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Soil erosion under different vegetation covers in the Venezuelan Andes

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Summary. This comparative study of soil erosion considered different environments in an ecological unit of the Venezuelan Andes. The soils belong to an association of typic palehumults and humic dystrudepts. Soil losses were quantified by using erosion plots in areas covered by four types of vegetation, including both natural and cultivated environments. The highest soil erosion rate evaluated corresponded to horticultural crops in rotation: reaching a value of 22 Mg ha^{-1} per year. For apple tree (*Malus sylvestris* Miller) plots, soil losses reached values of 1.96 Mg ha^{-1} per year. Losses from pasture (*Pennisetum clandestinum* Hochst. ex Chiov.) plots, without livestock grazing, were as high as 1.11 Mg ha^{-1} during the second year of the experiment. The highest soil losses generated from plots under natural forest were equal to 0.54 Mg ha^{-1} per year. Environmental factors such as total and effective rainfall, runoff, and some soil characteristics as those related to soil losses by water erosion were evaluated. The type of management applied to each site under different land use type and the absence of conservation practices explain, to a large extent, the erosive processes and mechanisms.

Keywords: land degradation, land use, soil erosion, tropical Andes, Venezuela

Introduction

Soil erosion problems have been associated with the very particular and dynamic conditions of socio-economic development in Venezuela (Pla, 1990). In particular, the Andean region is considered as a zone of high fragility due to its topographic conditions with steep slopes and unstable geological substrates that are affected by the perturbing effect of agricultural activities. Studies on soil erosion in this region are scarce, especially those that relate soil loss to land use (Lizaso, 1980; Cagua, 1989; Montesdeoca, 1989; Altuve and Dávila, 1990; López, 1994; Villegas *et al.*, 1994; Ataroff and Monasterio, 1997; Rymshaw *et al.*, 1997; Pérez and López, 2000).

In the rural areas of Venezuela, land degradation is reflected in a decline of land productivity which has as cyclical causes and effects: a depletion of the plant cover, soil exposure to erosion, reduction of soil organic matter and nutrient content, and the deterioration of soil structure (Casanova *et al.*, 1989; López, 2000). Recently, this problem has been aggravated by large-scale deforestation, slash-and-burn agriculture, overgrazing and over-cultivation. In Táchira State, the conversion of forest into grasslands and agricultural lands has occurred intensively since the 1950s. In the El Valle River basin, the original forest vegetation has been reduced to 65 percent between 1952 and 1998 (Rebolledo, unpublished data).

In lands used to grow annual crops, tillage operations are performed using a plough pulled by oxen, mainly due to the difficulties represented by land steepness and soil stoniness, which are common in the region. Even with the application of this less disturbing practice, soil erosion occurs at

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significantly high rates. In this context, the objective of this study was to evaluate soil loss by water erosion on hillsides with steep slopes under some of the most common land uses in the Venezuelan Andean zone. Thus, soil erosion under cultivated vegetation (horticultural crop rotation, pasture, and apple plantation) was studied and this was compared with soil erosion under natural vegetation (evergreen dry forest). The behavior of (a) rain pattern, (b) runoff, (c) soil erodibility, (d) agricultural activities calendar, and (e) soil conservation practices were also taken into account.

Study area

The study area is located at an altitude of 2250 m.a.s.l. in the El Valle River basin, whose most important town is El Cobre, Táchira State, in the Venezuelan Andes. This is an intramountain valley with a large altitudinal range from 1100 to 3400 m.a.s.l., located between 7°57′ and 8°05′ of North latitude and 72°00′ and 72°05′ of West longitude. El Valle River is an affluent of the La Grita River, which flows into Lake Maracaibo, located in the northwest of Venezuela.

The rainfall pattern is bimodal with two peaks: one from April to May and the second from October to November. The mean annual rainfall is 985 mm (1991–1995) and the mean annual temperature is 15.5°C (minimal mean 12°C and maximum mean 18°C, Ortiz, 1992). According to the soil survey undertaken by MANRN (1995), soils belong to an association of typic palehumults and typic humitropepts (Soil Survey Staff, 1990), which respectively correspond to typic palehumults and humic dystrudepts (Soil Survey Staff, 1998).

Experiments were conducted in four different environments: natural forest, horticultural crops in rotation (arracacha-carrot-potato), pastures, and apple trees grown on bench terraces; the first three were located in the farm "El Paraiso" and the last one in the farm "Mesa del Palmar." The principal characteristics of the four environments studied are as follows:

(1) Natural forest: the natural vegetation in this study area is an evergreen dry forest, adjacent to the rain forest (Sarmiento *et al.*, 1971). The more important species are *Roupala* aff. *pseudocordata, Escalonia floribunda, Psidium caudatum, Psidium guianense* and *Rapanea ferruginea*. The forest under study is located on steep lands (slope up to 89 percent).

