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Hydrological consequences of soil surface type and condition in colluvial mica schist soils after the agricultural abandonment

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ABSTRACT

Extensive semi-arid areas over mica schist in SE Spain have soils with a sandy loam texture, a poorly developed structure, a relatively high infiltrability and a quite high saturated hydraulic conductivity. Under non-tillage land use, a stony pavements armours the soil surface and is responsible for high infiltration, low runoff and almost negligible erosion. However, when this stony pavement is absent, and no plant cover is present, i.e. in tilled soils, this soil is very vulnerable to surface crusting and erosion. With the aim to ascertain the formation stages of this stony pavement as well as to know its hydrologic and geomorphologic behaviour, an experimental study has been carried out in a runoff plot under simulated rainfall. A laser micro-relief meter has been used to characterise the spatial distribution erosion-sedimentation patterns during the experiments, and soil micromorphology to characterise stony pavements and underlying sieving crusts. In the first stage of a rainfall event after the land has been tilled, runoff and erosion are very reduced because the newly created structure absorbs most of the water and the energy of raindrops progressively destroys clods, seals the surface, detaches and transports downslope most of the fine earth. In the subsequent stage, some minutes after the rainfall started, a physical surface crust develops, and runoff and erosion progressively increase. As rainfall continues, in a third stage, the progressive removal of fine particles from the surface leaves a residue of rock fragments and runoff and erosion decrease due to both an increase in infiltration and the armouring effect of the stony pavement.

Key-Words: sieving crust, rainfall simulation, erosion, runoff, roughness

INTRODUCTION

Extensive semi-arid range areas over mica schist in SE Spain usually exhibit a mosaic of soil surface types which may be controlled by either natural or man-induced processes. Every soil surface type can be characterised, amongst others, by morphological features, soil physical and chemical properties and also by their response to rainfall in terms of both hydrologic and erosion behaviour.

When considered at a local scale (< 1 km), these different types of soil cover may overlay identical or similar soil types. Because of the important large scale hydrological implications of the variability of the soil cover, it is important to know the behaviour of the different covers and what are their particular contribution to the overall landscape.

One quite extensive soil surface type in Mediterranean semiarid regions is a *filtration pavement* formed by a surface cover of rock fragments underlayered by a *sieving crust* up to a few centimetres thick. A *sieving crusts* may be either the lower part of a *filtration pavement,* or simply be taken as a synonymous for that last term, and is made up of a layer of loose sandy grains overlaying a layer of much finer particles (Valentin and Bresson, 1992). Valentin (1991) describes the most advanced form of a *sieving crust*, with three well-sorted layers: an uppermost layer composed of coarse grains, a middle layer formed by fine, densely packed grains with vesicular pores and a lower layer with a high content of fine particles with a considerably reduced porosity. A particular form of this type of crust has been identified as *coarse pavement crust* and commonly occurs in arid and semi-arid areas (Springer, 1958; Evenari et al., 1974; Figueira and Stoops, 1983) and has also been firstly reported in SE Spain by Nicolau et al.(1996) and Puigdefábregas et al. (1996, 1998, 1999). According several authors (Valentin and Figueroa, 1987; Valentin, 1986; Springer, 1958; among others), the textural differentiation within those crusts mainly results from mechanical sieving once the kinetic energy of rain drops has been able to disperse the soil material at the surface, so that the finer the particles, the deeper they are deposited. The hydrological consequences of this type of crust have been predicted, specially infiltration characteristics of soils at profile scale (Casenave and Valentin, 1992), but also reported for hillslope scale (Puigdefábregas et al., 1996; Nicolau et al., 1996; Puigdefábregas et al., 1999). Also, the protective effect of a well established rock fragment cover against erosive rainfall is well known (Poesen et al, 1994).

According to Casenave and Valentin (1989), in arid areas surface crusting processes self-accelerate when the soil is no longer in equilibrium with the vegetation and the soil fauna. However, the restoration of the surface soil structure remains reversible due to the capacity of arid vegetation and soil fauna to re-colonise crusted areas when conditions are improved (higher rainfall and/or lower human or grazing pressure) (Valentin and Bresson, 1992).

In the framework of all the above, and specifically in mica schist areas, it is very important to know how these crusts develop, evolve and behave under the main types of land use and soil management.

In order to verify formation mechanisms and infiltrability values of *sieving crusts* which were predicted by Valentin and Bresson (1992) for West Africa, and their validity on semi-arid mica-schist soils in SE Spain, as well as to know the susceptibility of such crusts to erosion, an experimental study was designed in which a series of rainfall simulations were carried out on a runoff plot on abandoned mica schist land, before and after tillage.

