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Effects of rock fragments cover and slope on infiltration, runoff and soil loss in an Entisol

Lobo D.*[a], Puentes, A.[a], Lozano, Z.[a], Rodríguez, G.[a], Saddy J.[a], Gabriels, D.[c]

[a]Universidad Central de Venezuela, Facultad de Agronomía, Venezuela.
*Corresponding author: lobod@agr.ucv.ve
[b]Empresa Nacional de Proyectos Agrarios
[c]UNESCO Chair on Eremology, Department of Soil Management, Ghent University, Belgium

Abstract

In order to evaluate the effects of rocks fragments and slope classes on infiltration, runoff and soil loss processes, an Entisol was selected in the 'Sector Cucurucho' at the Tovar municipality in Aragua State, Venezuela, with a high prevalence of particles (silt + very fine sand + fine sand) that reflects a low stability to the impact of the drops. However it shows a high stability to wetting, with the proportion of rock fragments (by weight and by volume) highly variable. The slope and rock fragment cover classes for this study were selected through a frequency analysis resulting from the determination of slope gradients and surface stoniness, using a clinometer and a 10x10 mesh, respectively. The slope classes were: <24, 24 - 36, 36-48 and > 48%, while surface stoniness classes selected were: <14, 14 - 28, 28 - 42 and > 42%. Infiltration rate, surface runoff and soil loss in each slope class and rock fragment cover class were evaluated in plots (20 x 30 cm) using a portable rainfall simulator applying rainfall intensities of about 100 mm h^{-1} during one hour. The effect of slope gradient was highly significant for runoff and soil loss, but not significant for infiltration rate, even though there was a slight tendency to decrease with slopes greater than 48%. The effect of rock fragment was not significant on infiltration rate, runoff and soil loss, which can be attributed to the variable rate of rock fragments within the soil volume. We found a positive association between runoff and soil loss (R = 0.857), while the infiltration rate showed a negative association with runoff (R = -0.562) and soil loss (R = - 0.445).

Keywords: rock fragments, runoff, infiltration rate, soil loss, Entisol.

1. Introduction

The infiltration process and hence the runoff are conditioned by a number of factors, which can be grouped as follows: (i) characteristics of the rain as intensity, drop size, kinetic energy, (ii) soil characteristics: state of the soil surface, roughness, sealing, crusting, stoniness; state and soil structural stability, presence of cracks, grain size, hydraulic conductivity of soil horizons, water storage capacity, initial moisture content, salinity and sodicity, coverage, (iii) characteristics of water quality: salt or sodium content, particles in suspension, temperature, (iv) characteristics of the medium: slope, vegetation, and (v) interfering factors: air trapped, recent tillage, trampling (Porta et al., 1999).

Rock fragments on the soil surface have the same effect as other materials that are used as soil mulch protecting the surface against the impact of raindrops, preventing the detachment of soil particles and hence the sealing of the surface (Mandal et al., 2005), also by decreasing the velocity of runoff, reducing the detachment and transport capacity of the surface flow (Poesen and Lavee, 1994). Therefore rock fragments may also influence infiltration and surface runoff production (Sauer and Logsdon, 2002).

In previous studies the effect of slope on infiltration, surface runoff, and sediment transport was evaluated (Barros et al., 1999; Liu et al., 2001; Truman et al., 2001; Haggard et al., 2005) where surface runoff often increased as slope increased. Some studies have found no relation between slope gradient and infiltration (Singer and Blackard, 1982), while others have found a decrease in infiltration with increasing slope gradient (Chaplot and Le Bissonnais, 2000) and others have reported decreasing infiltration rates with increasing gradient until a critical threshold was reached (Fox et al., 1997). In Venezuela, very few studies on stony soils focused on infiltration, runoff and erosion. However, these soils should be considered as important, because they are seats in important agricultural production systems (Lopez, 1999).