(2) Horticultural crops in rotation: from May 1994 until April 1996, three horticultural crops grown on a hillside with slopes of up to 76 percent were studied. At the beginning of the research, the first crop studied was arracacha (*Arracacia xanthorrhiza* Bancr.), which had been planted in November 1993. During the crop cycle, weeds were removed with a hoe in September 1994 and the soil was loosened in October 1994. The arracacha was partially harvested in January 1995 and harvested totally in April 1995. Subsequently, carrot (*Daucus carota* L.) was sown in May 1995, fertilized in July and harvested in August. In September 1995, the soil was ploughed three times by an oxen pulled plough. Potato (*Solanum tuberosum* L.) was planted and fertilized in October 1995. The crop was tilled and fertilized in November 1995, and herbicide was applied in December 1995. A pesticide was applied in January 1996, and another application of herbicide was made in February 1996. Finally, the crop was harvested in April 1996. Soil erosion was studied throughout all of these stages. Experiments with horticultural crops in rotation were carried out in the farm "El Paraiso," where a conventional tillage system has been applied since 1980. This tillage system utilizes a plough pulled by oxen, harrows, and mechanical equipment to cultivate the soil before the sowing (Vega *et al.*, 1992). The general crop rotation system includes successive crops of potato, cabbage, carrot and arracacha. Sprinkler irrigation was used to provide water to the horticultural crops. Previously, between 1940 and 1980, the farmlands laid in fallow until a legal succession problem was solved.

(3) Pasture: it corresponds to lands with slopes up to 52 percent, covered by kikuyo grass (*Pennisetum clandestinum* Hochst. ex Chiov.), which at times was grazed by livestock. During the two years period of this study, cattle grazed on the plot just once, in October 1994.

(4) Apple trees cultivated on bench terraces: the apple trees (*Malus sylvestris* Miller) were planted in 1992 on bench terraces that are 3.5 m wide with an internal slope of 5 percent (outward direction). There was a distance of 2 m between trees. The grass *Phalaris tuberosum* L. was used as a hedgerow on the free edge of the terraces. A sprinkler irrigation system provided water to the trees.

Materials and methods

In February 1994, three replicated erosion plots were established in each of the four described environments. In the experiments with natural forest, horticultural crops in rotation and pasture, plots had dimensions of 3 m × 6 m (Fig. 1). In the apple tree experiment, the plots were 3 m × 3.5 m on the existing bench terraces, and the runoff was collected in the outward direction (same direction of the slope). The results for the first three months of the study were rejected to avoid the effects of the changes resulting from construction of the plots. Weekly, during the first eight months and every fifteen days during the remaining time, the volume of runoff, the amount (dry weight) of the mineral fraction of soil trapped in collector channels and the sediment traps were measured.

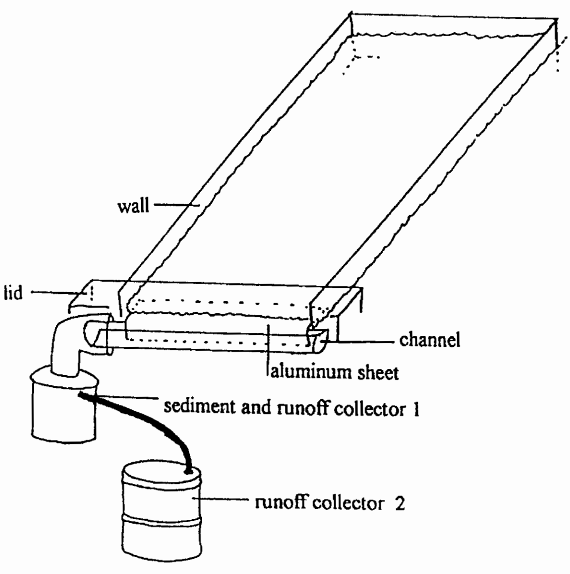

Figure 1. Diagram of erosion plot used in the research.

The mineral fraction was separated into coarse and fine materials, which corresponded to particle sizes greater and smaller than 4 mm, respectively.

Total rainfall was measured with a rain gauge (LICOR 1000-20). The effective rainfall was measured with ten throughfall collectors distributed at random in each of the studied environments. The throughfall collectors located in the forest, horticultural crop, and apple tree plots consisted of a plastic container (PVC) with a capacity of 3.5 l, to which was attached a funnel with a capturing area of 0.00893 m^2. In the pasture, the throughfall collectors were of the channel type, with the same capturing area.

Because direct evaluation of soil erodibility under field conditions requires extended time, high costs and human resources, it normally is determined indirectly through the knowledge of some other erodibility associated soil characteristics (Truman and Bradford, 1995). Based on this, topsoil texture, bulk density (Pla, 1977), organic matter content (Olarte *et al.*, 1979), and the water stability of soil aggregates (Mazurak, 1950; USDA, 1970) were determined. Because the soil erodibility factor (K) of the Universal Soil Loss Equation (Wischmeier and Smith, 1978) is widely used as an erodibility estimator, it was calculated as proposed by Kirkby and Morgan (1984) and based on the relation between erodibility, textural class and organic matter content of topsoil. A monitoring of the management practices applied in each environment was also accomplished.

All soil mineral fractions and runoff data presented in the results are the mean value of three plots, and they are plotted with the standard error. A correlation analysis was used to fit rainfall and runoff variability to soil mineral fraction loss. Comparison between the erosion of the four environments was analyzed by a two-way ANOVA, and differences between pairs of means were tested by the Turkey-Kramer method. Differences in erosion with and without human activities were analyzed by a two-way ANOVA.

