

EVALUATION OF THE USLE MODEL TO ESTIMATE WATER EROSION IN AN ALFISOL

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ABSTRACT

The USLE model was evaluated to estimate water erosion in an Alfisol located in San Pedro, Metropolitan Region of Chile. Values of erosivity (R) obtained by using the Arnoldus approximation (MFI) and equations proposed by the Institute for Nature Conservation (ICONA) in Spain were adapted to the conditions in Chile. For the evaluation of soil loss, data were used for each precipitation event causing erosion during the period 1996-2000, obtained by measurements on experimental plots with treatments of subsoiling, infiltration trenches and natural prairie. They were compared with estimated values of erosion in terms of basic statistics and indices based on variance and regression. In the descriptive and comparative analysis of the selected equations, it was determined that soil losses estimated with USLE using the equation of rainfall erosivity by ICONA provided soil loss values which were well-adjusted to the values recorded in Chile, compared to erosivity calculated by the Arnoldus approximation (MFI) that overestimated the soil loss values. According to the results or estimates in this study it was concluded that the USLE model was capable of detecting the trend of the data, and resulted in estimates consistent with the pattern observed in the field data.

Keywords: Soil erosion, erosivity, USLE.

INTRODUCTION

In Chile, the erosion hazard is considered one of the most important degradation processes leading to significant loss of land productive capacity (Nachtergaele *et al.*, 2010; Soto, 1999). It is precisely for this reason that there is a need to assess water erosion in terms of soil loss under different management practices, thus applying measures to prevent mayor soil losses.

The soil is the main productive resource that agricultural producers and foresters have at their disposal and its degradation involves a huge disadvantage in the current model of economic development (Santibáñez *et al.*, 1998), characterized by strong competition between producers, countries and even groups of countries. Because of this, the government of Chile has established programs aimed at

slowing or reversing the processes of degradation, allowing producers to access state resources to be devoted to promoting conservation, sustainable management and recovery of soils for agricultural use (Mancilla, 2006). This study provides a theoretical base and experimental practice to select adequate soil conservation strategies.

Different approaches have been developed. Qualitative models such as those proposed by Honorato *et al.* (2001) include the mapping of homogeneous units in terms of the main parameters that control the erosion. Quantitative models allow the numerical estimation of erosion and may include direct or indirect assessment. Direct assessment is carried out on field plots for erosion measurement or by measuring variables such as sediment in runoff water and from rainfall simulators (Verbist *et al.*, 2003), whose data are extrapolated to homogeneous areas. Indirect assessment methods are related to models which are simplified representations of reality, and within this group statistical models, physical models and parametric models can be distinguished.

The universal soil loss equation (USLE) was designed to make annual estimates of soil loss (Renard *et al.*, 1996). In this sense, the USLE model is used to estimate values at longer time scales than those obtained from field observations (Biesemans *et al.*, 2000), since the model is able to establish trends. Differences between model predictions and field measurements can be often attributed to low soil loss values, and thus relative higher measurement errors, but are also due to the use of monthly rainfall erosivity equations for rainfall (R) that can hide the erosive effect of high-intensity daily rainfall. Another source of possible differences can also be attributed to the fact that the USLE soil erodibility factor K does not consider soil moisture,

although the antecedent moisture has a significant effect on erosion. Similarly, the K factor does not reflect the short-term changes produced in soil physical characteristics, especially in disturbed sites. In addition, it has been shown that the presence of rock fragments on the surface of the soil reduces erosion rates and runoff (Oyarzún, 1993). All these aspects can lead to significant differences between erosion rates and estimates with the USLE. Basically, the choice of model (USLE) in this research is due to the fact that the empirical model is most widely used and relatively simple to assess soil loss by sheet and furrow erosion, and includes the influence of precipitation, soil texture, topography, soil cover or land use and conservation practices on soil loss estimates.

Erosion modeling studies using field plots for calibration are not very abundant in Chile, due to high field installation and maintenance costs. Honorato *et al.*, (2001) did evaluate soil losses in 42 agro-ecological situations in 6 locations between the IVth and IXth Region of Chile, with a precipitation range from 100 to 1800 mm. When comparing the USLE model with observations, the model had good predictive performance in areas with significant erosion ($> 2.5 \text{ Mg. ha}^{-1} \text{ yr}^{-1}$) and management practices that favored erosion such as bare soil and tillage. However, the model underestimated the observed soil loss by 50%, mainly due to R factor estimated by approximating Arnoldus (MFI) (1980), whose values did not provide sufficient accuracy to represent the rainfall erosivity, as well as due to the C factor whose values were not properly quantified in relation to the assigned management practices.

