Assessment of Erodibility, Runoff and Infiltration in an Uruguayan Vertisol

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ABSTRACT

Vertisols represents near 25% of agricultural land in Uruguay, often showing erosion damage. They are mostly montmorillonitic Typic Hapluderts. Gilgai -a special microrelief of Vertisols- with a deep and a shallow phase is a common feature. Objectives of this study were: a) to assess relative soil erodibility in a Vertisol by means of a field rainfall simulator b) to compare results with those obtained with the USLE nomograph and, c) to determine runoff volumes and infiltration rates considering the shallow and the deep phase of these soils. A Typic Hapludert of relevant use for crop production in Uruguay was studied. A portable rainfall simulator with three Vee-Jet 80/100 nozzles at 0.3 kg/cm^2 pressure and at 2.4 m height was used. Four rainfall events of 45, 20, 20 and 30 minutes with an intensity of 70 mm/h were applied on two 3.4 x 1.0 m experimental tilled bare soil plots, one on the shallow phase, one on the deep phase. Soil loss and runoff in relation to time were measured. Erodibility index obtained by rainfall simulation was Ks=0.03 and by the USLE nomograph was K=0.11 as average for both phases (plots). These values are lower than other erodibility indexes of Vertisols and of Uruguayan soils in general. Difference between Ks and K was attributed both to a) different methodologies and to b) an overestimation of soil losses when using USLE K under local conditions. Runoff was 33% in average, 44% for the deep phase and 22% for the shallow phase. This difference was attributed to lateral subsurface water movement due to "waving" horizons. The average final infiltration rate was 18 mm/h.

INTRODUCTION

The maintenance or increase of soil productivity in Uruguay is very relevant to its economy. There are strong evidences of past and present erosion in agricultural lands. Approximately one fourth of these lands are occupied by Vertisols. Mostly they are montmorillonitic thermic Typic Hapluderts. They have relatively high organic matter content (5-12%). Clay content ranges from 40 to 60%. They are characterized by a granular or fine blocky structure when they have not been degraded by cultivation (Durán, 1985). Gilgai -the special microrelief of Vertisols- is almost always present (Puentes, 1988) often showing a "wavy" soil surface (and subsurface) microrelief, with a "feather" pattern easily visible in the field and in aerial photographs). A well defined double profile is present. Significant cracks - 2 cm wide or bigger- are usually present in summer, sometimes up to early autumn, when a higher evapotranspiration produces a progressive decrease in soil moisture.

Soil erodibility assessments in Uruguay were mostly made using the USLE and its nomograph (Wischmeier et al., 1971; Puentes, 1981). More recent papers report erodibility estimations in Vertisols with rainfall simulation (Víctora et al., 1998).

OBJECTIVES

Major objectives of this study are:
  a) to determine a relative soil erodibility index (Ks) for a Vertisol by means of field measurements of soil loss under simulated rainfall,
  b) to compare Ks obtained by rainfall simulation with K obtained by means of the USLE nomograph and
  c) c) to determine runoff volume and infiltration rates considering the shallow and the deep phase of these soils.

MATERIALS AND METHODS
The soil

The Vertisol under study is a Typic Hapludert, Ombúes Serie, clayey textured, occurring in gentle sloping lands, slopes ranging between 2-6%. Its characteristics are presented in Table Nº 1. Several specific properties of these soils like cracks during dry seasons, a well defined double profile with a deep and a shallow phase and a wavy gilgai-micro-depressions (or m-valleys) and micro-ridges, corresponding to deep and shallow phase respectively (Dudal and Eswaran, 1988)- are present. Parent material is a brownish silty clay sediment from the Quaternary. (Initial soil moisture was 30%, being considered a medium value for these soils under local conditions).