Results and discussion

Soil erodibility

Topsoil textural characteristics and organic matter content (first 0.15 m) of each studied environment

Table 1. Textural and chemical characteristics of the topsoil (0–15 cm) of each studied environment, El Cobre, Táchira State, Venezuela

	Soil characteristics					
	(g/kg)					
Vegetation covers	Sand	Silt	Clay	Textural class	Organic matter (g/kg)	K factor* value
Natural forest	680	290	30	Sandy loam	73	0.030
Horticultural crops	430	400	170	Loam	36	0.045
Pasture	630	320	50	Sandy loam	40	0.032
Apple plant.	590	260	150	Sandy loam	40	0.038

* $Mg\ ha^{-1}/Mj\ ha^{-1}\ mm\ h^{-1}$.

are summarized in Table 1. In general, all textural classes are loam, but soils under forest and pastures have a lower clay content, which according to Levy *et al.* (1997) would mean a greater susceptibility to soil erosion. However, since soil structural stability increases as the organic matter content increases (Tisdall and Oades, 1982, cited by Auerswald, 1995) in forest soils, the greater amounts of organic matter would compensate for lower clay contents.

The K factor values (Table 1) indicate that soil under horticultural crops has a greater susceptibility to be eroded. Additionally, the knowledge of the infiltration rate and structural stability permits a better estimate of the soil erodibility (Paez and Pla, 1989). Table 2 summarizes characteristics related to these two factors for the topsoil of the different environments studied.

Bulk density for the pasture and forest soils yielded low values (Table 2) related to their textural classes (Brady and Weil, 2001) such facts could be explained by the high amounts of organic matter present in the forest soil and the high density of superficial roots of the pasture. Taking into account the percentage of water stable soil aggregates, the horticultural crops in rotation provided the environment whose soil had a greater susceptibility to be eroded, because it had a higher percentage of small aggregates and a low geometric mean of aggregates that are stable in water (Table 2). On the contrary, the forest soil had the greatest structural stability. Considering this set of characteristics, soil of the horticultural crop plots was more susceptible to erosion than that of the pasture plots and the apple tree plots on bench terraces, while that of the forest plots

Table 2. Bulk density (BD) and soil structural stability (SS) in topsoil (0–15 cm) of studied environments, El Cobre, Táchira State, Venezuela

		Aggregate diameter range (mm)						
		Aggregation (%)						
Vegetation covers	BD ($Mg\ m^{-3}$)	0.25–0.5	0.5–1	1–2	2–3	3–4	4–6.3	Geometric mean (mm)
Natural forest	1.03	3.7	6.7	6.6	10.1	9.5	63.4	1.4
Horticultural crops	1.79	8.5	10.6	8.9	4.3	15.2	52.6	0.7
Pasture	1.12	3.2	5.4	8.0	10.5	8.3	64.6	1.1
Apple plant	1.68	0.9	1.3	4.2	7.7	6.6	79.3	1.2

Observation: a criteria for the evaluation of structural degradation is the percent of water stable aggregates minor to 0.5 mm in diameter, according to the following scale (Malagón, 1976): More than 50% of aggregates with a diameter less than 0.5 mm = Very high degradation; Between 40–50% of aggregates with a diameter less than 0.5 mm = High degradation; Between 20–40% of aggregates with a diameter less than 0.5 mm = Medium degradation; Between 10–20% of aggregates with a diameter less than 0.5 mm = Low degradation; Less than 10% of aggregates with a diameter less than 0.5 mm = Very low degradation.

seems to posses conditions most favorable to suppressing erosion.

Rainfall and runoff

Total rainfall during the study period was 1217 and 1100 mm for the first and second year, respectively (Table 3). However, the horticultural and apple tree plots were irrigated. The amount applied was equivalent to 36 to 47 percent of total rainfall in the horticultural crop plots and 18 to 28 percent in apple tree plots (Table 3, Fig. 2).

Different characteristics of vegetative cover in each environment explains the observed differences in throughfall. Thus, the horticultural crops resulted in the lowest rain interception (17 percent), while the natural forest resulted in the highest interception (27 percent). Interception in the pasture and apple tree plots averaged 20 and 19 percent, respectively (Ataroff and Sánchez, 2000). Runoff water, usually associated with soil erosion, was highest from the horticultural crop plots, followed by that from the natural forest

Table 3. Precipitation (pp), irrigation (irrig.), through fall (Th) and runoff (rf) on studied vegetation systems, El Cobre, Táchira State, Venezuela

Vegetation covers	Periods	pp	*Irrig.*	Th	rf
Natural forest	May 1994–April 1995	1217	0	847	22
	May 1995–April 1996	1100	0	840	29
Horticultural crops	May 1994–April 1995	1217	437	1408	34
	May 1995–April 1996	1100	512	1292	41
Pasture	May 1994–April 1995	1217	0	1022	23
	May 1995–April 1996	1100	0	870	11
Apple plant.	May 1994–April 1995	1217	337	1187	23
	May 1995–April 1996	1100	201	1125	15

Note. All values in mm.