Millas (1977) estimated a soil loss of 8.8 and 9.9 $\text{Mg ha}^{-1} \text{ yr}^{-1}$ in two granitic soils of the Cauquenes series (with a crop rotation of potato, wheat, barley and fallow) using USLE, while Riquelme

(1994) calculated a value of 8.8 Mg h⁻¹yr⁻¹ for a monoculture of wheat and conventional tillage and the same soil.

The present work aims at studying the goodness of fit in estimating water erosion by the USLE model on an Alfisol under different soil management in the Metropolitan Region of Chile, specifically in a watershed located in the Village of San Pedro, comparing soil loss estimates provided by the model with the respective erosion measurements obtained at experimental plots with three different treatments for different years. Special attention was given to the estimation of the R factor for this area, which was found to be a source of model error previously.

Description of the study area

The experimental plots were located in the town of Alto Loica, Commune of San Pedro, Melipilla Province in the Metropolitan Region of Chile (Figure 2), and is located on the eastern slopes of the Cordillera de la Costa, 120 km southwest of Santiago de Chile; at -34°01'58.8" Latitude and -71°25'1.2" Longitude (Tokugawa and Vargas, 1996).

The type of soil where the measurements were located corresponds to an Alfisol belonging to the Cauquenes Series. The representative pedon of the Cauquenes association is a member of the Ultic Paleoxeralfs; fine, kaolinitic, isomesic, according to the soil classification system of the USDA (1993). These are deep soils formed in situ from granitic rocks, and evolved to yellowish reddish brown 5 YR hue on the surface and deep yellow hue in the same above. It rests on a substrate consisting of highly weathered granite and occupies a topographic position on hills and hillocks. It features brick structure in the first two horizons, both glass and granite gravel on the surface. Located in highly undulating

slopes with 15 to 20%, they are characterized by severe erosion and are mostly well drained. Regarding usability of the soil, it was classified as Class VII (of 8), which means low soil quality, and was attached the letter (e), which means limited erosion (Martínez, 2004).

Alto Loica (San Pedro) has a temperate, Mediterranean climate characterized by a dry summer season (December to March). Average annual rainfall is 399 mm and tends to increase eastward toward the Andes, because orographic effects, and from north to south, due to an increased influence of the midlatitude storm track. The temperature range is very low with an annual average of 14°C, a maximum of 28°C in the summer period, and winter minimum temperatures of 5 to 6°C (Tokugawa and Vargas, 1996).

The typical vegetation of the area consists of Espino (*Acacia dig*) Quillay (*Quillaja saponaria*), Boldo (*Peumus boldus*) and Maíte (*Maytenus boaria*), Romerillo (*Lomatia ferrugenea*), Trevo (*Dasyphyllum diacanthoides*) and Huañil (*Proustia cuneifolia*) and are characterized by low heights. The understory vegetation is dominated by grasses.

Evaluation of soil loss

The treatments evaluated in this study were developed under the project: "Erosion control and reforestation in watersheds of the semiarid zone of Chile", which was cooperation between the National Forestry Corporation (CONAF) and the International Cooperation Agency (JICA) from 1993-2000. The purpose of the CONAF-JICA project was the development and application of techniques of tree nursery, forestation and soil and water conservation, to recover land that was degraded by water erosion. In this project



Figure 1. Photo of the different treatments, with a) subsoiling, b) infiltration trenches and c) natural prairie.

