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Estimating Soil Productivity Loss Due to Erosion in Uruguay in Terms of Beef and Wool Production on Natural Pastures†

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ABSTRACT

Although USLE and RUSLE have been adjusted and validated for use in Uruguay, soil mass losses should be expressed in terms of soil productivity or land value losses, in order to guide management decision-making, and assess its impact in productive and economic terms. Procedures to this have been published (e.g. EPIC), but are not yet validated in Uruguay. Being extensive animal production, based on natural pastures grazing, the main agricultural activity in Uruguay (about 80% of the land), soil productivity loss due to soil erosion should be better expressed in these terms. Uruguay has a system of soil productivity assessment at individual farm level, that expresses soil potential animal production of beef and wool as a quantitative Productivity Index (PI), referred to the national average (PI=100). This system was developed 25 years ago overlapping soil maps at 1:20,000 scale, with the official records of production of 721 administrative divisions of the country, and the available experimental information. It was finally adjusted considering the opinion of qualified agronomists working as private consultants or official extensionists. The objective of this system was to base land taxing on soil productivity, and it became so widely accepted that it has been guiding the land market from 1980. The system recognizes variations in its PI due to past soil erosion. The objectives of our work were 1) to quantify the different degrees of erosion recognized by the system and its relationship with PI, and 2) to develop a procedure to transform soil erosion rate estimates into PI loss estimates, and to give examples of its use. The linear regression between the numerically coded soil erosion classes (nil, slight, moderate, severe, very severe) change, and the PI change had r^2=0.77; its slope indicates 21% of PI change for each soil erosion class change, corresponding to 25% of the A horizon depth change. Using 17 soils representative of the country variability, which are the dominant soils of mapping units occupying 32% of the territory, soil loss estimates were made for 5 types of use and management, and converted in the time needed to loss 21% of their PI. Predictions ranged between 8 and 7295 years. The meaning of T values in terms of PI was also evaluated.

INTRODUCTION

Research and development of models to estimate soil mass loss due to erosion have been disproportionate compared with development of tools to estimate and predict soil erosion impact on soil productivity (Pierce, 1991; Pierce and Lal, 1994). This inequality is even more accentuated by the increasing need of environmental impact evaluation in physical but also economic terms.

In Uruguay, a small country (17.4 Million ha), the work conducted from the 1970's resulted in adapting and validating USLE, and more recently the C Factor according to RUSLE (Renard et al., 1991,1994, and 1997). This work is documented in, García Préchac (1992), García Préchac and Clérici (1996), and García Préchac et al. (1998 and 1999). But the need of expressing soil loss due to erosion in terms of soil productivity was not fully addressed. Recent efforts to use and validate EPIC has not been completed (Clérici and Del Pino, 1999). Moreover, EPIC considers soil productivity as it capacity to produce crops or crop sequences, according with the definitions given by SSSA (1975) and SCSA (1982). Around 80% of Uruguay agricultural land is used to produce beef and wool through direct grazing of mainly naturally vegetated pastures. Despite the fact that most animal production is based on vegetal production, for Uruguay's conditions it seems more appropriate to express soil productivity in terms of its predominant animal production.

Uruguay Reconnaissance soil mapping was published at 1:1 million scale (MAP-DSF, 1979), but the original information is at 1:40,000 scale. This soil inventory transformed to 1:20,000 scale was used to develop a system of land taxing based on soil productivity, officially know as CONEAT (MGAP, 1994). The map units at this level are homogeneous areas containing soil associations. The total number of soil units and subunits is 188.

The productivity concept in the CONEAT system is the annual mean production of beef and wool on natural pastures, using current technology. This technology does not include pasture fertilization nor interseeding of improved species. The system has a Productivity Index (PI) given to each soil unit. The PI of each unit is a percent referred to the National annual mean production of beef and wool per unit area with the current technology (PI = 100). A soil unit having PI = 50 has an annual mean productivity that is half of the National annual mean; conversely, a soil unit with PI

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= 200 is one with double productivity than the National annual mean. The PI of an individual farm is the average of the soil units present on the farm, weighted by area.

The assignation of the PI's to the soil units (known as CONEAT units) was made during the middle 1970's based on long term production records of 721 administrative divisions covering the whole country, and the available experimental information. These divisions are normally occupied by more than one soil unit, but for most of them, a single soil unit is clearly dominant. This made it possible to estimate the PI of the majority of the units, and when it was not totally clear, the expert opinion of Agronomists working as extensionists or consultants, and also of selected Farmers, was used to make the PI assignation.