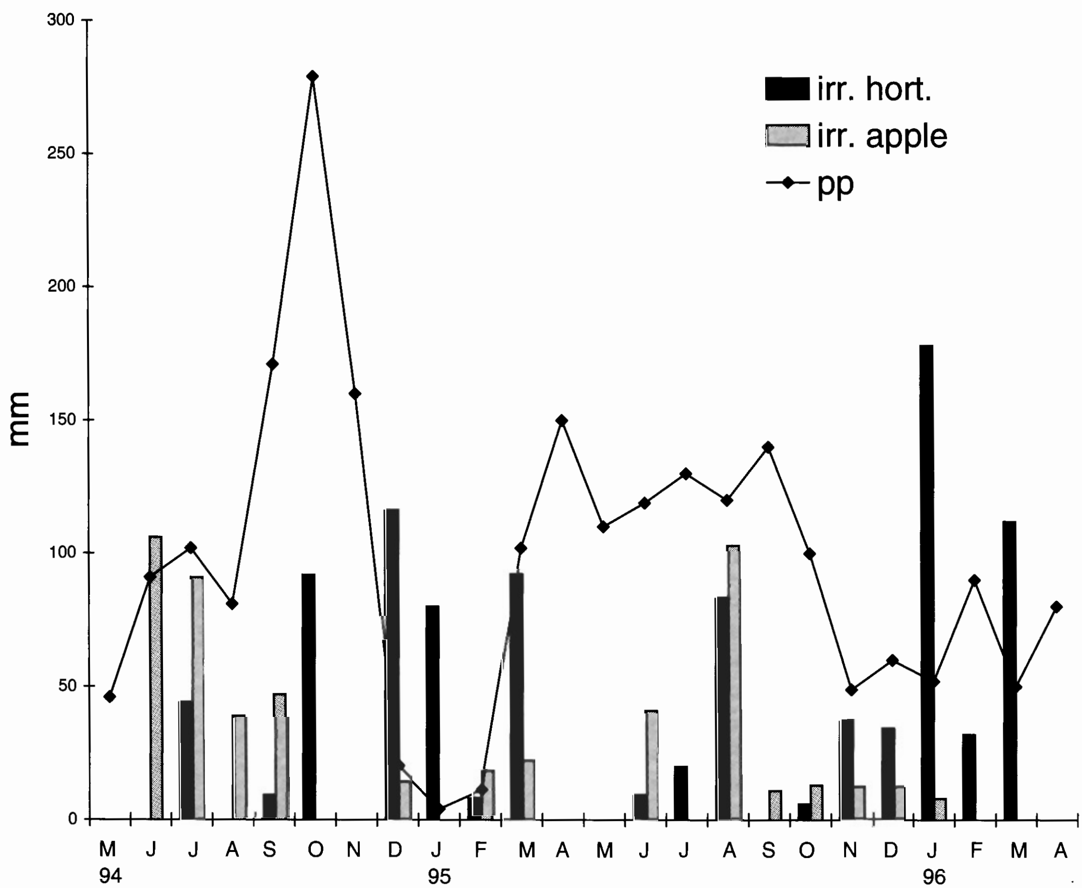

Figure 2. Rainfall (pp) and irrigation in horticultural crops (irr. hort.) and apple trees (irr. apple) plots.

and apple tree plots. Runoff was lowest from the pasture plots Table 3 (Ataroff and Sánchez, 2000).

Soil losses

The erosion measured on the four vegetation systems showed significant differences (ANOVA, $F = 17.28$, $P < 0.01$). The evergreen dry forest and pastureland presented the lowest soil erosion losses, and the differences between them were not significant (Turkey-Kramer method, $P < 0.05$). Erosion measured in horticultural crop plots and apple tree plots showed significant differences when individual comparisons between such systems and the natural forest and pasture land were established (Turkey-Kramer method, $P < 0.05$). A description of the results obtained for each one of the systems evaluated regarding erosion losses is presented as follows.

Natural forest. Losses of fine and total soil particles were lowest from the natural forest plots, with an average of 0.43 Mg ha^{-1} year^{-1} for the two years (Table 4). This low loss rate agrees with the lower soil erodibility as well as with the denser vegetative cover and the leaf-litter characteristics of the forest. Losses of the fine particles were slightly higher than those of the coarse particles (Table 4). In general, monthly soil losses decreased throughout the study period (Fig. 3), except for the high losses in July and August 1995. However, between May and July of the first year, the values were higher than those of other months with equivalent rainfall (Fig. 2), meaning that stabilization had not been reached after six months. The higher soil losses in September and October of the first year and July and August of the second coincided with the highest amounts of rainfall and runoff. The correlation, however, between these two factors and soil loss was low ($R^2 = 0.36$ and 0.41, respectively for the total fraction, and $R^2 = 0.49$ and 0.0057 for the fine fraction).

The forest soil was the least susceptible to erosion. It had the highest structural stability, the highest basic infiltration rate, and the lowest bulk density.

Horticultural crops. Horticultural crops in rotation plots resulted in the highest rate of soil loss, with 7.91 Mg ha^{-1} for the first year under the arracacha crop and 22.48 Mg ha^{-1} for the second year under two successive crop cycles: first carrot (4.39 Mg ha^{-1}) and then potato (18.08 Mg ha^{-1}) (Table 4). Losses of coarse and fine soil fractions were similar for the plot under arracacha crop (51 percent fine and 49 percent coarse), but losses were slightly higher for the fine fraction for carrot (53 percent fine and 47 percent coarse), and higher for soil fine fraction under the potato crop (62 percent fine and 38 percent coarse) (Table 4).

Monthly soil loss shows that the higher amounts are associated with cultural operations (Fig. 3).

Table 4. Losses of mineral fraction (M.F.) in all of the environments, El Cobre, Táchira State, Venezuela

Vegetation covers	Periods	M.F. fine <4 mm	M.F. coarse >4 mm	M.F. total
Natural forest	May 1994–April 1995	0.31	0.23	0.54
	May 1995–April 1996	0.20	0.09	0.29
Horticultural crops	May 1994–April 1995	4.07	3.84	7.91
	May 1995–April 1996	13.44	9.04	22.48
	May 1995–Aug. 1995	2.32*	2.08*	4.4*
	Sept. 1995–April 1996	11.12*	6.96*	18.08*
Pasture	May 1994–April 1995	1.03	0.09	1.12
	May 1995–April 1996	0.14	0.03	0.17
Apple tree	May 1994–April 1995	1.16	0.80	1.96
	May 1995–April 1996	0.63	0.47	1.10

Note. Values in Mg ha^{-1} year^{-1}; except *Mg ha^{-1} period^{-1}.