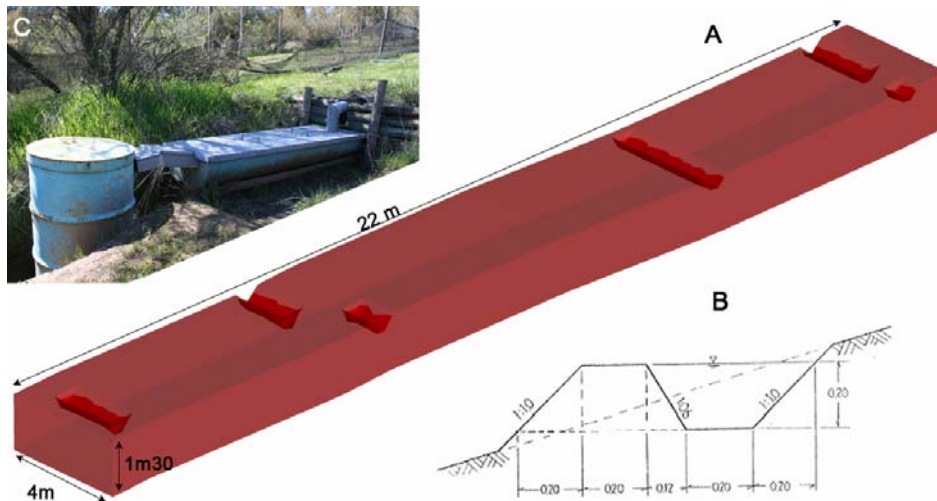


Figure 2. (a) Layout of the infiltration trenches on the Wischmeier plot, (b) trench dimensions and (c) collector drums at the plot outlet.

techniques for recovery of degraded soils were installed and soil loss measured to evaluate the effectiveness of the different techniques (Tokugawa and Vargas, 1996).

For the evaluation of soil loss, data were obtained for each rainfall event during the period 1996-2000, obtained by measuring total sediment loss (g) and total runoff amount (l) on experimental plots with treatments of subsoiling, infiltration trenches and a control treatment with natural prairie (Figure 1). Each treatment was 4 m wide and 22.14 m long (the

dimensions of a typical Wischmeier plot), with a total area of 88.56 m², bounded on its perimeter with metal sheets. In the lower base of the plots, the catchment area was equipped with a collection channel that extends across the width of the plot where the flow converges to two large metal drums (200 l each) for runoff and sediment collection (see also Figure 2c). The characteristics of each of the treatments are given in the subsequent sections.

Subsoiling treatment

Subsoiling was applied one month before the forestation (i.e. April 1995) using a caterpillar tractor of 120 HP equipped with a single spear (ripper) under dry soil conditions. Subsoiling to a depth of 0.5 m was performed perpendicular to the slope by following slope contours with the aim of improving root growth and infiltration of rainwater. The field plot has a slope of 5.7% and the vegetation is represented by *Acacia* species (Figure 1a).

Treatment of infiltration trenches

The infiltration trenches in this treatment were also established in 1995 (Figure 1b), and consisted of 6 trenches with variable lengths (0.6 to 3.9 m), arranged in a near checkerboard pattern (Figure 2a). They were designed to have a rectangular section of 0.2 m in height, 0.2 m base and a top width of 0.52 m, as shown in Figure 2b. The design also considers a lower slope angle at the upstream edge of the trench to facilitate entry of water and avoid erosion of the walls (Pizarro *et al.*, 2005).

The treatment of infiltration trenches is located on a slope of 9.2% and vegetation cover is represented by species of *Pinus radiata* (Figure 1c). At this point it is appropriate to note that for reasons of methodology to characterize the USLE, the average length of the catchment area on the slope (5 m) was taken.

Natural prairie treatment

Finally, a control treatment or natural prairie was evaluated, where no technique or practice of conservation was applied (Figure 1c). It had a slope of 10.2%, slightly higher than the other treatments and the plant cover in the treatment is represented by native grasses (*Bromus* sp.), characteristic of the study area.

Although the values obtained from the erosion plots represent only the same plots, and are not transferable to other areas with differing conditions (soil, management, use, slope), these plots are one of the few possibilities to look directly at soil losses related to management practices often applied in drylands of Chile, and can be used for the application and validation of erosion models.

Estimating water erosion by USLE

The USLE is the most widespread model for estimating erosion plots and includes the action of precipitation, soils, topography, cover and conservation practices, as indicated in Eq. 1:

$$A = R * K * L * S * C * P \quad [1]$$

where:

- A: soil loss expressed in the international metric system in $\text{Mg ha}^{-1}\text{yr}^{-1}$.
- R: erosivity of rain ($\text{MJ mm ha}^{-1} \text{h}^{-1}$).
- K: soil erodibility [$(\text{Mg ha}^{-1}) \cdot (\text{MJ mm ha}^{-1} \text{h}^{-1})^{-1}$]
- L: length factor (dimensionless), soil loss influenced by the length of the slope.
- S: slope factor (dimensionless), soil loss influenced by the gradient of the slope.
- C: crop factor (dimensionless), soil loss influenced by land use.
- P: management factor (dimensionless), soil loss influenced by the use of conservation practices.

