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Long-term erosional responses of volcanic Aridisols (Canary Islands, Spain): Implications for management of water resources

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Résumé

Dans ce travail se présentent les résultats de douze années de mesure et étude des processus d'erosión dans des parcelles conventionnelles sur aridisoles d'origine volcanique dans un secteur soumis à des changements d'utilisation par une croissance urbaine intense liée à l'activité touristique. Les événements pluvieux se produisent de manière sporadique et erratique, bien qu'avec une forte intensité, de sorte que l'érosion dans ces zones ne soit pas un processus continu. L'érosion hydrique qui commence de manière plus généralisée par le flux concentré produit dans des longues pentes, est attachée à l'erosivitée des pluies et à l'erodibilité des sols, à la basse capacité d'infiltration de ces derniers par sa susceptibilité à sealing superficiel et aux modifications du cycle hydrologique et du réseau naturel de drainage par l'occupation massive du sol par les infrastructures touristiques, résidentielles et de transport. Les mesures de contrôle de l'érosion doivent se diriger à des méthodes mécaniques qui raccourcissent la longueur de les pentes, en évitant l'accélération et la concentration du flux, principal agent du début des processus érosifs dans des rigoles et cárcavas prédominants dans ces zones et l'utilisation des écoulements superficiels concentrés.

Introduction

Water erosion is one of the most important environmental processes of soil loss in arid and semiarid regions characterized by a low average annual rainfall. Occasionally, very high rainfall intensities can occur, causing runoff and erosion on the hillslopes (Schiettecatte *et al.*, 2005). In these zones with low availability of water resources, an adequate management of sediment and runoff yields is necessary, so that they can be used by different means of water harvesting.

Approximately 41% (i.e., 853 km^2) of the surface area of Tenerife Island is severely affected by accelerated water erosion processes with soil losses higher than 12 tm.ha^{-1}year^{-1} (Rodríguez Rodríguez, 2001; Rodríguez Rodríguez *et al*., 1998).

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

In the more arid southern zone, soils are predominantly saline and carbonate-rich aridisols (Petric Calcisols), with a sparse plant cover. Erosive processes occur sporadically as a result of intense southern rains and are associated with changes in land use 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.

Some works have been carried out to characterize the erosion mechanisms associated with defforestation processes in Andosols of the humid, winward area (Rodríguez Rodríguez *et al*., 2002, 2004), but little is known about the erosive mechanisms in the arid volcanic soils

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affected by changes in land use. This work presents the results of twelve years of measuring and studying the erosion processes in conventional experimental plots.

Materials and Methods

On this slope, the study zone is located about 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.*). All these areas were cultivated until the early XX century, so that they are nowadays colonized by substitution communities corresponding to a steppe vegetation of herbaceous ruderal plants. The soils of these zones have developed over weathered pleistocenic basalts and heterogeneous colluvial deposits from higher areas, and are classified as *Petric Calcisols* (WRB, 1998) or *Typic Petrocalcids* (Soil Survey Staff, 1999). The soils of the study zone are slightly saline (EC_{es} = 2.7 dSm^{-1}) and the erodibility index (Wischmeier *et al.*, 1971) is 0.62 ± 0.08 $tm.yearMJ^{-1}mm^{-1}$. The study was carried out in two experimental erosion plots set up in 1993 on this type of soil, 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. One of the plots was cleared manually of vegetation and the other is colonized by annual steppe vegetation.

Results

The mean interannual rainfall is below 100 mm (89 mm) (Table 1), with a low interannual variability, and concentrates in localized events, in time and in space, from October to April when southwesterly storms are most common. The maximum intensity of these rains is low, as compared with the interannual mean value (58 mmh^{-1}). However, it must be taken into account that in this type of rainfall regime, the mean values do not accurately reflect the erosive potential since, sometimes, all the annual precipitation occurs in only one localized event.

Runoff percentages are always lower than 5% of the total rainfall and almost no sediments are generated in both plots (1.0-6.0 $gm^{-2}year^{-1}$), regardless the amount of rainfall and the intensity of rain events, and are more closely associated with the state of the soil surface and with the previous moisture content. Maximum runoff yields usually occur during the fall-winter seasons.

Table 1. **Annual and global assessment of rainfall and erosion**

Years	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Mean
Rainfall													
P (mm)	26.2	43.8	89.4	141.5	69.5	59.1	33.0	60.7	94.6	227.2	55.1	101.1	89.3
Imax (mmh^{-1})	33.6	31.2	57.6	36.6	24.7	28.8	31.2	50.4	31.2	17.0	14.4	16.8	57.6
R ($Mjha^{-1}$ mmh^{-1})	-	-	6.5	9.5	12.6	14.8	20.5	123.9	69.6	218.0	73.7	97.5	62.8
Sediments yields ($tha^{-1}year^{-1}$)													
Bare soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	2.1	0.2	0.06
Natural vegetation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.1	0.5	0.9	0.01
Runoff (mm)													
Bare soil	0.14	0.11	2.6	4.5	3.3	0.14	0.80	1.6	0.64	5.3	0.18	0.65	1.7
Natural vegetation	0.03	0.03	2.6	3.8	3.5	0.71	0.27	1.3	0.27	4.2	0.04	1.6	1.5

If the rain events occur sporadically and erratically in this zone, but with a high intensity, as stated above, erosion is not likely to be continuous, but rather discontinuously, and only are quantitatively important in some years or in some stormy episodes, in certain conditions of

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state and moisture content of the soil surface, as reported elsewhere (Mannaerts and Gabriels, 2000; Coppus and Imeson, 2002)).