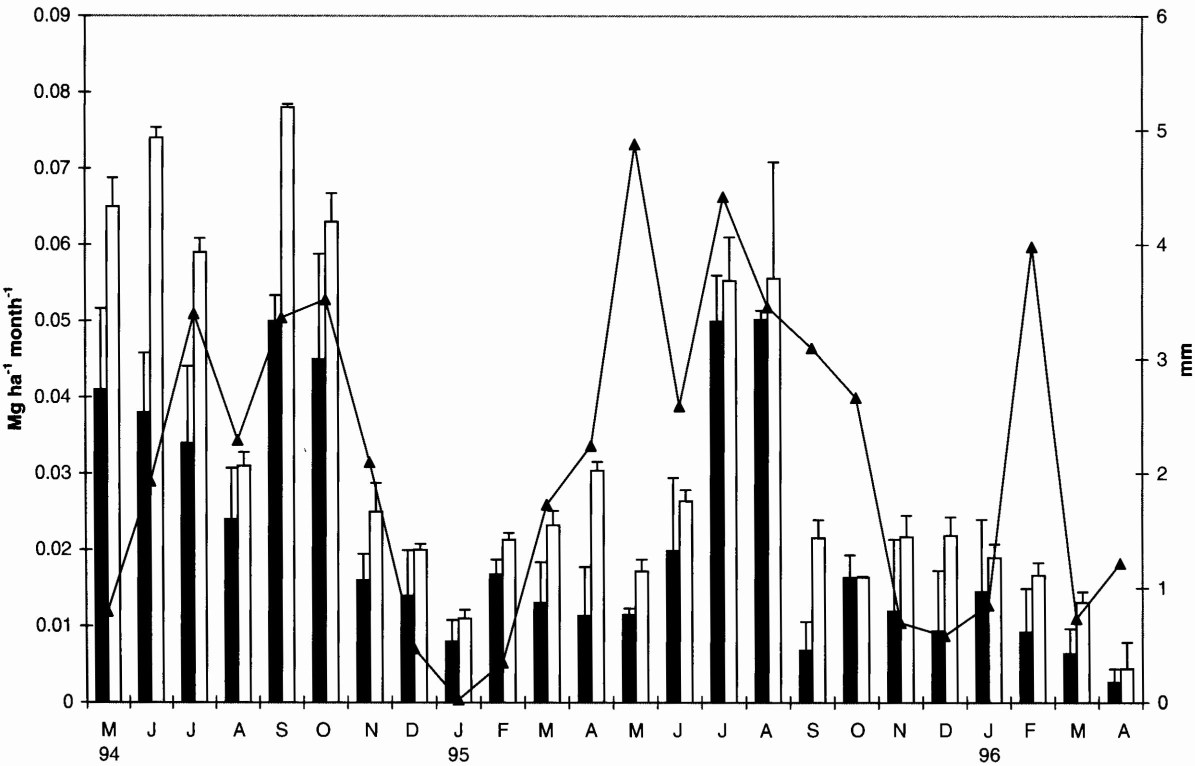

Figure 3. Erosion and runoff in Evergreen Dry Forest plots. Fine mineral fraction (<4 mm): black bars; total mineral fraction: white bars; runoff: continuous line. Standard error is shown for each data.

Differences in erosion with and without human activities were significant (ANOVA $F = 12.28$, $P < 0.01$). The importance of the agricultural activities on soil erosion has been referred to for other agricultural environments in the Venezuelan Andes (Ataroff and Monasterio, 1997). On the other hand, the relation between the losses of the soil mineral fraction due to rainfall and runoff did not show a meaningful correlation ($R^2 = 0.15$ and 0.062, respectively). In months with low rainfall, the crops were irrigated but this activity did not increase erosion (Table 5), probably because of a lower kinetic energy of the drops as compared with that of raindrops. The mean monthly erosion, when there is no human activity in the plots, was 0.16 Mg ha^{-1} month^{-1}, which is low, but not as low as in the natural forest, with a soil loss of 0.035 Mg ha^{-1} month^{-1} (Table 5).

The frequency of cultural operations was different for the three crops (Fig. 4). The arracacha crop only required four operations on the plots before harvest, and then a final plough of the soil for the following crops. The carrot crop, in its four months cycle, required three operations. The potato crop lasted eight months, considering the time from the previous tillage for planting to harvest. During this period, seven operations were necessary. Total soil losses of the different crops were: arracacha, 7.91 Mg ha^{-1} year^{-1}; carrot,

Table 5. Mean monthly values of mineral fraction losses under different management conditions, El Cobre, Táchira State, Venezuela

Management condition	Soil loss (Mg ha^{-1} month^{-1})			
	Natural forest	Horticultural crops	Pasture	Apple plant.
Without disturbance	0.035	0.16	0.025	0.10
Disturbed	—	1.26	2.80	0.12
Without irrigation	—	1.98	—	0.24
Irrigated	—	0.84	—	0.13