Obtaining parameters of the USLE

Rainfall erosivity factor (R)

Two different methods were used to estimate annual values of water erosion: a) using the Arnoldus (1980) approximation, called Modified Fournier Index or MFI and b) by using the equation

proposed by Valenzuela and Morales (2004) or ICONA.

The first option to estimate the rainfall erosivity from monthly data is through Eq. 2, where the rainfall erosivity R ($\text{MJ mm ha}^{-1} \text{h}^{-1}$) is obtained by regression onto the MFI, as suggested by ICONA (1988) and adapted to the Region of Coquimbo in Chile by Valenzuela and Morales (2004) and Vandekerckhove (2006), resulting in a slope factor of 1.6881 mm^{-1} :

$$R = 1.6881 \sum_{i=1}^{12} \frac{P_i^2}{P_t} = 1.6881 \text{ MFI} \quad [2]$$

where P_i represents the monthly precipitation and P_t the total annual precipitation (mm).

A second procedure was developed by the Institute for the Conservation of Nature (ICONA, 1988). It should be indicated that it originated in Spain,

specifically in arid and semiarid Mediterranean climate of Andalucía and Almería and therefore reflects a specific pattern of local weather rain. The erosivity index for these areas was calculated from monthly rainfall data provided by the National Institute of Meteorology and by applying the equations proposed by ICONA (1988) for Spain, modified to local conditions of each zone that country. This modification was made considering nine parameters from which it was possible to create zones for the entire country.

Researchers in Chile (Morales and Valenzuela, 2004; Vandekerckhove, 2006) have calibrated this approach for the Coquimbo Region taking the type of climate and rainfall amounts received in the area into account, resulting in the second option to estimate the erosivity factor based on monthly precipitation data for the period 1996 -2000:

$$R = 0,291 \cdot [PMEX]^{1,297} [MR]^{-0,511} [MV]^{0,366} [F24]^{0,414} \quad [3]$$

where R is the rainfall erosivity factor ($\text{hJ.cm.m}^{-2}.\text{h}^{-1}$), $PMEX$ the average monthly maximum of each year of the series (mm), MR is the average rainfall from October to May (mm),

MV is the average rainfall in the wet season from June to September (mm) and $F24$ is the concentration factor of the maximum daily rainfall, defined as:

$$F24 = \frac{(\text{maximum 24h rainfall in a year})^2}{\sum \text{maximum 24 hour rainfall of all months in a year}} \quad [4]$$

Soil erodibility factor (K)

The estimation of the soil erodibility factor (K) was done by using the nomogram proposed by Wischmeier, and Smith (1978), according to the characteristics (% silt + very fine sand) (% sand too coarse to fine), organic matter (%), permeability and soil

structure, as modified by Morgan (1997) in terms of international units.

To determine the textural characteristics, the particle size distribution was determined by the hydrometer method (Gee and Or, 2002). The different sand fractions at sizes of 0.1, 0.25, 0.5, 1 and 2 mm were obtained with three samples of dry soil from each

of the field plots (subsoil, trenches and grass), whereas the silt and clay fractions were separated by sedimentation.

The organic matter content was determined with the Walkley and Black method modified by Heanes (1984). Soil structure, obtained through field measurements, was classified according to USDA (1993) and was found to be blocky at all sites.

Finally, the permeability was determined with the tension infiltrometer (Clothier and White, 1981), resulting in a similar and slow permeability according to Porta *et al.* (1999) on all plots.

Topographic factors (LS)

The S factors were determined from Eq. 5 (Wischmeier and Smith, 1978) for each of the treatments:

$$S = 0,065 + 0,045s + 0,0065s^2 \quad [5]$$

where s is the slope (%).

To determine the length of the slope factor in the plot with infiltration trenches Eq. 6 was used:

$$L = \left(\frac{l}{22,1} \right)^\mu \quad [6]$$

where l is the length of the runoff on the slope, and μ a gradient-dependent factor, which is calculated by Eq. 7 (Wischmeier and Smith, 1978).

$$\mu = 0,6 * \left[1 - e^{(-35,835.S)} \right] \quad [7]$$

Factor use and land management (C) and conservation practice (P)

Factor C was set as a linear function in time to *Acacia* plantations and *Pinus radiata* located in the subsoil treatment and infiltration trenches, respectively, since the cover of both plantations varied

considerably over time. In this factor, the following three sub-factors were considered: (i) the canopy cover sub-factor and single story (Wischmeier and Smith, 1978), (ii) the reconsolidation of the soil, associated with soil disturbance by tillage (Wischmeyer and Foster, 1980) and (iii) the fine roots in the surface layer (Wischmeyer and Foster, 1980). In the case of the natural pasture treatment, the value C is considered stable since it was assumed that no significant changes in land cover occurred over time.