As the PI value of a Farm was directly related to the amount of land taxes, the owner has the right to ask for reassignment of the PI value of the land, based on technical arguments. During the first 4 to 5 years of the CONEAT system there were hundreds of claims that ended with different results (reduction, increase, or no change of the Farm PI). From the beginning of the 1980s, the claims were very few and the system was so well accepted that the PI became the most important index of land value in the market (MGAP, 1987). This gives it a clear and recognized characteristic of Land Value evaluator.

The soil map identifies different degrees of soil erosion and degradation in several soil units. The system recognizes these differences giving different PI values to different subunits due to erosion inside several soil units. Even when the soil units with an assigned PI value are not individual soils, in several of them there is one that is clearly dominant and responsible for the PI given to the unit. This allows us to expand the concept of PI to individual soils, in the same way that the long term production records of the administrative divisions were assigned to the mapping soil units to give them a PI value. If there is a relationship between soil productivity loss and soil erosion, it should be a quantitative relationship between the degree of soil erosion of a particular soil subunit and its change of PI, compared with the other subunits. Also, if the degree of soil erosion can be expressed in terms of soil mass loss, there exists a possibility of converting the results of any model that estimates soil erosion in terms of mass per unit area to PI terms, according to the system described above.

Our work had two objectives. The first one was to transform different morphological degrees of erosion recognized in the national soil map into a quantitative variable, and to establish its relationship with the PI. The second one was to develop a procedure to transform soil erosion rate estimates into PI loss estimates, and to give examples of its use.

MATERIALS AND METHODS

To address the first objective we revised the most recent official publication about the CONEAT system (MGAP, 1994). We found 11 cases of soil units divisions taking into consideration their different degrees of erosion, with their corresponding different PI values (Table 1). Their descriptions indicate the degrees of erosion given to them and their correspondence with 1:1million soil map. Based on this information we coded the degrees of erosion to a numerical scale and assigned them a percent of A horizon lost (Table 2).

We established a linear regression and correlation between the percent change in PI and the coded erosion degree change, for each of the 11 cases (Table 1). According with our criteria shown in Table 2, a change of one erosion degree means a change of 25% depth of the A horizon. By transforming soil erosion mass loss per unit area into soil depth loss, using the soil horizon A bulk density and the previously described regression, we developed a way of expressing soil mass loss in terms of the CONEAT system productivity, this addresses the first part of our second objective. To address the second part of the last objective we selected 17 individual soils (Table 3), dominant in one or more CONEAT units and representative of 15.2% of the National soil map units, occupying 5.5 million ha (31.6%) of the National land. We assumed that these individual soils have the PI value of the soil units in which they are dominant. We made soil erosion rates estimations using USLE/RUSLE for these soils under the following use and management systems:

1) Natural Pastures: C Factor = 0.009, determined in runoff plots under natural rain (RPNR) during four years Terra and García Préchac, (1998); 2) Pastures and Crops Rotation (PCR) of six years: Conventional Tillage (CT), three years of crops and three years of grass and legume pastures; C Factor = 0.09 estimated by García Préchac (1992); 3) PCR of six years, No-Tillage (NT): Similar to #2, but using NT, C Factor = 0.02, experimentally determined in RPNR (Sawchick and Quintana, cit. by García Préchac, 1992); 4) Continuous Double Cropping (CDC) with CT: Two crops a year with CT, C Factor = 0.3, experimentally determined in RPNR (García Préchac and Cardellino, 1984, cit. by García Préchac, 1992); and 5) CDC with NT: Similar to #4 but with NT, C Factor = 0.036, experimentally determined in RPNR (Sawchick and Quintana, cit. by García Préchac, 1992).

These estimations were made assuming that the model P Factor = 1.0. The annual soil erosion mass loss estimates were transformed into annual PI loss estimates, following the procedure presented in this paper, and number of years needed to cause 21% loss of the PI value was calculated. Also, for the 17 chosen soils we calculated the meaning of their assigned T (soil loss tolerance) values (Puentes, 1981) in terms of PI loss.

RESULTS AND DISCUSSION

The results presented in Figure 1 indicate that a reasonable relationship exists between coded erosion degree change and percent of PI change. The intercept of the regression is not far away from zero, and the slope indicates 21% of PI change for each coded unit of erosion degree (or 25% of A horizon depth) change.

The estimates made with USLE/RUSLE are shown in Table 4, both in mass loss rate and in time (years) needed to decrease 21% the PI value. These results are not going to be discussed in terms of the different erosion caused by the 5 use and management system chosen, nor in terms of the different results with the same use and management for the

Table 1 .- CONEAT Soil Units including subunits with different degrees of soil erosion.