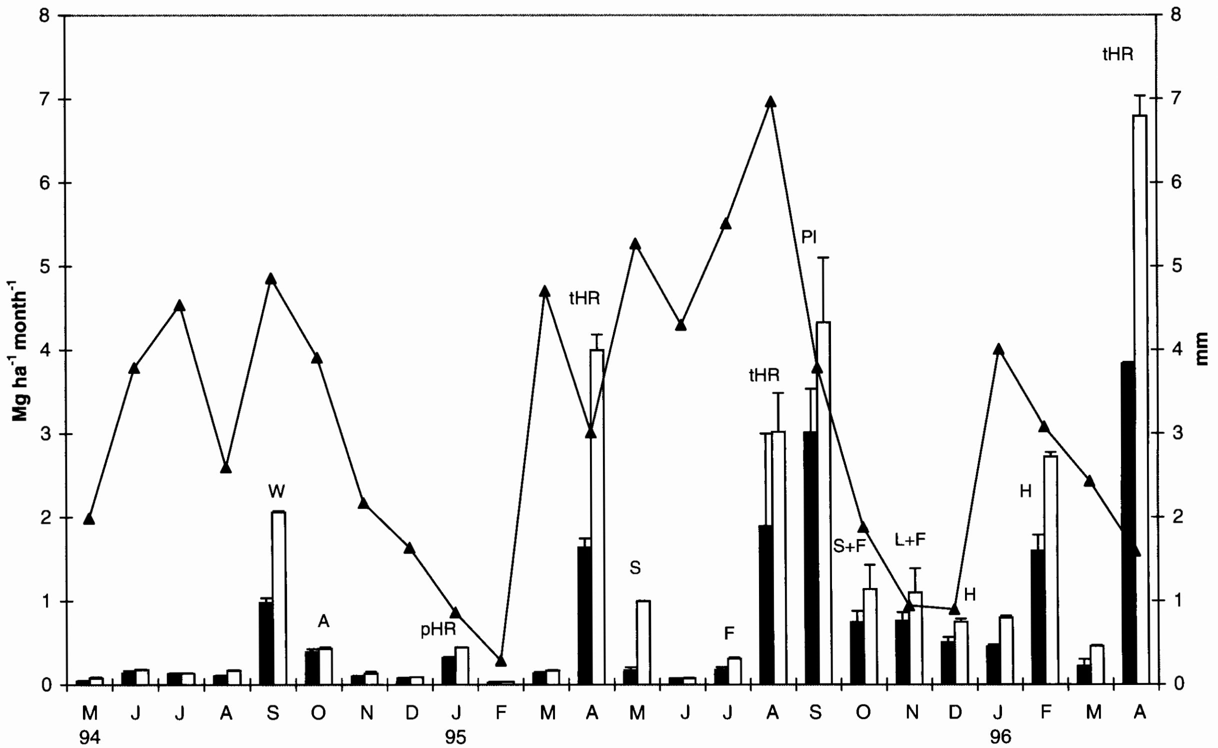

Figure 4. Erosion and runoff in horticultural crops plots. Fine mineral fraction (<4 mm): white bars; total mineral fraction: black bars; runoff: continuous line. Standard error is shown for each data. W: weeding; A: aeration; pHR: partial harvest; tHR: total harvest; S: sowing; F: fertilization; L: hilling; Pl: plowing; H: herbicide application.

4.39 Mg ha^{-1} in four months; and potato (including the previous tillage period), 18.08 Mg ha^{-1} in eight months. Comparing the monthly soil losses, arracacha resulted in less erosion than the other crops (0.66 Mg ha^{-1} month^{-1}). The carrot crop (1.1 Mg ha^{-1} month^{-1}) resulted in twice the loss per month as compared with arracacha crop. Soil loss under the potato crop (2.3 Mg ha^{-1} month^{-1}) was doubled in relation to that with carrot and 3.4 times as much as with arracacha.

Soil under horticultural crops had the least favorable characteristics with regard to erodibility, since it had low structural stability, high K factor values, low organic matter content, and high bulk density values. These conditions probably were due to tillage and the management practices applied to this soil.

Apple trees on bench terraces. Soil loss from plots with apple trees on bench terraces was much less than from plots with horticultural crops. The average rate for the two years was 1.47 Mg ha^{-1} year^{-1}. Soil loss was different for each of the two years studied, being 1.96 Mg ha^{-1} in the first year and 0.98 Mg ha^{-1} in the second year. During the two years, fine fraction loss was greater than coarse fraction loss (Table 4). Soil loss was not correlated either with total rainfall or with runoff (R^2 = 0.046 and 0.49, respectively). In this case, three of the five principal peaks of soil loss were directly related to the cultural operations performed on the plots (Fig. 5). The other two peaks, in September and October of the first year, did not coincide with operations, but weed removal during the previous months left the soil unprotected before the period of greatest rainfall. Average monthly erosion, when there was no human intervention, was 0.10 Mg ha^{-1} month^{-1}, which was lower than that from the horticultural crop but higher than the one from natural forest plots (Table 5).

