrain model of Uruguay corrected by DGRNR (2014a). The first definition of a basin was based on a seed area measuring 1,000,000 pixels from the corrected digital terrain model, where the pixel resolution was 30×30 m (DGRNR, 2014a). However, this automatic definition of basin polygons was later confirmed or modified manually depending on the position chose to water sampling by Project INIA Sa27 to help in the development of a model for freshwater pollution (Figure 1).

Estimation of soil loss

Estimation of the mean annual soil erosion (A) was performed using the information required by the USLE/RUSLE model (Eq. 1) validated for Uruguay (García-Prechac, 1992; García-Préchac and Duran, 1998; García-Préchac *et al.*, 2013) In this model, the mean soil loss (A) is expressed in units of t.(ha yr)$^{-1}$ according to Foster *et al.* (1981): the rainfall erosivity factor (R-factor) is expressed in (MJ mm)(ha h yr)$^{-1}$; and the soil erodibility factor (K-factor) is expressed in (t ha h)(ha MJ mm)$^{-1}$, where L is the slope length factor, S is the

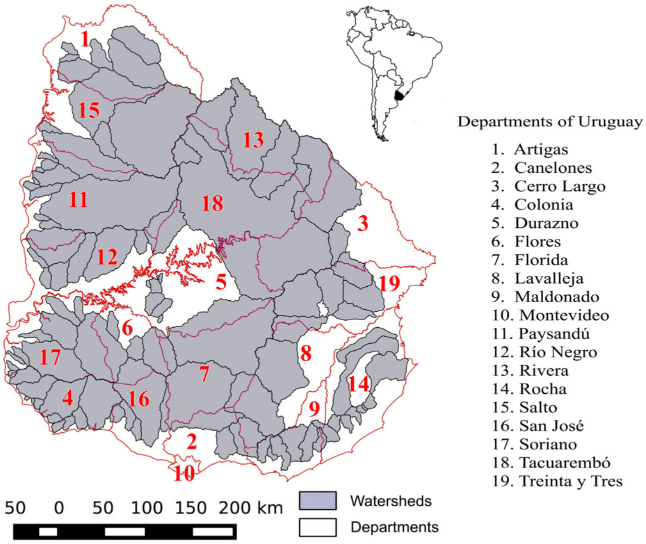

Figure 1. Study area. Watersheds are denoted by blue polygons with black borders and departments are delineated by red lines.

slope gradient factor, C is the crop management factor and P is the erosion control practice factor.

$$A=R * K * L * S * C * P \quad \text{[Eq. 1]}$$

The mean annual soil loss was estimated based on a shapefile developed by the intersection of the mapping of CONEAT's soil groups (DGRNR, 2014a, 2014b) and the shapefile of the drainage basins delineated in Project INIA Sa27. The estimation of soil loss was estimated by the multiplicative product of the all factors in the model (Eq. 1), where each factor of the equation was incorporated to the GIS as a new information layer (shape and/or raster layer).

Rainfall erosivity factor (R-factor)

The rainfall erosivity factor information was incorporated into the GIS by creating a raster file using the isoerodents of Uruguay (Puentes and Szogi, 1983) and the R-factor used by Erosion 6.0 (García-Préchac *et al.*, 2013) based on the historic rainfall records of Uruguayan meteorological stations. The raster layer was built by interpolation with a triangular model, using the rasterization tool of the QGIS program (QGIS Development Team, 2014), in which it was specified that the raster file contained 10,000 columns and 10,000 rows. Subsequently, the mean R-factor value each studied soil unit polygon was assigned using the region statistics tool of QGIS (QGIS Development Team, 2014). The R-factor information in these calculations was expressed in units of (MJ mm) (ha h yr)$^{-1}$ according to Foster *et al.* (1981).

Soil erodibility factor (K-factor)

The soil erodibility was allocated according the modal soils of CONEAT' soil groups (DGRNR, 2014a, 2014b; Molfino, 2012) in the study area. For this study, we used the Beretta-Blanco and Carrasco-Letelier (2017)'s K-factors, based on the K values assigned by Puentes (1981) for 99 modal soils. The K-factor information was handled at a scale of 1:20,000 in a shapefile with units expressed in (t ha h)(ha MJ mm)$^{-1}$ according to Foster *et al.* (1981).