Case No.	Map Unit[1]	Dominant Soils[2]	Degree of Erosion[3]	Productivity Index (PI)	% PI Change	Coded Degree of Erosion Change[4]
1	10.8b	fine, smectitic, Typic	Slight-moderate	184		
	10.8a	Hapludert and Vertic Argiudoll	Severe-very Severe	105	43	1.5
2	9.6	fine-loamy, mixed,	Slight	101		
	9.41	superactive, Typic Argiudoll	Slight-Moderate	88	13	0.5
3	9.6	"	Slight	101		
	9.42		Very Severe	35	65	3.0
4	9.41	"	Slight-Moderate	88		
	9.42		Very Severe	35	60	2.5
5	10.6a	fine loamy, mixed, thermic,	Slight-Moderate	206		
	10.6b	Typic and Oxyaquic Argiudolls	Severe	131	36	1.5
6	10.11	"	Slight	210		
	10.6a		Slight-Moderate	206	2	0.5
7	10.11	"	Slight	210		
	10.6b		Severe	131	38	2.0
8	10.3	fine, mixed active, Abruptic	Nil	140		
	10.13	Argiudoll	Slight-Moderate	109	22	1.5
9	10.3	"	Nil	140		
	10.14		Moderate-Severe	88	37	2.5
10	10.13	"	Slight-Moderate	109		
	10.14		Moderate-Severe	88	19	1.0
11	11.9	fine, smectitic, thermic, Typic	Slight	201		
	11.10	Argiudoll	Moderate-Severe	114	44	1.5

[1]MGAP (1979 and 1994)
[2]According with Soil Taxonomy
[3]Adapted from Soil Survey Staff (1951)
[4]See Table 2

Table 2. Numerical codification given to the different Degrees of Erosion and assigned percent of A horizon lost.

Degree of Erosion	Numerical Code	Percent of A horizon lost
Nil	0	0
Slight	1	25
Moderate	2	50
Severe	3	75
Very Severe	4	100

Table 3.- Selected soils relevant characteristics. Erosion Potential 1: LS for low rill/interrill erosion ratio (natural pastures, trees, No-till); Erosion Potential 2: even rill/interrill erosion ratio (conventional and reduced tillage) according with Renard et al. (1994), T: Soil Loss Tolerance (Puentes, 1981).

Uruguay 1:1M Soil Map Unit and Profile ID	Dominant Soil	A horizon		Erosion Potential $Mg\ ha^{-1}\ yr^{-1}$ Product R.K.L.S		T ($Mg\ ha^{-1}\ yr^{-1}$)
		Normal Depth (cm)	$Mg\ ha^{-1}\ cm^{-1}$	1	2	
Tl-Rd, I2-74	fine, smectitic Typic Hapludert	15	109.2	41.3	50	7
Tl-Rd, I 27-14	fine, smectitic Vertic Argiudoll	25	117.6	32	39	7
Yg, O 17-6	fine, smectitic Vertic Argiudoll	18	118.9	72.7	94.5	7
Bq, N 21-3	fine, smectitic Vertic Argiudoll	24	110.8	78.7	98.6	7
Ch, O 11-3	fine-loamy, mixed, superactive Typic Argiudoll	32	141.3	123.4	158.1	7
I-TA, M 13-1	fine, smectitic Typic Hapludert	69	98.2	25.8	31.4	7
I-TA, M 13-4	fine, smectitic Typic Hapludert	19	107.8	69	85.9	7
Af, F 23-42	fine, smectitic Abruptic Argiudoll	16	118.9	137.5	181.9	7
Ve, E 20-29	fine, smectitic Abruptic Argiudoll	26	129.9	143.2	189.5	7
Ta, J 12-11	fine-loamy, mixed, active Mollic Hapludalf	53	143.1	377.9	454.5	7
LM, C 14-33	fine, smectitic Vertic Argiudoll	20	120.6	165.4	211.3	5
Mc, H 22-3	fine, mixed, active Abruptic Argiudoll	25	132.7	74.2	91	5
SCa, E 27-2	fine, mixed, active Typic Hapludalf	24	128.3	233.2	306	5
SM, P 15-2	fine, mixed, superactive Typic Argiudoll	25	111.9	87.8	109	5
Rv, H 8-6	fine, mixed, semiactive Typic Hapludult	90	151.5	310.3	320.5	9
CH-PT, M 13-6	loamy, mixed, superactive Lithic Udorthent	15	100.7	159		2