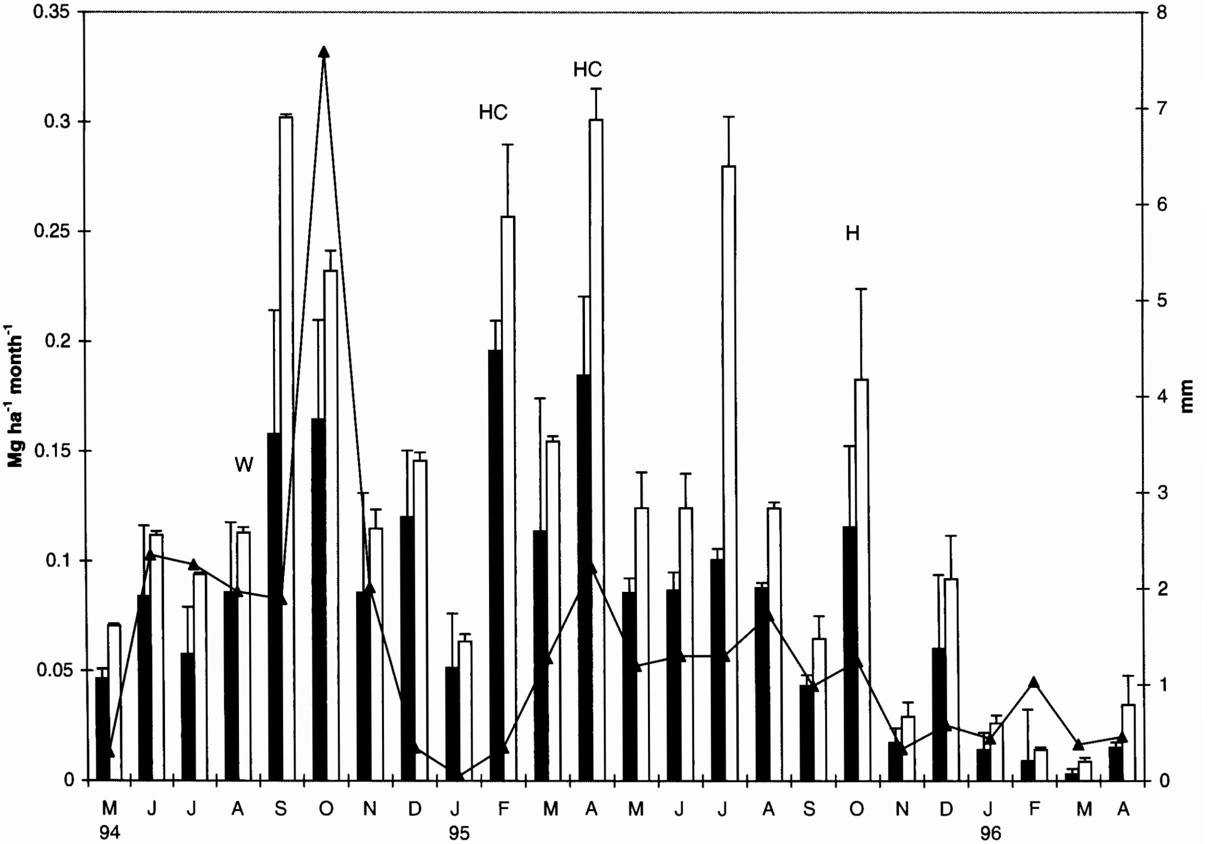

Figure 5. Erosion and runoff in apple tree plots. Fine mineral fraction (<4 mm): black bars; total mineral fraction: white bars; runoff: continuous line. Standard error is shown for each data. W: weeding; HC: hedgerows cutting; H: herbicide.

For the apple tree plots, the infiltration rate was equivalent to the one that occurred under the natural forest; however, the bulk density was much higher. Concerning the soil structural stability the geometric average size of stable aggregates was high and had the lowest proportion of aggregates smaller than 5 mm (Table 2). The monthly soil loss average under this crop (0.12 Mg ha^{-1}) is similar to that found by Fernandez (1994) for a peach crop (0.11 Mg ha^{-1} $month^{-1}$) in the "Bajo Seco" Experimental Station in the Cordillera de La Costa, in northern Venezuela.

Pasture. Soil loss from pasture plots was very low during the period when cattle were not grazing. It was 0.37 Mg ha^{-1} during the first year and 0.18 Mg ha^{-1} during the second year; which was even less than that under natural forest. Grazing by the cattle in the pasture plot, during less than a week, resulted in a soil loss of 0.7 Mg $ha^{-1}\cdot$ $week^{-1}$ (Fig. 6). Soil loss for the fine fraction was much higher than for the coarse fraction, even with cattle grazing (Table 5), probably as a consequence of the characteristic dense vegetative cover and roots of the pasture, which prevent movement of the coarse fraction. From these results, it is important to emphasize, on one hand, the high degree of retention exerted by the kikuyo grass. The impact of the cattle grazing on pasture generated an amount of soil loss equivalent to 33.6 Mg ha^{-1} $year^{-1}$ (Table 5). This is related to the pressure exerted by the cattle on the soil, which is equivalent to 9 kg cm^{-2} (Anaya, 1986).

