WATER EROSION RATES AND MECHANISMS IN ANDOSOLS AND VOLCANIC ARIDISOLS IN TWO CONTRASTING BIOCLIMATIC REGIONS (CANARY ISLANDS, SPAIN)

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Abstract

This paper shows the results of water erosion rate monitoring in Andosols and Aridisols in two contrasted bioclimatic regions on Tenerife Island. Erosion mechanisms are different in both soil types and climatic zones, being basically related to rainfall dynamics and to the structural characteristics of the soil surface. This has important consequences for the design of erosion control strategies and the management of water resources in both areas.

Additional Keywords: erosion plots, Fulvudands, Petrocalcids, runoff

Introduction

Approximately 42% of the surface area of Tenerife Island (853 km^2) is severely affected by accelerated water erosion processes with soil losses in excess of 12 t ha^{-1} $year^{-1}$, equivalent to a thickness of 1-1.5 mm of soil per year (Rodríguez, 2001, Rodríguez *et al*., 1998).

There are two clearly differentiated bioclimatic regions on this island, one windward in the North under the influence of the trade winds and another leeward in the South that receives sporadic torrential rains with occasional southern storms.

In the rainiest northern zone, the soils are andic and there is a relatively high plant density so erosion is constant and associated with changes in land use associated with deforestation. In the more arid southern zone, soils are predominantly saline and carbonated aridisols, with a sparse plant cover where erosive processes occur sporadically as a result of intense southern rains and are also associated with changes in land use but in this case resulting from occupation of the land by urban constructions and a variety of infrastructures associated with tourist activity, which in many cases obstruct natural drainage channels for runoff.

This paper describes the results of a nine year study of erosion processes of both situations in conventional experimental plots.

Material and Methods

Northern Zone.

The study area at an altitude of 1000 m a.s.l. is characterized by a subhumid mesophytic thermomediterranean bioclimate (Rivas Martínez *et al*., 1993), with a potential vegetation corresponding to laurel forests (*Lauro azoricae-Perseeto indicae S.*), although most of the original woodland has been deforested and replaced by *Pinus radiata D. Don* plantations. The soils in this area have developed over a complex geological material of Pleistocene basaltic outflows and successive ash deposits of the same composition and variable granulometry, that can be classified as allophonic Andosols or fulvic silicaceous Andosols (WRB, 1998) (*Ultic fulvudands*, Soil Survey Staff, 1999).

The study was carried out in three erosion plots set up in 1993, with a surface area of 200 m^2 (25 x 8 m), each one equipped with pluviograph and rainwater collectors furnished with capacitor probes and ultrasound devices to quantify runoff.

The erodibility of the soil calculated by the method of Wischmeier *et al*., 1971 is very low and values of K = 0.21 ±0.04 $tyearMJ^{-1}mm^{-1}$ were obtained for the plot soils. In the first plot, the soil was kept bare by manually removing plant cover, the vegetation of the second plot is characterized by Pinus radiata with a density of 65% and the third is colonized by the substitution vegetation that establishes when the pine plantations are cleared (*Rubio-periclymeni-Rubetum*), that has a density of 100% (Rodríguez *et al*., 2002a).

Southern zone

On this slope, the study zone can be found around 200 m a.s.l. and is characterized by an arid desertic inframediterranean type bioclimate (Rivas Martínez *et al.*,1993), with a potential vegetation that corresponds to the climax vegetation of sweet tabaiba scrub (*Ceropegio fuscae-Euphorbieto balsamiferae S.*), although at present since all these areas were cultivated until the beginning of the XX century they are colonized by a substitution undergrowth that corresponds to a steppe vegetation of herbaceous ruderal plant communities. The soils of these zones have developed over pleistocenic basaltic alterations and heterogeneous colluvia produced by erosion of soils in higher areas and are classified as *Petric Calcisols* (WRB, 1998) or *Standard petrocalcids* (Soil Survey Staff, 1999). The soils of the plots are slightly saline (EC_{es} = 2.7 dSm^{-1}) and the erodibility index (Wischmeier et al., 1971) is around 0.62± 0.08 $tyearMJ^{-1}mm^{-1}$.

The study was carried out using two erosion plots of similar characteristics and equipment to those established in the northern zone. One of the plots was cleared manually of vegetation and the other is colonized by annual steppe vegetation.

Results and Discussion

Table 1 shows the annual and global results for the whole study period of the evaluation of the water cycle and erosion.

In the northern zone, the mean annual rainfall was 625 mm (Figure 1), although there was a high interannual variability (Table 1), with the rains mainly concentrated in February-March and October-November. Although high intensity rains can occur (up to 240 mmh^{-1}), the maximum intensity of the rains in this zone ranges from 30 to 80 mmh^{-1}, with a high homogeneity in the mean intensity of rainfall (7-15 mmh^{-1}).