MATERIALS AND METHODS

The Rambla Honda experimental area is a representative part of semi-arid SE Spain where mica schist lithology is quite abundant (Puigdefábregas et al., 1996). At the foot slope of the Filabres range, the most frequent land use over extensive alluvial fans is grazed rangeland on more than 25 years abandoned agricultural fields (Fig. 1). Soils on alluvial fans, within the study experimental site, are classified as sandy loam *Eutric Fluvisol*, with low organic matter content, neutral pH, and salt free (Puigdefábregas et al., 1992, 1996).

Figure 1.- General view of the Rambla Honda experimental site

A runoff plot of 2 x 2 m, at the medium sector of an alluvial fan, with a slope gradient of 12°, left ungrazed since 1990, was used for the experiment. A large rainfall simulator was installed over the plot with a series of sprinklers installed at 5 m altitude, to automatically provide an homogeneous rain intensity of 65 mm/h over an area of about 2.5 x 2.5 m. Runoff was collected in a 200L tank and automatically recorded with a tipping bucket. Total erosion was estimated at the end of every rainfall-runoff event from a proportional water sample collected in the tank.

In the same plot, the following sequence of soil surface conditions were tested for their hydrological and erosion behaviour (the numbers after the capital letters indicate the microprofile measured with the laser instrument):

A.- Undisturbed soil cover, representing a typical surface after 25 years of agricultural abandonment, ungrazed, and characterised by a sparse perennial vegetation (dwarf shrubs of *Artemisia*) and annuals (mainly *Stipa capensis*).

B.- Same soil surface but after burning all vegetation with a gas lamp. The aim of this test was to compare the role of annual plants along with a stony pavement versus a stony pavement alone.

C.- Same soil surface as in B but after removing the upper layer of the sieving crust (gravel and coarse sand). The aim of this test was to know the hydrological and erosion behaviour of a surface crusted layer. C1 and C2 are the two rainfall simulations performed after this treatment.

D.- After tillage (manually, with a hoe up to a depth of 15 cm, and further flattening with a rake). D1, D2 and D3 are respectively the first, second and third rainfall simulation after this treatment.

Undisturbed samples for micromorphology were taken before A and after D3.

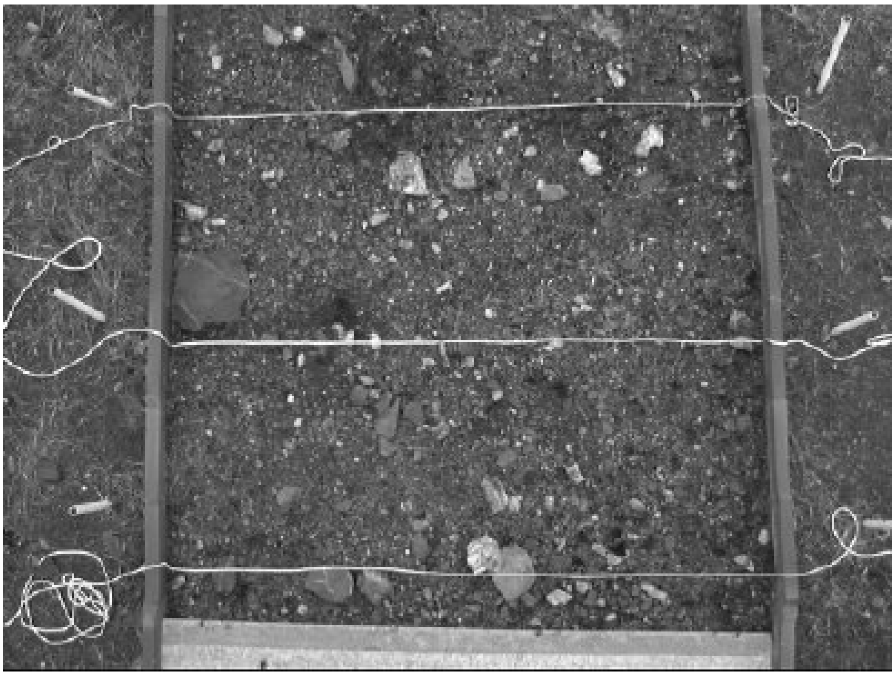

Figure 2.- Bounded runoff plot where the soil surface was experimentally modified to test the behaviour of simulated rainfall. Horizontal white lines indicate where the micro-relief profiles were taken. Distance between tile rows: 2 m

With the aim to know spatially sediment sources within the plot, as well as to provide an alternative method for soil erosion determination, the micro-topography of three transverse transects was measured by means of a portable laser microrelief-meter (Pini et al., 1997) before and after every rainfall simulation for all treatment (Fig. 2). Micro-relief profiles were named *-B*, *-C*, *-D* when obtained before rainfall simulations and *+B*, *+C*, *+D* after them. Treatment A (undisturbed soil surface) was not suited for laser micro-relief measurement due to the high amount of live annual plants.