The objective of this study was to assess the effect of rock fragments on infiltration rate, runoff and soil loss in an Entisol of the North-Central region of Venezuela.

2. Materials and Methods

The study was conducted on a Entisol soil, located in Sector Cucurucho, Colonia Tovar, Venezuela (10° 24' 13''N; 67° 17' 14''W) located at 1,240 masl., with a mean annual rainfall of 1,279 mm, a reference evapotranspiration (ETo) of 1,196 mm, and a mean annual temperature 15.3 °C.

The research was carried out according to a completely randomized design with a factorial 4 x 4 x 3 with four classes of slope, four classes of rock fragments cover and three repetitions.

Rock fragments cover and slope classes were selected using a frequency analysis resulting from the determination of slope gradients and rock fragment on the surface, using a clinometer and a 10x10 mesh, respectively. The selected slope classes were: <24, 24-36, 36-48 and >48%, while rock fragment cover classes were: <14, 14-28, 28-42 and >42%.

Soil characteristics at different levels of slope and rock fragments cover are shown in Tables 1 and 2. In general, the soil has a sandy loam texture with predominance of the sand fraction (values between 56.5 and 73.0%) and low clay content (values between 5.06 and 10.74%). Important to note is the high proportion of the fraction silt + very fine sand + fine sand (50-250μm), which promotes a low soil structural stability and a high susceptibility to separation, favoring the formation of surface sealing (Poesen, 1986)

Table 1. Particle size distribution of the fine fraction

Slope Class (%)	Rock fragment cover class (%)	<2 μm	2-50 μm	50-100 μm	100-250 μm	250-500 μm	500-1000 μm	1000-2000 μm	Texture class
<24	<14	7.6	30.4	29.2	11.4	10.9	6.0	4.6	Fa
	14-28	9.0	22.0	35.0	15.8	10.7	4.6	2.9	Fa
	28-42	8.9	27.3	31.7	10.4	10.8	6.1	4.8	Fa
	>42	6.0	26.0	18.1	24.5	10.3	8.5	6.7	Fa
24-36	<14	8.4	24.6	34.3	17.2	8.5	4.3	2.8	Fa
	14-28	6.7	26.2	24.7	15.7	12.1	9.1	5.5	Fa
	28-42	6.8	25.4	32.0	14.5	9.1	6.5	5.7	Fa
	>42	8.6	28.2	32.7	11.5	10.4	6.1	2.5	Fa
36-48	<14	9.9	26.3	30.6	12.7	8.9	6.2	5.4	Fa
	14-28	7.6	28.4	24.4	12.9	11.0	8.7	7.0	Fa
	28-42	4.8	25.2	30.1	13.7	11.2	8.6	6.5	Fa
	>42	7.3	26.0	28.6	11.1	9.5	9.9	7.6	Fa
>48	<14	5.1	27.4	7.3	18.4	30.6	7.6	3.5	Fa
	14-28	5.1	21.9	36.1	14.8	11.6	7.2	3.3	Fa
	28-42	6.5	27.4	35.0	11.3	10.4	6.0	3.6	Fa
	>42	10.7	32.7	28.5	11.5	8.3	5.5	2.8	Fa