Moreover, with respect to the contour tillage factor (P factor) the subsoiling treatment was assigned a value of 0.5 as proposed by Wischmeier and Smith (1978) according to the gradient of the slope.

Comparison of actual and simulated erosion

The measured soil loss values at the erosion plots located in the study area with different land use types and conservation practices were compared with values estimated by the USLE erosion, applying two versions of R factor calculations: a) estimated by Arnoldus approximation using MFI (1980) and b) estimated from the ICONA equation (1988).

The comparison between estimated and measured values was performed by comparing the average, standard deviation, skewness and kurtosis, statistics based on differences such as simulation efficiency (EF) (Greenwood *et al.*, 1985), the coefficient of agreement (d) (Willmott and Wicks, 1980), the mean absolute error (MAE) (Shaeffer, 1980) and finally the regression-based statistics; the Pearson correlation coefficient and slope, intercept and the probability that the slope and intercept are one and zero.

RESULTS

Measured soil loss

Table 1 shows the values of soil loss and the respective amounts of total precipitation for the period of evaluation, clearly highlighting the erratic annual rainfall, showing above normal rainfall conditions during the years 1997 and 2000, with 1034.5 and 866 mm respectively, while the average for the study area is 399 mm. In contrast, very little precipitation was observed in 1998 (141.5 mm). This shows that rainfall is highly influenced by the direct influence of El Niño in the years of highest rainfall total, as already documented for the IV Region of Coquimbo by Verbist *et al.* (2010). The remaining years 1996 and 1999 had more normal rainfall seasons, with rainfall amounts of 314.4 and 487.5 mm respectively.

It is emphasized that the highest soil loss was generated in the years with highest annual precipitation. This confirms that observed soil losses are closely related to rainfall, in part by the power of detachment by rain drops impacting the soil and partly due to the scouring effect by runoff on sediment detachment and transport (Wischmeier and Smith, 1978).

The values of the standard deviation and coefficient of variation for all treatments are considered high, more than 50% for the latter, confirming the high interannual variability of the data series.

Comparison of measured and estimated soil loss

Evaluation of the treatments individually

Differences were observed between the soil loss observed in the subsoiling treatment and the modeled values using

USLE, with both approximations of the R factor, as observed in Table 1. For the period 1996-1998 both modeled soil losses overestimate the measured value, while the USLE version using R (MFI) resulted in the largest values. For the last two years (1999-2000), both model versions subestimated soil losses, with R (ICONA) showing the lowest values. Nevertheless, the same trend was observed with both the model versions and the measurements, showing a similar trend.

In the Infiltration trench treatment, soil loss was overestimated with both USLE versions (Table 1), with the USLE with R (MFI) showing much higher values than obtained with R (ICONA). In general, however, both model versions generated a similar tendency in soil loss values as observed in the field, although the absolute values differ in some years, especially for the model version with R (MFI).

In the case of the natural prairie, the adaptation of the USLE model with R (MFI) also gave an overestimation of the soil loss since the start of the observations (Table 1), as observed in the treatment of subsoiling and infiltration trenches. The USLE version with R (ICONA) on the other hand, gave values with little variation in time that were close to those observed at that treatment.

Evaluation of the treatments together

Comparing the measured erosion values in all treatments with their simulated values, shown in Table 2, both USLE versions with different R values overestimated soil erosion. The USLE with the ICONA R value presented total and average values closest to those measured, whereas the R estimated from MFI showed a clear overestimation, with significant bias, increased skewness and kurtosis.

Table 1. Precipitation, USLE subfactors and modelled soil loss, as well as field measured soil loss values for the three treatments.