Salm (1995), in the valley of Tarija in the Bolivian Andes, also measured low soil losses (0.64 Mg ha^{-1} $year^{-1}$) in protected pastures with no cattle grazing. In this study, the monthly soil

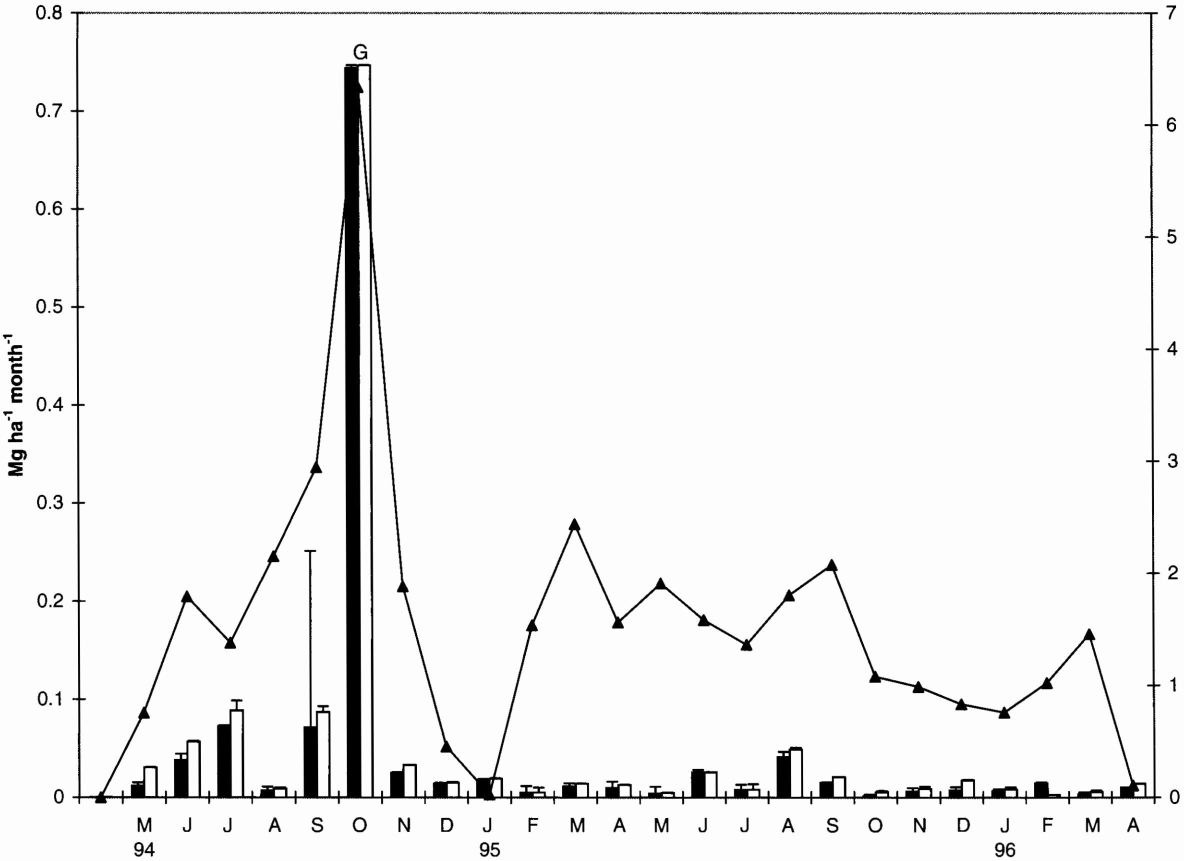

Figure 6. Erosion and runoff in pasture plots. Fine mineral fraction (<4 mm): black bars; total mineral fraction: white bars; runoff: continuous line. Standard error is shown for each data. G: grazing.

losses, when there is no cattle grazing effect, were 0.03 Mg ha^{-1} month^{-1}, much less than from plots with crops and similar to plots in natural forest (Table 5). This can be related to the characteristics of the grass (coverage and root density). Without cattle grazing, the correlation between total rainfall and runoff with the fine fraction loss was $R^2 = 0.74$ and 0.78, respectively. The important role of roots for the retention of surface water in this system is clear. The results suggest that intense and continuous grazing by cattle is unsustainable. Pasture rotation for grazing has been recommended in other locations for similar reasons related to management problems (Perea *et al.*, 1991). For soils under pastures (*Brachiaria decumbens* and *Homolepis atuluensis*) with cattle grazing in Caquetá, Colombia, Pinzón (1991) found higher bulk density values and lower infiltration rates than those of soils of a neighboring forest.

Conclusions

The results of this research can be summarized as follows:

- — The erosion measured on the four vegetation systems shows significant differences, being the lowest soil loss rate associated to the natural forest, with an average value of 0.43 Mg ha^{-1} year^{-1}.
- — Agricultural operations and cattle grazing have a direct and determinant effect on soil losses, increasing them.
- — The highest soil loss occurred with horticultural crops in rotation, with an average value

close to 15 Mg ha^{-1} $year^{-1}$. Such a loss was more than 10 times higher than those in the other systems. Erosion under the potato crop was twice the erosion under carrot, and this was twice the erosion under arracacha (comparing mean values per month).

— For apple trees on bench terraces, the average soil loss was 1.47 Mg ha^{-1} $year^{-1}$, a relatively low value for a cultivated field with conservation practices.
— Soil loss from pasture plots was very low (close to that from the natural forest) when the plots did not support livestock, but with cattle grazing soil losses were greater than those with the other environments.
— The eroded material from all environments always contained higher amounts of fine mineral fraction than coarse, which would have important effects on soil productivity.
— In general, soil erodibility properties such as bulk density, aggregate stability, and K factor were correlated with soil water erosion; but no correlation was found with throughfall and runoff.

Land use and the type of management applied to each site explain, to a large extent, the occurrence of the erosion processes. Nevertheless, there are socio-economic factors out of the scope of this research, such as population and agricultural land distribution in the valley, capital abundance, price stability of the agricultural products, level of education of the farmers, among others, that have a profound influence on the magnitude and generalization of the occurrence of soil erosion processes on the lands of the watershed of the El Valle river.

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