Table 2. Rock fragments and bulk density

Slope Class %	Rock fragment cover class (%)	Proportion of rock fragments by weight (%)	Proportion of rock fragments by volume (%)	Soil Bulk density (Mg m^{-3})	Bulk density of fine fraction (Mg m^{-3})	Bulk density of coarse fraction (Mg m^{-3})
<24	<14	21 ± 18	16 ± 11	1.57 ± 0.15	1.46 ± 0.08	2.52 ± 0.30
	14-28	8 ± 6	5 ± 4	1.23 ± 0.19	1.19 ± 0.16	2.03 ± 0.16
	28-42	19 ± 17	14 ± 14	1.62 ± 0.18	1.52 ± 0.09	2.35 ± 0.13
	>42	30 ± 9	20 ± 3	1.47 ± 0.19	1.29 ± 0.29	2.16 ± 0.09
24-36	<14	12 ±13	7 ± 8	1.37 ± 0.03	1.29 ± 0.11	2.74 ± 0.72
	14-28	5 ± 4	3 ± 2	1.64 ± 0.28	1.60 ± 0.27	2.79 ± 0.39
	28-42	14 ± 10	9 ± 8	1.36 ± 0.01	1.29 ± 0.05	2.24 ± 0.32
	>42	5 ± 2	4 ± 1	1.44 ± 0.03	1.41 ± 0.06	2.28 ± 0.96
36-48	<14	24 ± 10	20 ± 12	1.59 ± 0.37	1.58 ± 0.50	2.15 ± 0.06
	14-28	31 ± 5	22 ± 11	1.64 ± 0.57	1.48 ± 0.61	2.33 ± 0.03
	28-42	27 ± 5	15 ± 3	1.32 ± 0.11	1.14 ± 0.14	2.32 ± 0.03
	>42	31 ± 16	22 ± 13	1.42 ± 0.02	1.24 ± 0.09	2.08 ± 0.07
>48	<14	8 ± 5	5 ± 3	1.53 ± 0.04	1.48 ± 0.07	2.52 ± 0.11
	14-28	16 ± 15	11 ± 12	1.40 ± 0.14	1.31 ± 0.09	2.57 ± 0.78
	28-42	35 ± 14	28 ± 13	1.65 ± 0.16	1.47 ± 0.11	2.17 ± 0.05
	>42	5 ± 2	3 ± 3	1.49 ± 0.12	1.47 ± 0.12	2.59 ± 0.80

The proportion of rock fragments by weight and volume are highly variable within the different rock fragment classes, ranging between 5 and 35% by weight, while the proportion of rock fragments by volume was between 3% and 28% (Table 2).

The total bulk density was determined by the excavation method (Blake and Hartge, 1986), whereas the bulk density of fine and coarse fractions was calculated using the equation proposed by Flint and Childs (1984). These values are highly variable because of the variability of the rock fragments content.

The infiltration and surface runoff were evaluated in plots (20 cm x 30 cm) using a portable rainfall simulator, designed by Nacci and Pla (1991) applying rainfall intensities of about 100 mm h^{-1}. Such evaluations were performed for each slope class and rock fragment cover. The minimum infiltration rate and % runoff were determined in each simulated rainfall event.

Results were submitted to a descriptive analysis (mean and standard deviation) and variance analysis of data using SPSS software, version 11.0. The degree of association between the evaluated variables was calculated with Pearson coefficients (parametric) for runoff and soil loss, and Spearman (nonparametric) for infiltration, since those values are not normally distributed.

3. Results and discussion

Effect of slope and rock fragments on infiltration

The slope effect on infiltration was not significant (Fig. 1), but the lowest value of infiltration was found in slopes greater than 48%. It should be understood that the average values are the result of values with high variation.