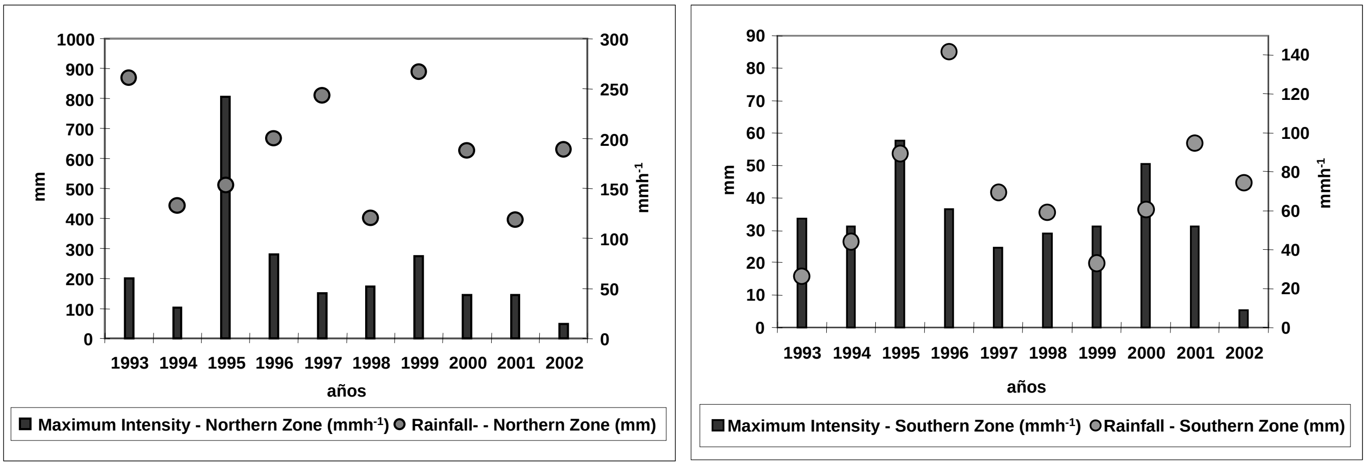

Figure 1. Annual distribution and maximum intensity of rainfall

However, in the southern zone, the mean interannual rainfall does not reach 100 mm (69 mm) (Figure 2), it has a low interannual variability and is concentrated in rain events very localized in time and space, in the months from October to April when southwesterly storms are most common. The maximum intensity of the rains in these conditions is low when the interannual mean is estimated. However, it must be taken into account that in this type of rainfall regime, with sporadic rain events that occur with the arrival of stormy fronts but that usually leave an important amount of rain with a strong hourly intensity, mean values do not accurately reflect the erosive potential since, sometimes, all the annual precipitation occurs in only one localized event.

With these very different rain conditions in the two zones, the production of sediments and the generation of runoff is also very different, and must also take into account the different characteristics of the soils.

In the Andosols, the percentages of runoff oscillate between 2% and 30% of the precipitation on bare soil, indicating a high infiltration capacity on the surface horizons of these soils that increases when there is plant cover. In this case, the percentages of runoff do not exceed 0.6% of the total rainfall, regardless of the amount and intensity of the rain. Consequently, erosion rates also present a high interannual variability (Table 1), with a mean soil loss in the cleared plot of 9.0 tha^{-1}year^{-1}, while soil loss is practically nil in the plots with vegetation.

Table 1 . Annual and global assessment of rainfall and erosion

Years	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Media**
Northern zone											
Rainfall											
P (mm)	870	443	511	667	811	403	889	627	396	631	625
Imax(mmh^{-1})	60	31	242	84	45	52	82	43	43	14	242
R (Mjha^{-1}mmh^{-1})	828	398	342	497	959	435	1220	886	218	383	617
Sediments yields (tha^{-1}año^{-1})											
Bare soil	28.9	8.7	5.6	17.4	14.9	3.0	9.5	0.8	0.4	0.4	9.0
Natural vegetation	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reforested pine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Runoff (mm)											
Bare soil	94.4	80.9	156.3	155.9	105.6	77.4	70.4	5.5	5.0	3.3	75.4
Natural vegetation	5.5	1.3	0.7	2.3	1.4	0.8	1.2	0.6	0.4	0.6	1.5
Reforested pine	3.2	0.7	0.7	1.5	1.3	0.5	1.8	0.9	0.8	1.2	1.3
Southern zone											
Rainfall											
P (mm)	26.2	43.8	89.4	141.5	69.5	59.1	33.0	60.7	94.6	74.4	69
Imax(mmh^{-1})	33.6	31.2	57.6	36.6	24.7	28.8	31.2	50.4	31.2	5.4	58
R(Mjha^{-1}mmh^{-1})	-	-	6.5	9.5	12.6	14.8	20.5	123.9	69.6	31.6	29
Sediments yields (tha^{-1}año^{-1})											
Bare soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.01	0.04
Natural vegetation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.00
Runoff (mm)											
Bare soil	0.14	0.11	2.6	4.5	3.3	0.14	0.80	1.6	0.64	2.9	1.7
Natural vegetation	0.03	0.03	2.6	3.8	3.5	0.71	0.27	1.3	0.27	2.6	1.5