Topographic factor (LS-factor)

The slope gradient factor (S-factor) expressed in degrees, radians and percent was estimated by applying the second-degree polygons with free GIS software gvSIG (www.gvsig.org) to the corrected digital terrain model of Uruguay (DGRNR, 2014a). The results were used to generate a raster layer of slope gradients expressed in percent. Subsequently, a mean slope gradient was assigned to each polygon of study zone using the Polygon grid tool of free GIS software gvSIG (www.gvsig.org). The S-factor of each polygon was estimated using the functions in RUSLE proposed by McCool *et al.* (1997) (Eq. 2 and Eq. 3). In both equations, θ represents the slope gradient expressed in degrees, and s is the slope gradient expressed in percent.

$$S=10.8 * \sin \theta +0.03 \quad s<9\% \qquad [Eq. 2]$$

$$S=16.8 * \sin \theta - 0.5 \quad s\geq 9\% \qquad [Eq. 3]$$

The slope length factor (L-factor) was calculated using the function proposed by McCool *et al.* (1997) for the RUSLE model (Eq. 1), where the value of *m* was estimated using Eq. 5 by Cruchaga Bermejo (2013). In these calculations, the length of the slope (*l*) was assigned a value of 100 m and θ represented the slope gradient expressed in radians.

$$L=\left(\frac{l}{22.3}\right)^{m} \qquad [Eq. 4]$$

$$\text{where } m=0.1342 * \ln \theta + 0.192 \qquad [Eq. 5]$$

Estimated L and S-factors for each polygon were used for the generation of a shapefile with LS-factor for the study's GIS.

Crop management factor (C-factor)

The Land Cover Classification System (LCCS) of 2011 - developed for Uruguay by FAO *et al.* (2015) – was used to allocate the crop management factor in a new shapefile. The C-factor used was based on those developed by García-Préchac works (García-Préchac, 1992) and included in the current version of free software Erosion 6.0 (García-Préchac *et al.*, 2013) for the estimation of mean annual soil loss. The C-factors allocated for each crop management are listed in Table 1. These C-factors correspond to a time-weighted C-factor of each land use of every crop rotation scheme.

Erosion control practice factor (P-factor)

The erosion control practice factor (P-factor) in this study was assumed to be equal to 1 because management practices that reduce erosion are not frequently used in Uruguay.

Data analysis

The basins were analyzed by a cluster analysis for definition of homogeneous regions, and in each cluster, the factors that contribute in an important manner in the erosion process was determined. For this last analysis, a regression adjustment was done using the stepwise procedure (Zar, 2014). The average values of the factors in each cluster were compared using the Tukey statistic, and differences were considered significant if p was less than 0.05. All of this data analysis was performed using the InfoStat/P program (Di Rienzo *et al.*, 2014).

Results

Analysis and management of the USLE information in the GIS

The implementation of validated USLE/RUSLE model in a GIS was possible for the basins described by Carrasco-Letelier *et al.* (2014). The incorporation of the different information layers to GIS generate some results that will describe in the next paragraphs.

- Information layer of soil erodibility factor information: it was developed based on the characterization of the CONEAT 's soil groups in the drainage basins (Figure 2a).

Table 1. Allocation of C-factors based on the LCCS layer classification.