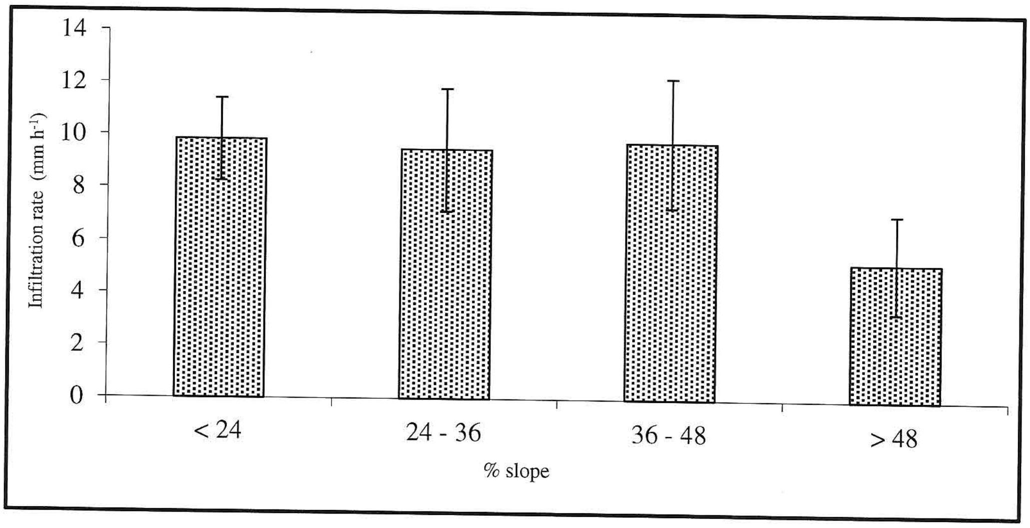

Figure 1. Effect of slope on infiltration rate.

The effect of rock fragment cover on infiltration rate was not significant (Fig. 2), which may be due to the fact that the proportion of rock fragments by weight and volume are highly variable. However, one can observe a tendency of increasing infiltration up to the class between 28 and 42 %, and thereafter a decreasing trend. Rock fragments can have ambivalent effects on infiltration rate and runoff, depending on various factors such as: size of rock fragments, position (on the surface, partially immersed, and totally immersed) and the % cover (Poesen et al., 1990; Poesen and Lavee, 1994; Cousin et al, 2003).

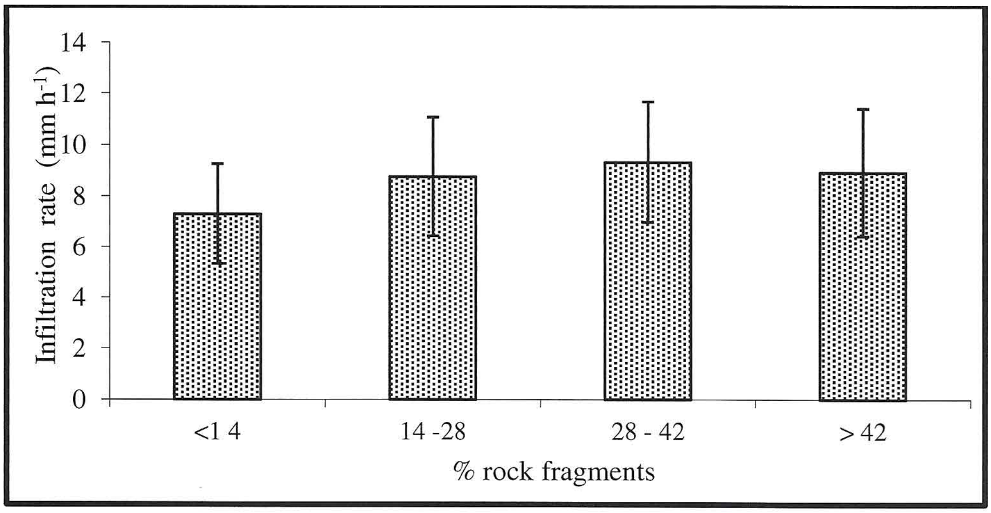

Figure 2 - Effect of rock fragment cover on infiltration rate.

Effect of slope and rock fragments on runoff

The effect of the slope on runoff was significant (Fig. 3), generating two groups: for slopes <24% and class between 36 to 48%, and classes with slopes between 24 and 36% and > 48%. This response could be associated with the proportion of rock fragments in the soil volume.