The rainfall simulator

The portable field rainfall simulator used in this study was developed in 1983 by Puentes et al (unpublished) based on the models of Meyer's (1958) and Swanson's (1965). It is composed of an iron structure holding an oscillating pipe, which carries a pressure gauge and 3 Vee-Jet 80/100 nozzles working at 0.3 kg/cm^2 pressure and at 2.4 m height, producing a rainfall with a drop size distribution similar of those of temperate regions. The field equipment also

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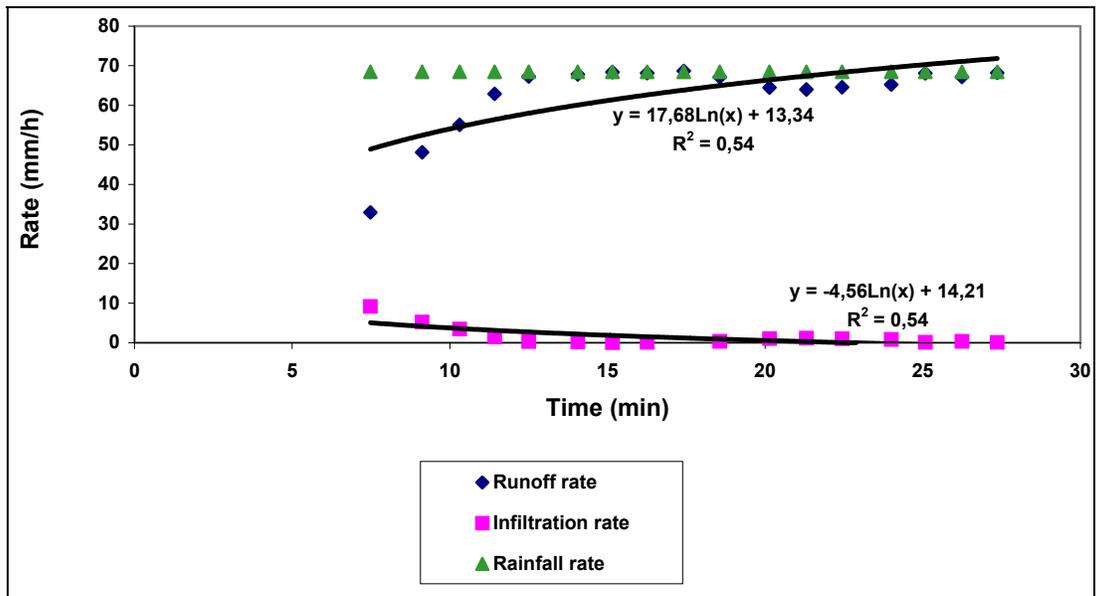
y = runoff, infiltration or rainfall rate (mm/h) ; x = time (min)

Figure 1a. Rainfall, runoff and infiltration rate in last run, deep phase (plot A).
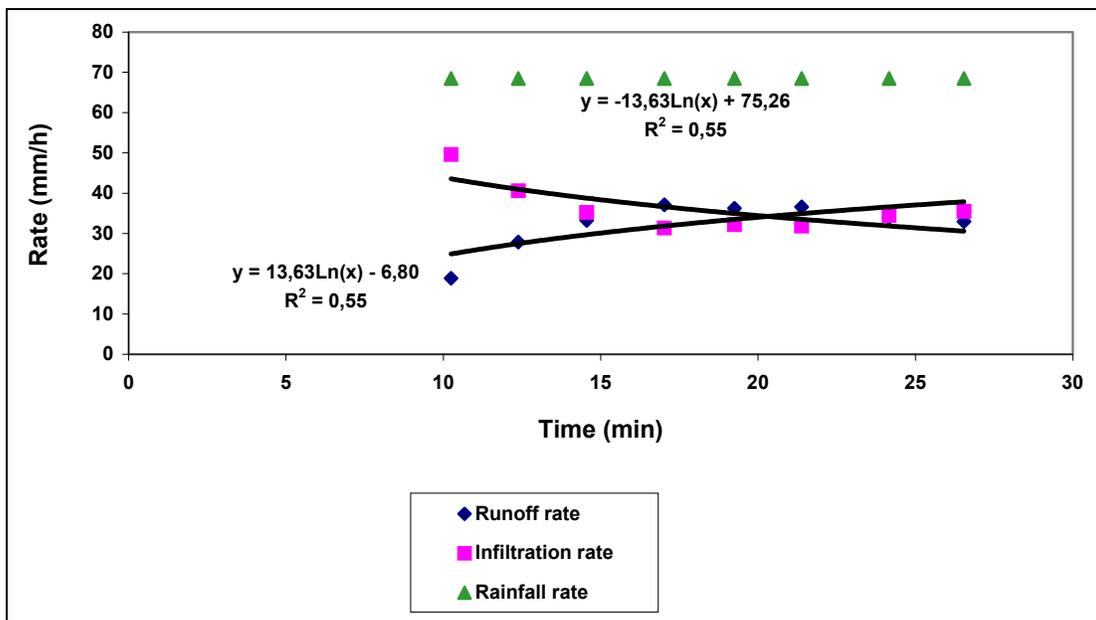
y = runoff, infiltration or rainfall rate (mm/h) ; x = time (min)