LCCS layer classification	C-factor	Allocation criterion
Lakes, reservoirs and jetties	0.0000	
Industrial areas	0.0000	
Quarries, sand deposits, surface mines	0.0000	
Port areas	0.0000	
Urban areas	0.0000	
Consolidated rock	0.0000	
Lagoons	0.0000	
Watercourse	0.0000	
Airports	0.0000	
Airfields	0.0000	
Sports facilities	0.0000	
Channels	0.0000	
Eucalyptus plantation > 5 ha	0.0060	Implanted forest
Forest plantation > 5 ha	0.0060	Implanted forest
Planted coastal forest	0.0060	Implanted forest
Planted pine forest > 5 ha	0.0060	Implanted forest
Native mountain and stream brush	0.0060	Implanted forest
Native gallery brush	0.0060	Implanted forest
Native brush	0.0060	Implanted forest
Dispersed urban and forest plantation	0.0060	Implanted forest
Urban park	0.0060	Implanted forest
Rice plantation > 4-5 ha	0.0070	Rice
Permanently flooded herbaceous (scrubland)	0.0070	Rice
Humid and seasonally flooded soil	0.0070	Rice
Natural park brush	0.0130	50% implanted forest + 50% natural field
Scrubland and natural prairie	0.0130	50% implanted forest + 50% natural field
Palm grove	0.0130	50% implanted forest + 50% natural field
Seasonally flooded herbaceous	0.0135	50% rice (being flooded) + 50% natural field
Natural prairie with dispersed palm groves (1-15%)	0.0179	15% implanted forest + 85% natural field
Sugar cane or rice > 4-5 ha	0.0190	50% rice + 50% cover crop
Natural prairie	0.0200	Natural field
Dispersed urban and natural prairie	0.0200	Natural field
Natural prairie with rock outcrops	0.0200	Natural field
Psammophilous herbaceous	0.0200	Natural field
Sugar cane	0.0310	Cover crop
Irrigated crops > 4-5 ha	0.0954	70% soybean (C=0.111) + 30% corn or sorghum (C=0.059)
Dryland crops > 4-5 ha	0.0954	70% soybean (C=0.111) + 30% corn or sorghum (C=0.059)
Dryland crops < 4-5 ha	0.0954	70% soybean (C=0.111) + 30% corn or sorghum (C=0.059)
Dispersed urban land and crops	0.0954	70% soy (C=0.111) + 30% corn or sorghum (C=0.059)
Irrigated crops < 4-5 ha	0.0954	70% soybean (C=0.111) + 30% corn or sorghum (C=0.059)
Shade and shelter brush < 5 ha	0.1050	Forest being implanted (C=0.105)
Citrus plantation	0.1050	Forest being implanted (C=0.105)
Fruit plantation	0.1050	Forest being implanted (C=0.105)
Beach sand	0.1550	Fallow land
Bare soil	0.1550	Fallow land
Dunes	0.1550	Fallow land

The K-factors in the study area ranged from 0.0073 to 0.088 (t ha h)(ha MJ mm)$^{-1}$, with the highest values corresponding to soils in the north and east (Departments of Tacuarembó, Rocha and Treinta y Tres, Figure 2a).

- Information layer of rainfall erosivity factor information: the generated raster file was produced with a pixel size equivalent to 162 by 135 m. The R-factors was ranged from 3,547 to 9,342 (MJ mm)(ha h yr)$^{-1}$ and displayed a trend of northward increase, reaching

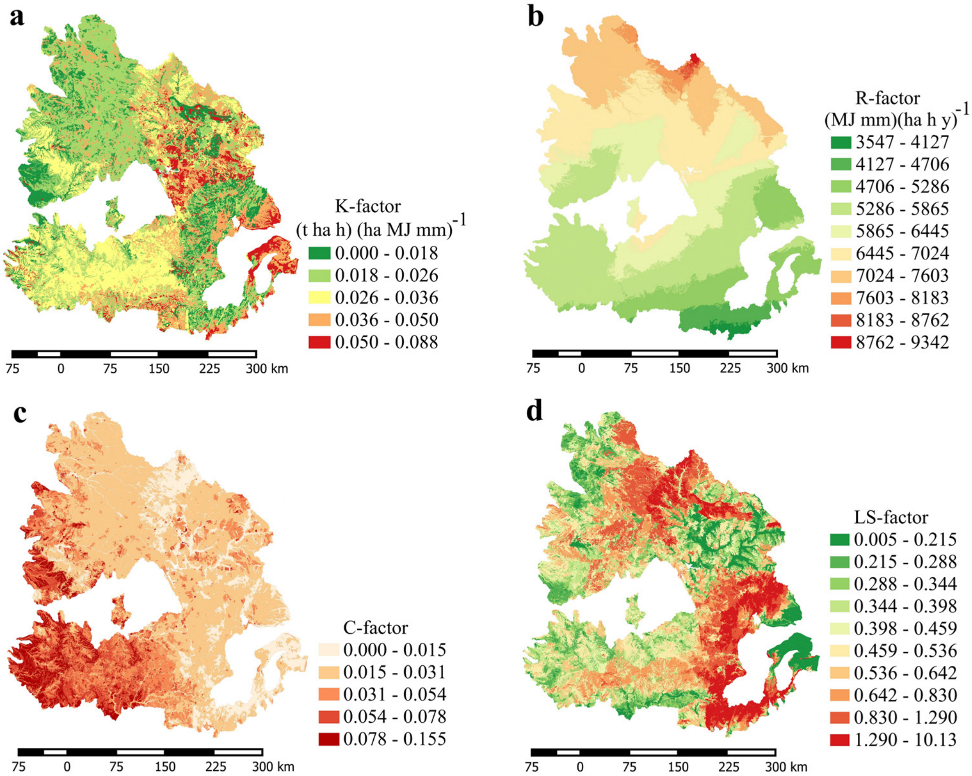

Figure 2. Soil information maps of study area related to the (a) K-factor; (b) R-factor expressed in (MJ mm)(ha h y)$^{-1}$; (c) C-factor and (d) mean values of the product of the L and S-factors.