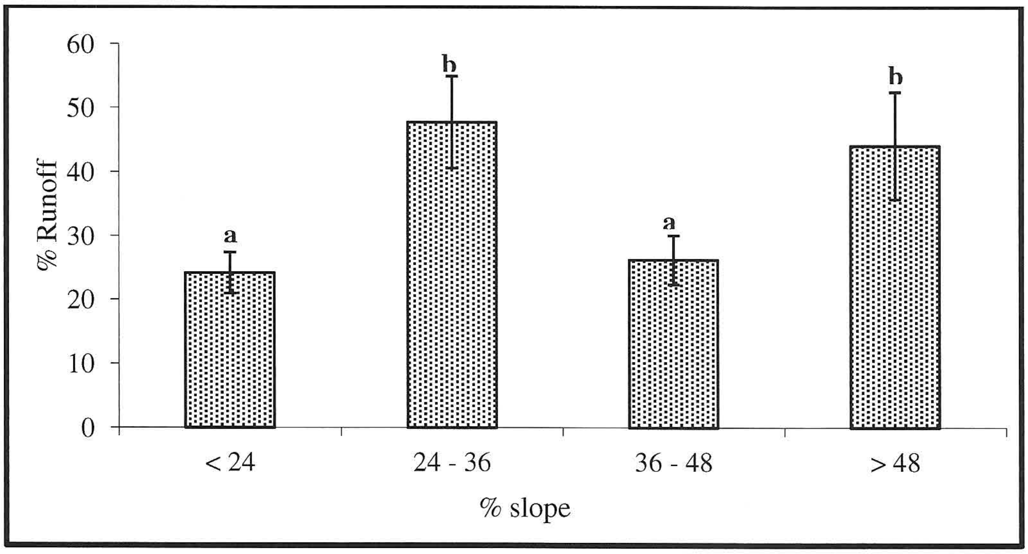

Figure 3. Effect of slope on runoff.

The effect of rock fragment cover on runoff was not significant (Fig. 4), most likely because of the differences in the proportion of rock fragments within the soil volume.

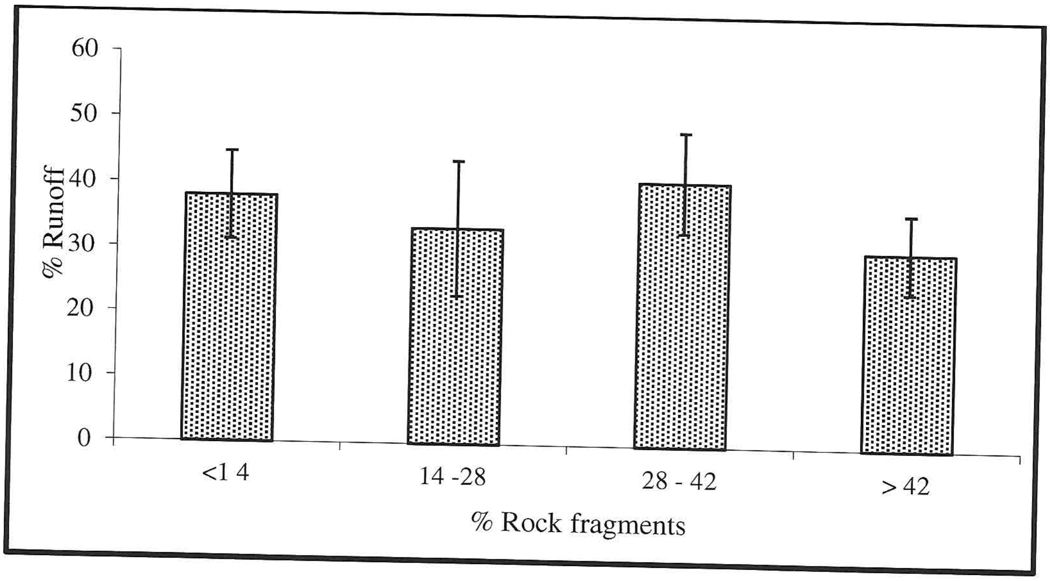

Figure 4. Effect of rock fragment cover on runoff.