Figure 1b. Rainfall, runoff and infiltration rate in last run, shallow phase (plot B).

Table 1. Characterization data of Vertisol Ombúes Serie, deep phase and shallow phase.

	DEEP PHASE					SHALLOW PHASE	
Horizon	A 11	A 12	A 13	AC 1	AC 2 Ca	A 1 Ca	AC Ca
Depth (cm)	0 - 30	30 - 53	53 - 84	84 - 110	110 - 125	0 - 29	29 - 80
Color	10YR2/1	7.5YR2/0	10YR2.6/1	10YR3/2	7.5YR4/2	10YR2.4/2	10YR4/1
pH (H2O)	7.0	6.8	7.3	7.8	8.0	8.0	8.3
Org. mat.%	8.0	4.7	1.8	1.2	0.6	5.76	0.79
Total N %	0.36	0.19	0.10	0.08	0.07	0.32	0.07
Clay %	42.5	47.2	50.3	49.8	48.7	49.7	48.1
Silt %	32.1	30.5	24.0	26.6	28.3	41.6	40.4
Sand %	25.4	22.3	25.7	23.6	23.2	8.7	11.5

Table 2. Runoff, sediment load, erodibility, SSI and final infiltration rate of the Vertisol Ombúes Serie.

	Deep phase plot A	Shallow phase plot B	Average
Runoff (%)	44	22	33
Sediment load (g/l)	1.4	1.9	1.62
Ks	0.03	0.03	0.03
K	0.11	0.11	0.11
SSI	---	---	5.1
Final infiltration rate (mm/h) (last run)	0	36	18

includes a mobile 1500 l tank, an electric generator, a water pump and a windshield.

The plots

Two 3.4 x 1.0 m plots (termed A and B) were established on a homogeneous slope. Each plot corresponded to a different phase of the studied Vertisol (A: deep phase, B: shallow phase). Soil surface was manually tilled as a seedbed. A previously calibrated central collector and container for rainfall intensity measurement and control, plus runoff collectors and graduated recipients for each plot were used.

Data collected and registered

Rainfall intensity, runoff volumes and time were recorded on the field. Runoff samples for sediment load determinations were collected and soil sampling for initial soil moisture and structural stability determinations were performed.

Procedures

Four rainfall events (runs) of 45, 20, 20 and 30 min were applied. The first 45 min run is performed the first day. The

following day, the second and third runs are separated by a 15 min interval. The third and fourth runs are separated by a 60 min interval. The rainfall intensity used was 70 mm/h approximately, obtained by intermittence. The runoff was sampled at volumetric intervals and time was recorded when sampling. A structural stability index (SSI) was determined by the wet sieving method (Yoder, 1936). Soil moisture was determined by the gravimetric method.

Calculations

Soil loss during the period between each runoff sampling was estimated n function of the sediment load observed in the sample corresponding to the end of that period and the runoff volume recorded during the same period The energy for erosivity assessments was estimated using the following equation:

$E = 11.9 + 8.73 \log X$ (Wischmeier and Smith, 1978).