maximum values in the north (Departments of Rivera and Artigas) (Figure 2b).

- Information layer of crop management factor: the allocation of C-factor was based on the land cover information obtained from shapefile LCCS-2011 developed by FAO *et al.* (2015). For the correction of the several geometric files of LCCS-2011 file, it was rasterized with a pixel size of 30 by 30 m, using the regional statistical tool QGIS (QGIS Development Team, 2014), and the C-factor was assigned to each soil polygon in the basins. The C-factors in this new raster file were used to estimate the mean of the crop management of each polygon. The C-factor noted in Table 1 corresponds to a mean C-factor for a type of crop rotation developed with no tillage, according to the land cover identified by shapefile LCCS-2011 and soil aptitude information (Molfino, 2013). These C-factors in the studied basins ranged from 0 to 0.155 (Figure 2c), with the highest values corresponding to the southwestern and southern coast (Departments of Paysandú, Soriano, Colonia, San José, Montevideo and Canelones) associated with horticultural, fruit, and milk production and dryland agriculture.

- Information layer of topographic information: The digital terrain model allowed a geo-referenced LS-factor for each soil polygon in the studied basins. The estimation of these factors indicated that 78% of the area had slope gradients less than 4.3%, with the highest slopes located in the eastern and northern parts of Uruguay, in the Cuchilla Grande and Cuchilla de Haedo mountain ranges, respectively (Figure 2d). The LS-factor exhibited a mean value was 0.6679, and 75% of the values were lower than 0.73.

Estimation of mean annual soil loss

The mean annual erosion in each CONEAT's soil group was estimated on base of USLE/RUSLE with the GIS, whose results are in Figure 3a. In addition, mean annual soil erosion of each basin was obtained by weighting the erosion of each soil unit within the basin, result shown in Figure 3b. This forecast of soil erosion by water indicated that 92.9% of the studied soil polygons (Figure 3a, Table 2) and 99.9% of basins (Figure 3b, Table 2) would experience a mean soil loss lower than tolerable levels (7 t ha^{-1}) defined for Uruguay.

Identification of homogeneous regions

The drainage basins were assigned to four groups using cluster analysis based on a matrix of Euclidian distances between the-factors in the USLE/RUSLE model. The clusters shown in Figure 3c are named as follows: (1) northern-western-southern basins cluster; (2) Sierras del Este basins cluster; (3) eastern plains and knolls basins cluster and (4) northern sandstones basins cluster.

The regression adjustment using the stepwise procedure (sle=0.15 and slo=0.15) showed that the factors with more weight on respective mean annual soil loss were soil erodibility, topographic and crop management factors in basins cluster 1; rainfall erosivity, topographic and crop management factors in basins cluster 2; and topographic factors in basins cluster 3. Finally, it was not possible to attribute any dominant factor in basins cluster 4.

Table 2. Estimated soil loss in the soil polygons and drainage basins in the study area.

A value t ha^{-1}	Fraction of study area† %	Number of drainage basins	Soil area ha
Less than 2	15.8	17	4,955,560
2 to 5	78.7	67	5,930,053
5 to 7	5.3	14	1,188,834
More than 7	0.1‡	1	534,318

† Percentage of the total area of 12,608,765 ha.
‡ The maximum value was 7.17 t ha^{-1}