Effect of slope and rock fragments on soil loss

With respect to slope gradient, the soil loss followed the same trend as the runoff (Fig. 5), that is to say the slope classes where there was more runoff, corresponded with higher soil losses. Liu et al. (2001) studied by the use of the wave theory of kinematics, the laws of the factors affecting soil erosion, which vary with slope gradient. They found that the critical slope gradient for soil erosion depends on texture, soil bulk density, surface roughness, time to initiate runoff, excess of net rainfall and the coefficient of friction of the soil.

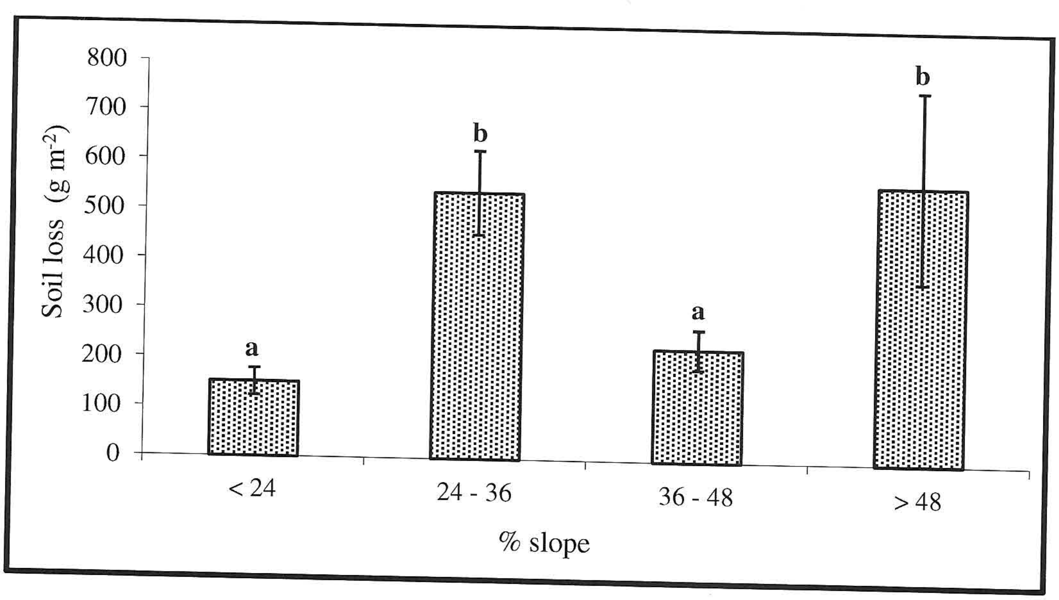

Figure 5. Effect of slope on soil loss.

The effect of the rock fragment cover on the soil loss was not significant (Fig. 6). This can be attributed to differences in the proportions of rock fragments embedded within the soil volume. Some studies have reported negative relations between fragments on the soil surface and the soil losses (Agassi and Levy, 1991; Poesen and Ingelmo-Sanchez, 1992; Cerda, 2001), and between the embedded fragments into the soil volume and soil loss (Rieke-Zapp et al., 2007). But also positive relationships were found between the content of fragments in the soil volume and soil loss (Poesen and Ingelmo-Sanchez, 1992).