USLE factors C and P = 1 (tilled bare soil). The slope was corrected according to topographic factors LS (Renard et al., 1994).

Erodibility index obtained with rainfall simulator (Ks) was considered as the slope of the linear regression equation that relates USLE factors RLS to soil loss (A) in each plot; the Ks values here presented are an average of the values

obtained for the four runs for each soil phase (and plot). The average of both values is considered as the Ks of the soil.

Runoff percentage was calculated as total runoff volumes in relation to total applied rainfall volumes in the four runs. Infiltration rate obtained with the rainfall simulator was considered as the difference between applied rainfall rate (intensity) and runoff rate.

RESULTS

Table No. 2 presents erodibility, runoff, sediment load, SSI and infiltration rate for both deep and shallow phases of the Vertisol under study (Ombúes Serie).

Figures 1.a and 1.b shows rainfall, runoff and infiltration rates in the last run, for the deep and the shallow phase of the Vertisol, respectively.

DISCUSSION

Both Ks (simulated rainfall) and K (USLE nomograph) values obtained - 0.03 and 0.11 respectively - were in general medium to low when compared to other Vertisols, and low when compared to other soil Orders in Uruguay (referred to the same methodologies and considering a "medium" initial soil moisture as it occurs in spring and autumn).

Ks value was lower than K value. Even without a clear relationship, Ks have been usually lower than K for Uruguayan soils (Víctora et al., 1998). Also empirical data indicate an overestimation of K values in many cases. This overestimation has been often observed when applying the nomograph to local conditions and comparing the obtainedvalues with empirical assessments inferred from soil properties and experience: nomograph often showed higher values than those coming from expert opinion. Probably the main reason for this overestimation are the differences between both methodologies here used for the erodibility assessments (Loch, 1984). This author points out that the nomograph uses empirical relationships that are valid only for certain range of soils properties and cannot be used with confidence in all cases in every region, in relation to Australian soils. This is probably a similar situation as in Uruguay, where many soils have a high active clays and organic matter contents.

Final Ks value for the studied Vertisol was obtained as the average of both deep and shallow phase, considering field experimental results of each one under simulated rainfall (average of 4 runs in each plot, then average of plots A and B). Final nomograph K was obtained as an average of

K values obtained for the deep and the shallow phase separately. In spite of very important differences in soil profiles, final Ks values were coincidental in both phases and the same occurred for USLE's nomograph K assessments (Table 2). These particular coincidences could be explained by different reasons in each case. For Ks, runoff from deep phase (plot A) was double than that from shallow phase (plot B). This fact was probably due to undulating or "waving" subsurface soil horizons. This special characteristic of some Vertisols, which are often found in Uruguay and some other countries, is associated to a surface and subsurface micro-relief -originated in shearing forces within the soil due to shrinking-swelling processes. Depressions and ridges around 0.5 m height difference, with short slopes (1 to 2 m long) are present in surface, as well as in subsurface horizons, giving a very characteristic wavy soil surface. This surface and internal slopes could have produced an important subsurface flow or lateral soil water movement from the shallow phase (plot B) towards the deep phase (plot A). The process was surely favored by an upper layer that was ploughed, thus loosen, up to 20 cm deep. This can explain the difference in runoff volumes between both plots 44% vs. 22%, in spite of an approximately equal amount of rainfall applied.

The lower runoff volume obtained in the shallow phase was counteracted by a higher sediment concentration, thus producing soil losses similar to those of the deep phase. This interactions between runoff volume and sediment concentration has been observed in previous research with simulated rainfall (Víctora et al., 1997).

The coincidence of K values obtained with the nomograph - 0.11 for both the shallow and the deep phase - can be explained considering that the higher silt (and fine sand) content in the shallow phase, a soil characteristic which increases factor K values, was counteracted by a higher clay content, rising K factor, in surface soil horizon of this phase.