RESULTS

Surface morphology, micromorphology and significant soil properties

A.- Undisturbed "natural" soil cover was formed by sparse perennial vegetation (dwarf shrubs of *Artemisia*) and a annuals (mainly *Stipa capensis*) and an almost continuous rock fragment cover (formed by fine and medium gravel: 71% between 4 and 64 mm, 13% rock fragments larger than 64 mm) (Fig. 3). Under the surface, the sieving crust was characterised by a series of layers decreasing downwards in particle size as seen through the optical microscope. Upper layers were characterised by the sorting of coarse sand and the lack of fine particles (very fine sand, silt and clay). The latter, however, were concentrated just below the coarse-sand layer in a quite dense packing mode, and most probably as a result of mechanical sieving as suggested by Valentin (1991) (Fig. 4). Below this washed-in layer, the Ap horizons, 10 to 15 cm thick appears: the texturally heterogeneous groundmass is formed by an unoriented mixture of gravel and fine earth with abundant macropores and very fine roots. After the first rainfall simulation, surface morphology apparently did not changed.

Figure 3.- Detail of the soil surface, with a typical rock fragment cover (lens cap = 65 mm)

B.- After burning all vegetation, the same type of rock fragments as previously described, covered 100% of the area, with minor amounts of ashes replacing the live vegetation. The second rainfall simulation removed all the ashes and left 100% rock fragments.

C.- After removing the upper part of the filtration pavement (layer of coarse gravel and underlayering fine gravel and coarse sand), a smooth layer formed by very fine sand and finer particles constitutes the whole surface. After two short rainfall events (C1, C2), the surface was crossed downwards by some rills.

Figure 4.- Micrograph of the upper centimetre of the soil before the experiment (non grazed soil, undisturbed during at least 25 years). Notice the well developed sieving crust (fine particles have been washed out and accumulate below the surface layer of coarse particles)

D.- After tillage and further flattening, the surface appeared covered with relatively small clods and aggregates (<2cm) giving a rough aspect. After three short simulated rainfall events (D1, D2, D3), some rills developed and about 30% of rock fragments appeared at the surface, 71% of them between 4 and 64 mm, and 13% larger than 64 mm. The sieving crust started to develop as the surface layer: it was characterised by a series of layers decreasing downwards in particle size, very similarly to the features observed in the undisturbed soil. Upper layers were characterised by their progressive sorting and lack of very fine particles (Fig. 5). The latter were concentrated just below the coarse-grain layer, as a result of mechanical sieving as suggested Valentin (1991).

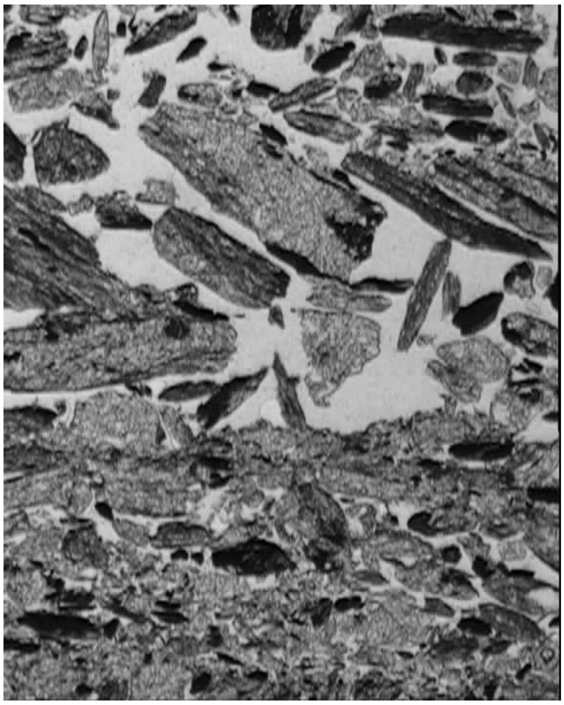

Fig. 5. Micrograph of the upper centimetre of the soil after the experiment. Notice how the sieving crust has developed again.