Year	Precipitation	R		K	L	S	C	P	A (Mg ha ⁻¹)		
		MFI	ICONA						MFI	ICONA	Measured
Subsoiling											
1996	314.4	132.97	101.97	0.03	1	0.532	0.172	0.5	0.183	0.140	0.097
1997	1034.5	378.37	170.40	0.03	1	0.532	0.138	0.5	0.417	0.188	0.151
1998	141.5	66.65	34.11	0.03	1	0.532	0.104	0.5	0.055	0.028	0.026
1999	487.5	177.64	154.20	0.03	1	0.532	0.071	0.5	0.101	0.087	0.278
2000	866.0	782.75	672.40	0.03	1	0.532	0.037	0.5	0.231	0.199	0.276
Infiltration trenches											
1996	314.4	132.97	101.97	0.03	0.475	1	0.148	-	0.280	0.215	0.051
1997	1034.5	378.37	170.40	0.03	0.475	1	0.118	-	0.636	0.287	0.163
1998	141.5	66.65	34.11	0.03	0.475	1	0.088	-	0.084	0.043	0.042
1999	487.5	177.64	154.20	0.03	0.475	1	0.058	-	0.147	0.127	0.083
2000	866.0	782.75	672.40	0.03	0.475	1	0.028	-	0.312	0.268	0.115
Natural prairie											
1996	314.4	132.97	101.97	0.04	1	1.2	0.005	-	0.032	0.024	0.020
1997	1034.5	378.37	170.40	0.04	1	1.2	0.005	-	0.091	0.041	0.036
1998	141.5	66.65	34.11	0.04	1	1.2	0.005	-	0.016	0.008	0.030
1999	487.5	177.64	154.20	0.04	1	1.2	0.005	-	0.043	0.037	0.068
2000	866.0	782.75	672.40	0.04	1	1.2	0.005	-	0.188	0.161	0.072

Table 2. Basic statistics of measured and simulated erosion for all treatments (n=15).

Basic statistics	Measured	USLE-calculated	
		R (MFI)	R (ICONA)
Sum (Mg ha ⁻¹)	1.50	2.81	1.85
Average (Mg ha ⁻¹)	0.10	0.18	0.12
Standard deviation (Mg ha ⁻¹)	0.08	0.16	0.09
Skewness	1.31	1.49	0.37
Kurtosis	0.90	2.38	-1.19

Evaluation of different simulations

The simulation efficiency is shown in Table 3, resulting in negative values for both versions of the USLE model, which means that the generated error magnitudes suggest that the average of the measured values would be a better estimate than the simulated results obtained. According to the index values match, the option of USLE which generated a higher value was R (ICONA), which is interpreted as greater consistency between the values of measured and simulated erosion. The average absolute error was higher for the option of USLE with R (MFI), i.e. a greater average difference between measured and estimated values. In general, both absolute mean error values

are considered high since they are higher than half the standard deviation of the measured values.

Evaluation of correlation and trend

As shown in Table 4, the regression coefficient was higher for the USLE option with R (ICONA), but both values gave low or weak correlations between the measured and simulated erosion. Evaluating the joint probability that the intercept is zero and slope one, indicated that for both model versions this probability is very similar. However, studying the separate probabilities, it is noted that the intercept has a greater probability of being zero in the USLE version with R (MFI), likewise for the probability that the slope is one.

Table 3. Statistics based on difference of measured and estimated erosion for all treatments.

Index	USLE using	
	R (MFI)	R (ICONA)
Simulation efficiency (EF)	-3.60	-0.25
Concordance index (d)	0.45	0.67
Mean Absolute Error (MAE)	0.12	0.06

Table 4. Regression statistics of measured and estimated erosion for all treatments.

Parameters	USLE using	
	R (MFI)	R (ICONA)
Correlation coefficient (R)	0.40	0.48
Intercept (b0)	0.10	0.06
Probability of Intercept (b0)	0.13	0.06
Slope (b1)	0.82	0.53
Probability of the slope (b1)	0.74	0.11
Probability b1=1; b0=0	0.25	0.21

According to Figure 3, which shows measured and estimated erosion by the two versions of rainfall erosivity for each of the treatments, it is clear that most of the estimated soil loss values are above the 1:1 line. With regard to the low values of soil loss observed, these tend to be

overestimated by the adaptation of USLE with R (MFI), except for two events of lower magnitude. On the other hand, the adaptation of USLE with R (ICONA) had values close to the measured values. Overall, it appears that both adaptations despite the differences in magnitude follow the same trend.