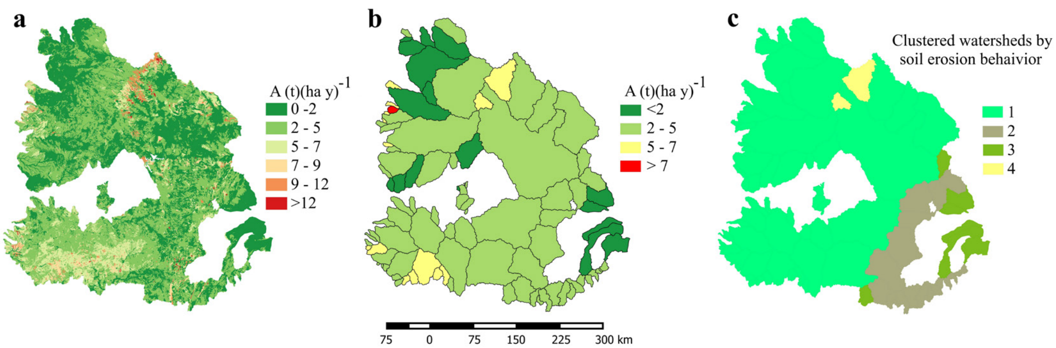

Figure 3. (a) Map of soil loss due to soil erosion by water, estimated using the USLE/RUSLE model, corresponding to soil units in the drainage basins; (b) map of soil loss due to soil erosion by water, estimated using the USLE/RUSLE model, corresponding to weighted averages of the drainage basins and (c) watershed clusters based on the C, K, LS and R-factors obtained from the USLE/RUSLE model. The basins clusters were named as follows: (1) northern-western-southern, (2) Sierras del Este, (3) eastern plains and knolls and (4) northern sandstones.

Table 3. Results of regression adjustment using the stepwise procedure with mean values of the factors in USLE/RUSLE model in each basins cluster. Values with different lowercase letters denote statistically significant differences.

Cluster	Factor C	Factor K† Mg MJ^{-1}	Factor LS	Factor R MJ ha^{-1}	Estimate of A‡ t ha^{-1}	R^2
1	0.0513a	0.0268b	0.4527b	6148b	-4.34+60.58C+6.15LS+73 K	0.82
2	0.0177b	0.0298b	1.5375a	4698c	-3.27+140.15C+0.96LS+4.5x10^{-3}R	0.78
3	0.0187b	0.0449a	0.4257b	5133c	- 0.32 + 4.22 LS	0.76
4	0.0165b	0.0314b	1.565a	7180a	--	--

† The units are shown in simplified form.
‡Model adjusted using the stepwise routine, where sle=0.15 and slo=0.15.

Discussion

Neither the USLE model nor RUSLE were developed for estimating soil erosion in drainage basins and methodological errors may occur when using them for this purpose. These models, however, have been used to evaluate and manage watershed erosion, most likely because of their simplicity and the availability of existing information for use in a GIS (Bonilla *et al.*, 2010; Panagos *et al.*, 2015). In this study, it was possible to access or estimate all the required information to estimate the soil erosion across 73% of continental Uruguayan territory. The model factors were derived from field experiments; thus, our estimate may approach the real value and allow to highlight the regions and basins with high demand of an environmental management in the short term.

In the erosion estimates corresponding to the soil units and drainage basins, lower results than the current tolerable loss (7 t ha^{-1}) across 90% of the land surface were observed. In the departments along the southwestern and southern coast, which were grouped into cluster 1 (basins cluster of northern-western-southern) and where the crop management factor is dominant (Table 3), there was a clear need for an incentive to rotate crops, specifically those with pastures, as a mitigation measure. Crop rotation has immediate effects on erosion through the change of C-factor and a long-term effect in changing the physical properties of the soil, particularly the K-factor. This last factor seems an unchanged property of soil, but since it has a relationship with the soil organic carbon, any increasing of it could reduce the erodibility factor. In this framework, the results of a 50-year experiment on crop rotations of Experimental Station Alberto Boerger INIA La Estanzuela (Colonia, Uruguay) (Quincke *et al.*, 2012) suggest that crop rotation in the short term reduces soil erosion and, in the long term, increases the soil organic carbon and therefore indirectly should reduce the erodibility. For these reasons, in recent years the Uruguayan Ministry of Livestock, Agriculture and Fishing has enforced that agricultural areas higher than 100 ha. regulate soil use and management plans.