SP, # 9-CL	fine-loamy, mixed, semiactive Lithic Hapludoll	25	118.8	440.7		2

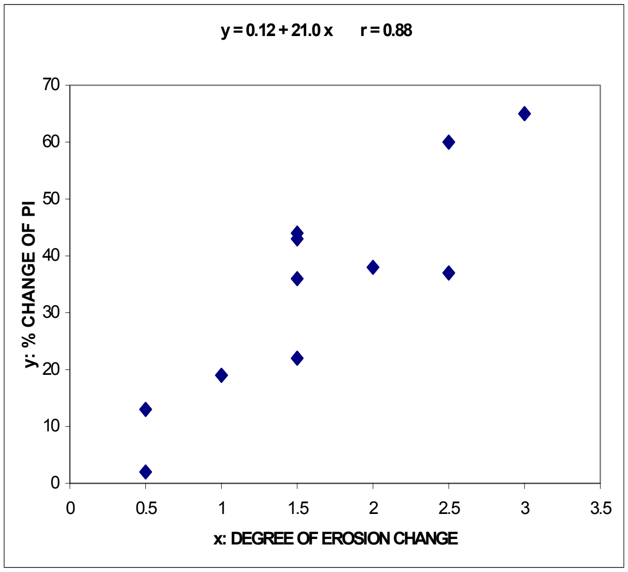


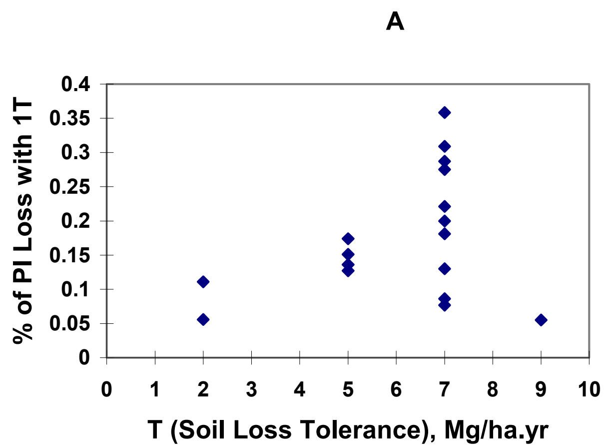
Figure 1.- Correlation between the coded degree of erosion change and the percent change of the Productivity Index (PI) of the 11 cases that recognizes the Uruguayan system of soil productivity assessment in terms of beef and wool on natural pastures (CONEAT).

17 different soil-topography-site erosivity combinations. They are an example of the different meaning of both ways of expressing soil erosion, and by inspection of the estimates ($Mg.ha^{-1}.yr^{-1}$ and years to decrease 21% the PI), it can be observed that they are not linearly related. This is because there are more variables involved in the estimation of %PI loss than in soil erosion rate. The change of PI results from changes in the amount, quality and seasonal distribution of forage produced by the natural pastures, and their consequences on animal production, in response to the differences in soil quality caused by erosion. The main merit of expressing erosion in terms of PI, is that in Uruguay it has a meaning in economic terms and it can be used by environmental economists to make better approximations of erosion impact both, in environmental impact assessment, and accounting. This cannot be done with soil mass loss due to erosion. Also, PI loss has a clearer meaning for Agronomists and Farmers than $Mg\ ha^{-1}\ year^{-1}$.

Figure 2A is a plot of the conventional T values versus the T values expressed in terms of percent of PI loss. For the conventional T value= 7 $Mg.ha^{-1}.year^{-1}$, in the chosen soils sample the % PI loss with 1 T of erosion ranges between 0,07 and 0,37, leading us to propose the consideration of a certain value of percent PI loss as a different soil loss tolerance criteria. To illustrate this idea we choose 0.1% of annual PI loss, transformed it to soil mass loss, and plotted it versus the conventional T values (Figure 2B). For the ten

Table 4.- Estimates of annual erosion rates ($Mg\ ha^{-1}\ yr^{-1}$, left column), and of the number of years needed to loss 21% of PI or 25% of the A Horizon (right column).