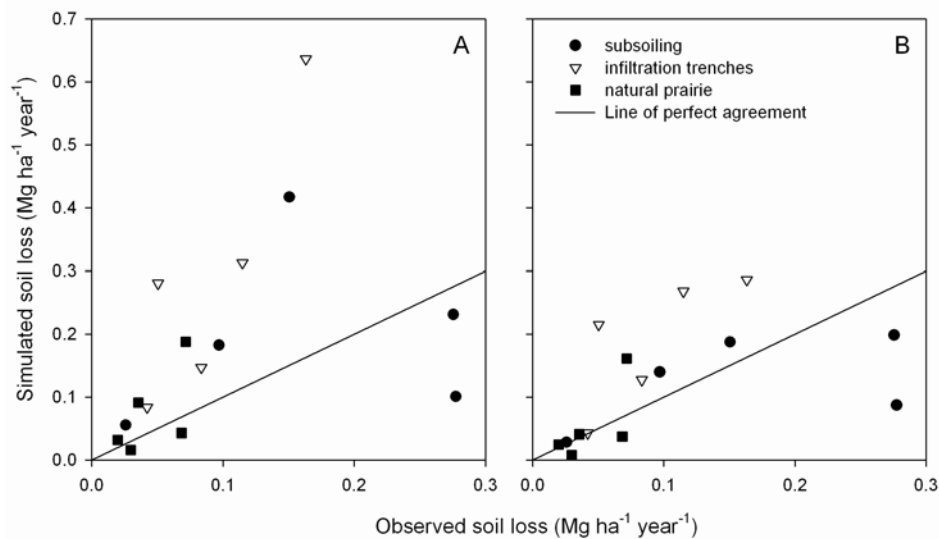


Figure 3. Measured and estimated soil erosion by USLE with (a) R (MFI) and (b) R (ICONA) for each of the treatments. The gray line indicates the line of perfect agreement.

Overall, the statistics used to compare the soil loss values measured in the field and estimated by two USLE model options show comparable trends, indicating that the estimated values follow a similar distribution to those observed in the field.

The USLE model was evaluated by Honorato *et al.*, (2001) at 6 locations between IV and IX Region of Chile, with a precipitation range from 100 to 1800 mm. The model was not a good predictive performance in areas with significant erosion ($> 2.5 \text{ Mg. ha}^{-1} \text{ yr}^{-1}$) with bare soil treatments such as tillage. The model did not provide good estimates of erosion, mainly due to R factor estimated by approximating Arnoldus (MFI) (1980), whose values did not provide sufficient accuracy to estimate rainfall erosivity.

The R factor from the station of Las Cardas, Chile ($40.2 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ y}^{-1}$) was estimated by (Vandekerckhove, 2006) using the linear regression between MFI and R of Valenzuela and Morales (2004). Where R itself was already an estimation of the R calculated with the RUSLE method. The resulting estimated absolute values are unlikely to be very good estimates because of the following reasons: first, the lack of adequate rainfall data to calculate a good average erosivity factor R and second, RUSLE is an empirical model, designed for homogeneous agricultural fields in North America. The lack of data to calibrate and validate the RUSLE model makes it difficult to assess the validity of the RUSLE model.

Because of the high variability of the rainfall, an event based model would probably yield better estimates, but then, accurate data of each used rainfall event would be needed, which are not always available.

CONCLUSIONS

Because of the empirical origin of the Universal Equation Soil Loss (USLE) and the procedures for calculating each of the factors, it is stressed that these are not universal, i.e. the uncertainty of its predictions is far greater than the conditions that apply to resemble the conditions that initially were obtained. For this reason, the resulting simulated values obtained in this study should be interpreted only to derive general trends. Indeed, the USLE model was able to represent the trend of the data, i.e. the estimated data were consistent and followed the same pattern of data taken in the field, despite the over- and underestimations.

Possible causes of model behavior in USLE erosion estimates for the study area are first, the low soil loss observed in the treatments of subsoiling, infiltration trenches and natural prairie, where the error can be larger than the observed value. Likewise, the use of monthly precipitation in both equations used to calculate the factor of rain erosivity, which may obscure the erosive effect of high intensity daily rainfall.

By way of recommendation it should be stressed that there is a need to include a plot of bare soil in this type of study, allowing to compare with a control situation when estimating the influences of the C and P factors on land use and land management. It would also be recommended to estimate the rainfall erosivity factor for the study area from high resolution rain gage data, which would allow a more accurately estimate for the rain erosive capacity in the area, through the calculation of the EI30 index.

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