Estimation of mean annual soil loss was performed based on a specific situation regarding the soil cover information obtained from 2011 satellite imagery (FAO *et al.*, 2015). It would be valuable to build on this finding both in retrospective terms and in terms of updated yearly information to reconstruct the recent erosion history of the soils and generate an annual forecast of national erosion. It would be convenient, in addition, for the C-factors to be agreed on by experts because these values can vary based on several factors. The geo-referenced C-factor should be updated every year and perhaps adapt it to assess the current crop rotation in each region using NDVI satellite data, as was done in Jordan by Farhan *et al.* (2013) and in Greece by Kouli *et al.* (2008). Similarly, it would be beneficial to update the other factors in the equation, for example, the L and S-factors by increasing the resolution of the digital terrain model, the R-factor through updating of climate data and the K-factor based on new measurements. Updates that can increase the spatial resolution would increase the scope of soil erosion forecasts (i.e., with more advanced global climate change). These updates will require additional field studies focused on validating the current proposed K-factor values by Beretta-Blanco & Carrasco-Letelier (2017). Updates are required to reduce the potential errors in present estimations.

From the cluster analysis (Figure 3c) and results of regression adjustment using the stepwise procedure (Table 3), it is possible to identify two main topics for the Uruguayan environmental management: first, it is possible to control soil erosion by water through land use control, at least in the northern-western-southern basin (cluster 1, Figure 3c) and Sierra del Este (cluster 2, Figure 3c). Therefore, management of soil erosion by water can be significantly improved by rotating crops on a scale of properties in these two clusters, with a greater impact in the Sierras del Este basins cluster. In contrast, in the eastern plains and knolls basins cluster (cluster 3, Figure 3c) and northern sandstones basins cluster (cluster 4, Figure 3c), modification of crop rotation system is not expected to modify soil erosion because in these regions, the topographic factor or rainfall erosivity are the main factors. A second aspect that arose from this cluster analysis and the results of soil erosion in the basins (Figure 3b) is that the basins that need a modification of their land use to protect the freshwater quality are in the South, a region currently dominated by soybean crop rotations and dairy production.

The main conclusions are as follows. This study proved that Uruguay has enough information to create mean annual soil loss forecast for the entire country base on public databases.

In 2011, there was land cover that promoted a mean annual soil loss higher than tolerable values in the northern, western and southern regions that was probably linked to soybean crop rotations and dairy production.

The studied basins can be grouped into 4 clusters, and only the northern-western-southern and Sierras del Este basins clusters showed the possibility of erosion control at plot basin scale though land use management.

The information and strategy developed could help create new forecasts of soil erosion and guide public policies that protect freshwater quality and soil conservation.

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Resumen

L. Carrasco-Letelier, A. Beretta-Blanco. 2017. Erosión hídrica del suelo estimada para 99 cuencas uruguayas. Cien. Inv. Agr. 44(2): 184-194. La erosión del suelo puede ser acelerada por la intensificación agrícola, y el sedimento generado puede alterar la calidad de los cuerpos de agua. Por lo tanto, la producción agrícola sostenible en términos de erosión y contaminación potencial del agua requiere una capacidad para manejar la erosión. En Uruguay, donde hay un uso intensivo del suelo por la agricultura, es necesario desarrollar y actualizar continuamente las políticas de manejo de la erosión. En este marco, estimamos la erosión en 99 cuencas de drenaje analizando y manejando la información requerida (K, L, S, C y R) por la ecuación universal de pérdida de suelos (USLE/RUSLE) en un sistema de información geográfica (SIG). Las cuencas estudiadas abarcan el 73% de la superficie del Uruguay. Los resultados incluyen los siguientes valores: los factores K van desde 0.0073 hasta 0.088 (t ha h)(ha MJ mm)$^{-1}$, los factores R van desde 3,547 a 9,342 (MJ mm)(ha h año)$^{-1}$, los factores C van desde 0 a 0.155, las pendientes son menores al 4.3% en el 78% de los suelos y los productos de L y S son menores a 0.73 en el 75% de los casos. Las características de las cuencas de drenaje permitieron identificar 4 regiones homogéneas en base a su comportamiento erosivo. Las agrupaciones norte-oeste-sur y Sierras del Este apuntan a la posibilidad de manejar su erosión a través del control de la cubierta vegetal, representada por el factor C. En general, este pronóstico de erosión hidráulica (92.9% de los polígonos del suelo analizados y 99.9% de las cuencas de drenaje) indica una pérdida media de sedimentos de menos de 7 t (ha año)$^{-1}$ correspondiente a la cubierta del suelo estudiada en 2011.

Key words: Cuencas hidrográficas, erosión, RUSLE, SIG, USLE.

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