Table 3 shows results obtained with the same methodology in other Vertisols from Uruguay. As expected, in the results here obtained and in previous studies, Ks values were related to sediment load, runoff and SSI. A high Ks corresponds to a high sediment load, as in Jesús María

Serie, where Ks is 0.07 and sediment load is 4.3 g L^{-1}, in spite of a low runoff (14%). On the other hand, the Ombúes and Tala Series, show a lower Ks - both 0.03 - and also a lower sediment load: 1.6 and 1.9, with higher percentages of runoff, 33 and 43%, respectively.

The lower SSI of Jesús María with respect to the other soils compared, is related to a higher particle detachment and sediment yield, counteracting a lower runoff. Considering that the infiltration rate was calculated as the difference between applied rainfall and runoff, the infiltration rate was higher in the shallow phase than in the deep phase. While the final infiltration rate for the shallow phase was of 36 mm h^{-1}, for the deep phase the obtained value was of 0 mm h^{-1}, what is explained by the addition of runoff coming from the shallow phase, as explained above. The average infiltration rate when taking in account both phases was of 18 mm/h. This value can be considered as the infiltration rate of these kind of soils -Vertisols with double profile- when considering the soil as a unique soil (for taxonomic purposes or land management). This average rate of 18 mm h^{-1}, is a rather low value compared to other Vertisols in Uruguay when using rainfall simulation. Initial soil moisture of 30% allows to expect an increase of infiltration in summer and an decrease in winter.

CONCLUSIONS

Erodibility index Ks obtained for the studied Vertisol by rainfall simulation was of 0.03 and of 0.11 by the USLE nomograph. These are rather low values when compared to other erodibility indexes of Uruguayan soils in general and medium to low when compared to Vertisols in particular.

Rainfall simulation produced lower values of erodibility indexes than the USLE nomograph, in coincidence to previous research. The overall difference was attributed to differences between both methodologies, including a probable overestimation of soil losses when using the USLE K factor under local conditions for some kind of soils.

Runoff was 33% in average for the deep and the shallow phase. An important difference between both phases was registered, where runoff coming from the deep phase doubled runoff from the shallow phase - 44 vs. 22% -. This fact was attributed to lateral subsurface water movement due

Table 3. Soil taxonomy, texture, Ks, runoff, sediment load and SSI of three Typic Hapluderts from Uruguay

USDA SOIL TAXONOMY (1976) AND SOIL SERIE	Textural Family (†)	Clay	Silt + v.f. Sand	Ks	RUNOFF (%)	SEDIMENT LOAD (g/l) (AVERAGE)	SSI
Typic Hapludert, Ombúes Serie	C	42.5	41.5	0.03	33	1.62	5.1
Typic Hapludert, Jesús María Serie (‡)	L	38.6	44.7	0.07	14	4.3	3.0
Typic Hapludert, Tala Serie (‡)	SiC	26.1	37.3	0.03	43	1.9	5.62

(†) Si: silty, C: clayey, L: loam, S: sandy. (‡)Víctora et al, 1998

to "wavy" surface and subsurface horizons present in this soil.

The final infiltration rate was 18 mm/h (average for deep and shallow phases) being a rather low value when using rainfall simulation, when compared to other Vertisols in Uruguay.

Considering three cases of Vertisols, they showed expected differences in Ks values according to their characteristics. SSI and its related soil properties had a higher weight than runoff percentages in soil loss. High differences and interactions with respect to surface and subsurface water movement between the deep and the shallow phase were observed.

The results here presented could be used in most Vertisols and in similar soils with a high montmorillonitic clay content in order to improve nomograph assessments in such cases. Simultaneously, these results suggest that the USLE K factor should by adjusted for particular set of soils. It would be useful a) to continue this studies so to obtain K factors for soils of Uruguay (and other countries?) with a better fitness to local conditions and, with the same objective, b) to study other set of soils, particularly those cases where the nomograph does not provide satisfactory results.

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