In these conditions, the highest erosion rates are not clearly related with the most intense rains or with the sites of runoff generation. Most sediment and runoff is produced with rains that fall on dry ground. Given the known hydrophobicity of the surface organic horizons of the Andosols, with the dry soil considerable runoff is generated that drags along aggregates from the surface of the bare soil, regardless the rainfall intensity. Afterwards, owing to the slow humectation of the soil, the high infiltration rate and, especially, the high water retention capacity of these soils, very little runoff is generated and is only produced in the case of rain events with a large volume of water (regardless of their intensity) which then drag along with them, by laminar flow, the humectated aggregates that have been fragmented by the impact of previous high intensity rain drops (Rodríguez *et al*., 2002b). The proposed hypothesis (Rodríguez *et al*., 2002c) would be that laminar erosion in Andosols takes place by a mechanism that does not cause dispersion of particles before these are mobilized by the flow, but instead the particles are mobilized in the form of small aggregates (<0.5 mm) that are highly stable to dispersion.

In petric Calcisols, the percentages of runoff are always lower than 5% of the total rainfall and almost no sediments are generated in both plots, independently of the amount of rain and the intensity of rain events and are more closely associated with the state of the soil surface and with the previous water content.

If, as we have mentioned, the rain events occur sporadically and erratically in this zone but with a strong intensity, erosion in these conditions would, probably, not be a continuous process as it is in Andosols from the northern zone. This, therefore, occurs in a discontinuous, or sporadic manner, and only has a quantitative importance in some years or in some stormy episodes, when certain conditions of the state and humidity of the soil surface are combined. This type of soil, saline and limey, has a high capacity to form a sealing surface crust of up to 1.5 cm thick, as a result of the weaker rains that usually precede the more intense rain events. The seal generated by these rains, produces a drastic reduction in infiltration at the time of the most intense rains generating an important runoff that circulates in laminar flow over the sealing crust. Since this crust presents mechanical resistance to cutting, there is no disaggregation or separation of solid particles and most of the rain events occurring generate a high runoff but do not produce erosion.

Only occasionally, in the case of several consecutive intense rainy episodes sediments are generated by laminar erosion in the interior of the plots. This occurs because the sealing crust loses stability by humectation resulting in the disaggregation of individual particles that are dragged along by the laminar flow. However, in most of these soils an intense erosive morphology is observed in rills and small gullies that do not correspond to the laminar erosion detected in the plots. In these cases, as the length of the slope increases (lengths much longer than the dimensions of the plot) the laminar flow concentrates in streams as its speed and turbulence increase which move towards open drainage channels already on the slopes or open new rills and furrows, since the stream acquires a cutting strength that can break the surface seal, and after each rain event there is a characteristic gully dynamics.

Conclusions

In Aridisols from the south of the island where, in contrast to the northern forestry Andosols, most erosion is in concentrated flow generated on long slopes, the experimental plots do not seem to be a suitable way to evaluate soil losses by erosion. They can, however, be used to provide information about the dynamics of surface laminar flow and about mechanisms that initiate production of runoff in areas in which water resources mainly correspond to exploiting surface runoff waters. There are, therefore, importance differences in the management model of water resources compared to areas with Andosols, where infiltration processes and replenishing of aquifers must be encouraged since, in these cases, the water always collects underground. Also, the design of measures to control erosion must be different. In the northern areas, biological and agronomical measures are required that maintain a permanent plant cover on the soil, reduce the kinetic energy of the water drops that constitute the main agent responsible for triggering the laminar erosion that predominates in these areas and improve infiltration and replenishment of the aquifers.

In the southern Aridisols, measures to control erosion must be based on mechanical methods that shorten the length of the slope, thus preventing the acceleration and concentration of the flow, the main agent responsible for starting erosive processes in the rills and gullies predominant in these areas and also on channeling and exploiting the surface runoff generated.

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