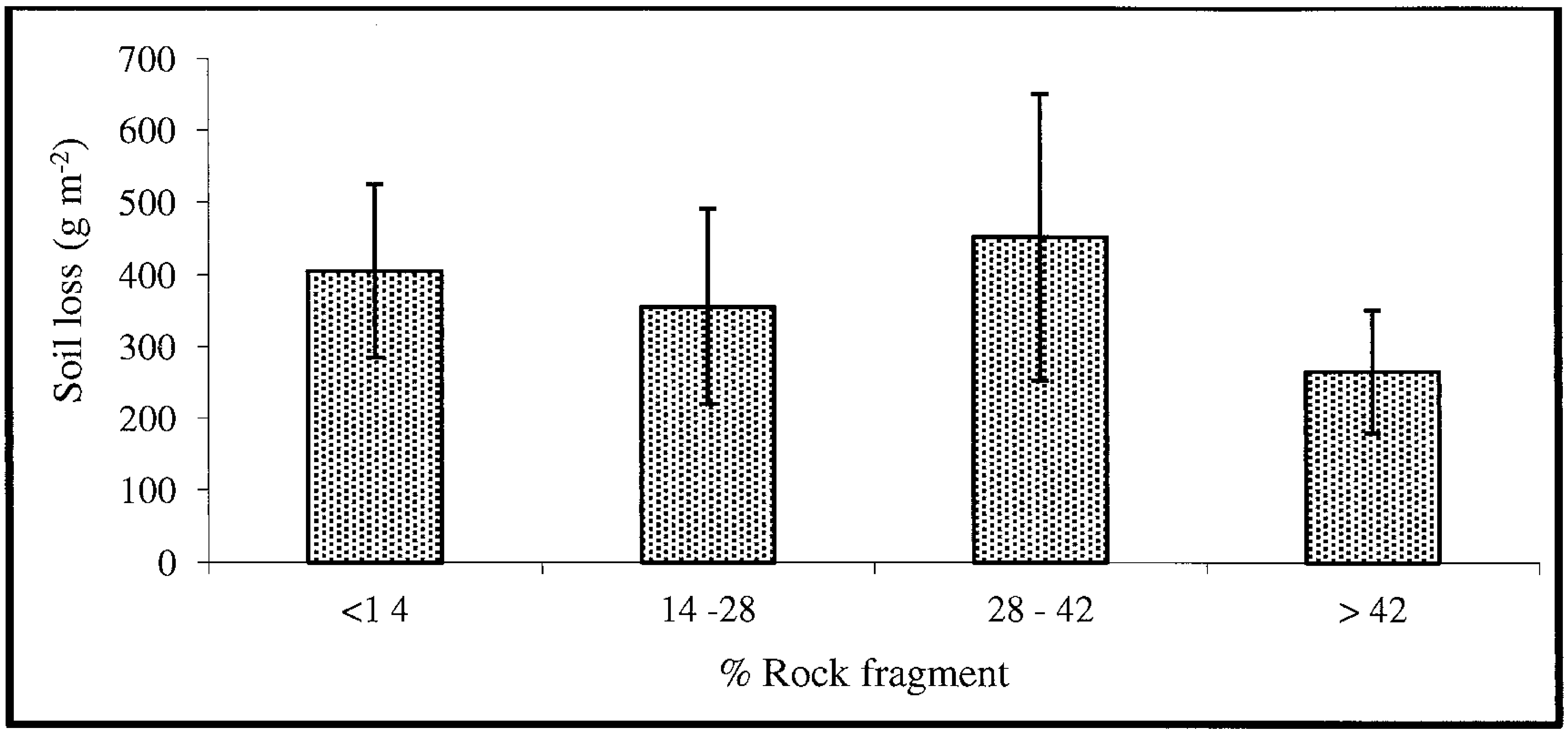

Figure 6. Effect of rock fragment cover on soil loss.

The soil loss followed the same trend as surface runoff, with a high significance ($R = 0.857$, $P < 0.001$). On the other hand, the infiltration rate was negatively associated with surface runoff ($R = -0.562$, $p < 0.01$) and soil loss ($R = -0.445$, $p < 0.05$)

4. Conclusions

The proportion of rock fragments by weight and volume, showed a high variability for different classes of slope and rock fragment cover.

The slope gradient effect proved to be significant on runoff and soil loss, whereas it has no significant effects on infiltration.

The effect of rock fragment cover on infiltration, runoff and soil loss was not significant. Such a result can be attributed to differences in the proportion of rock fragments embedded in the soil volume.

A positive association between runoff and soil loss (R= 0.857) was found, while the infiltration showed a negative association with runoff (R= -0.562) and soil loss (R= -0.445)

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