This saline, silty soil may have a surface sealing crust of up to 1.5 cm thick, as a result of the weaker rains that usually precede the more intense ones. This sealing results in a drastic decrease in infiltration rate at the time of the most intense rains, thus generating an important runoff that circulates in laminar flow over the crust. Provided the high mechanical resistance of the crust towards cutting, no disaggregation or separation of solid particles occurs, and most of the heavy rain events may generate a high runoff, but no erosion is produced.

Only occasionally, after several consecutive intense rainy episodes, sediments are generated by sheet erosion in the plots. This occurs when the sealing crust loses stability by wetting, resulting in the slaking of individual particles that are dragged along by the laminar flow. Outside the plots, however, clear erosive morphologies (rills and gullies) can usually be observed along slopes whose length greatly exceeds that in the experimental plots. In these conditions, the slopes are long enough to allow the laminar flow to concentrate in streams of increasing speed and turbulence, that move towards already existing drainage channels and that also may open new rills and furrows, as they are capable of cutting the surface sealing. The net result is a typical gully dynamics after each rain event (Figure 1).

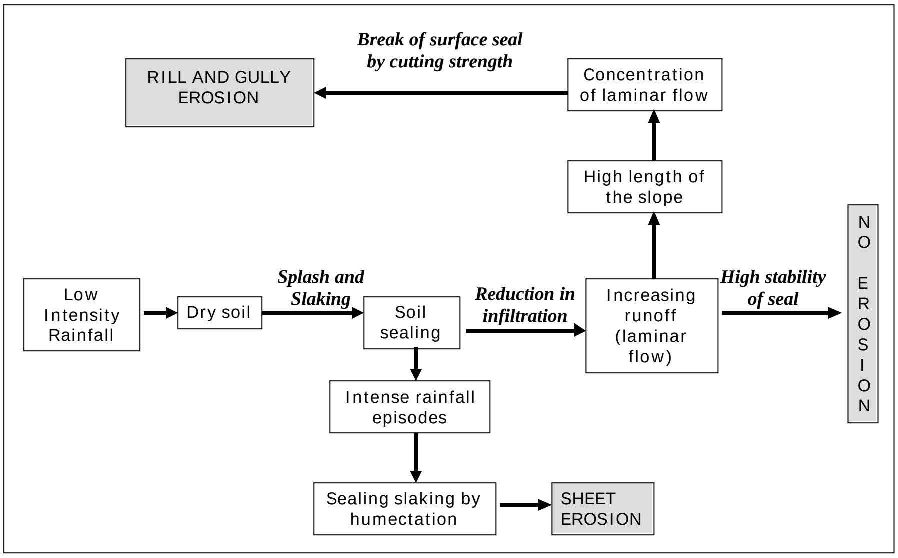

Figure 1. Interpretative scheme of the erosive cycle

Discussion and conclusions

Water erosion in Aridisols at southern Tenerife generally results from concentrated flows along long slopes, and it is strongly associated both with the high erosivity of rains and the erodibility of soils. In particular, the low infiltration capacity of the soil caused by surface sealing, as well as the modifications of water cycling altering the natural drainage network due to a massive occupation derived from touristic residences and the derived infrastructures, play a first-order role in this sense. In such an scenario, the use of small experimental plots may not allow to evaluate soil loss by erosion precisely. Another kind of experimental installations, covering a wider surface as a small instrumentalized basin, together with specific systems to measure water dynamics in rills and gullies would be best suited.

However, experimental plots like those used here may supply useful information on the dynamics of laminar flow and the mechanisms that trigger water runoff, in an area where water resources come basically from surface runoff harvesting.

There are, therefore, important differences in the management model of water resources, as compared to that for Andosols, where the infiltration processes and replenishing of aquifers must be encouraged as, in these cases, the rainfall is mostly collected as groundwater. In addition, the design of strategies to control erosion must be different. In the northern areas, biological and agronomical practices are required to maintain a permanent plant cover on the soil, thus decreasing the kinetic energy of water drops, the main agent responsible for triggering the laminar erosion in these areas, and improving infiltration and replenishment of the aquifers.

On the contrary, in the southern Aridisols, such measures must be based on mechanical methods, capable to shorten the length of the slope, thus preventing the acceleration and concentration of water flows, the main agent responsible for starting erosive processes that form the rills and gullies predominant in these areas, as well as on channeling and exploiting the surface runoff generated.

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