Uruguay 1:1M Soil Map Unit and Profile ID	Use and Management System: 1: Natural Pasture		2: Pasture-Crop Rotation, Conv. Tillage		3: Pasture- Crop Rotation, No-Till		4: Continuous Double Cropping, Conv. Tillage		5: Continuous double Cropping, No-Till	
	0.37	1102	4.5	91	0.8	496	15.0	27	1.5	275
Tl-Rd, I 27-14	0.29	2552	3.5	209	0.6	1148	11.7	63	1.2	638
Yg, O 17-6	0.65	818	8.5	63	1.5	368	28.4	19	2.6	204
Bq, N 21-3	0.71	939	8.9	75	1.6	422	29.6	22	2.8	235
Ch, O 11-3	1.11	1018	14.2	79	2.5	458	47.4	24	4.4	254
I-TA, M 13-1	0.23	7295	2.8	599	0.5	3283	9.4	180	0.9	1824
Tl-Rd, I2-74	0.62	825	7.7	66	1.4	371	25.8	20	2.5	206
Af, F 23-42	1.24	384	16.4	29	2.8	173	54.6	9	5.0	96
Ve, E 20-29	1.29	655	17.1	50	2.9	295	56.9	15	5.2	164
Ta, J 12-11	3.40	557	40.9	46	7.6	251	136.4	14	13.6	139
LM, C 14-33	1.49	405	19.0	32	3.3	182	63.4	10	6.0	101
Mc, H 22-3	0.67	1242	8.2	101	1.5	559	27.3	30	2.7	310
SCa, E 27-2	2.10	367	27.5	28	4.7	165	91.8	8	8.4	92
SM, P 15-2	0.79	885	9.8	71	1.8	398	32.7	21	3.2	221
Rv, H 8-6	2.79	1221	28.8	118	6.2	549	96.2	35	11.2	305
CH-PT, M 13-6	1.43	264								
SP, # 9-CL	3.97	187								



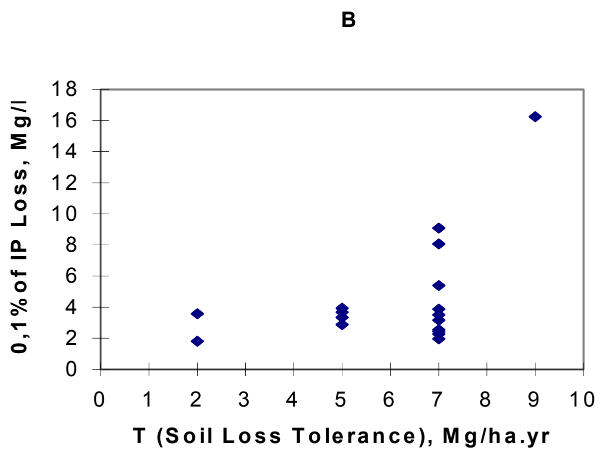


Figure 2.- A: percentage of Productivity Index (PI) loss per one Soil Loss Tolerance (1T), for the 17 selected soils (Table 3). B: 0.1% of PI loss expressed in $Mg.ha^{-1}.yr^{-1}$, compared with the conventional T values.

soils in the sample with T = 7 $Mg.ha^{-1}.year^{-1}$, 0.1% of annual PI loss shows a variation between 1.95 and 9.01 $Mg.ha^{-1}.year^{-1}$. We are not proposing to abandon the conventional T values and substitute them for 0.1% of PI loss. Even if such substitution could be considered, the percent of PI loss chosen could be different and need to be discussed with the Uruguayan soil scientists community, as well as with agronomists, environmentalists and economists. Nevertheless, the concept of a different soil loss tolerance criteria based on PI loss deserves to be considered in addition to the conventional T values, because it has an economic meaning under the particular Uruguayan predominant production systems. (Figure 2B). We are not proposing to abandon the conventional T values and substitute them for 0.1% of PI loss. Even if such substitution could be considered, the percent of PI loss chosen could be different and need to be discussed with the Uruguayan soil scientists community, as well as with agronomists, environmentalists and economists. Nevertheless, the concept of a different soil loss tolerance criteria based on PI loss deserves to be considered in addition to the conventional T values, because it has an economic meaning under the particular Uruguayan predominant production systems.

CONCLUSIONS

A reasonable relationship was found between numerical codification of the erosion degrees recognized in the Uruguayan soil survey and the Productivity Index (PI) of the system of soil productivity evaluation (CONEAT). This codification was assumed to be directly related to A horizon depth loss, enabling a simple procedure to transform soil erosion rate in terms of $mass.area^{-1}.time^{-1}$ into PI loss rate.

As the PI has recognized economical meaning in Uruguay, the above mentioned transformation offers the opportunity to consider soil erosion in economic terms for land use planning, environmental impact evaluation and accounting.

Also, the possibility appears for considering loss of productivity as criterion of tolerance of soil loss due to erosion.

Updating of the information used to determine the PI's, with emphasis in approaching its assignation to individual soils, and PI relationship with actual land value and taxing, appear as future needs to make more useful the procedure presented in this paper.

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