Microtopography.

For some pairs of micro-relief data, -B and +B, -C and +C, -D and +D, it was the impact of rainfall which caused micro-relief changes. The pair +B -C was also meaningful because it provided a good estimate of the volume, and hence the weight, of the removed stony pavement. Different patterns have been observed from the three transects and between the different soil surface treatments:

After 30 minutes of high intensity simulated rainfall, imperceptible changes have occurred between –B and +B in the three transects (Fig 6A), because the rock fragment cover is armouring the soil and protecting it against erosion.

However, when this stony pavement is removed, leaving a smooth crust-like surface, -*C*, a quite homogeneous lowering of the surface (+*C*) is the direct consequence of the erosive rainfall (Fig 6B).

Micro-relief data *–D1* and *+D3* were taken before and after three simulated rainfall events of 10 min each (Fig 6C). Differences between these micro-relief profiles represent the impact of rainfall and they vary according to their position within the slope: positive value differences were indicative of depressions of the previous soil surface, ascribed to erosion; negative value differences are indicative of a surface raise interpreted as a localised sedimentation. Erosion was dominant in the upper transect, while abundant deposition is common at the lower one, while at intermediate positions, erosion is almost compensated by deposition.

The pair +B –C represents the removal of the stony pavement, and a lower and smooth surface appears (Fig 6D). The average thickness of the stony pavement calculated from the laser micro-relief data (7 mm) coincides with the data obtained from dividing the total weight (43 kg) by the total surface (4 m²) and the result divided by the bulk density of this surface layer (1.4 kg L^{-1}).

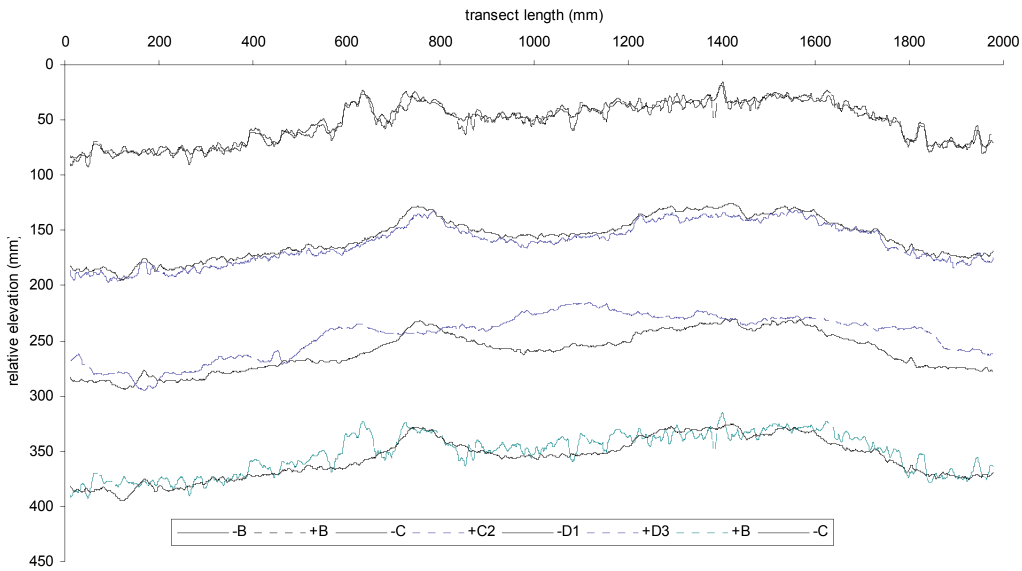

Figure 6.- Micro-relief profiles of the soil surface at several stages during the experiment: B, C and D indicate the treatments, and – (minus) and + (plus) indicate before and after the treatments

Runoff

Cumulative runoff curves from all the simulations are presented in Fig 7. Two distinct behaviours can be observed. The low runoff group includes soil surface conditions A (natural ground cover after 25 years of abandonment), B (after removing plant cover) and D1 (just after tillage). The high runoff group includes C1, C2 (after removing the rock fragment cover) and D2, D3 (2nd and 3rd rainfall simulations after tilling the plot). The same classification can be established for *time to runoff* from the different treatments (Fig. 8).

Erosion

Also for erosion, two distinct groups have been obtained (Fig. 8). From negligible (A and B, less than 1 g m^{-2}) and low erosion (D1 and D3, less than 25 g m^{-2}) to relatively high erosion values (C and D2, around 100 g m^{-2}).

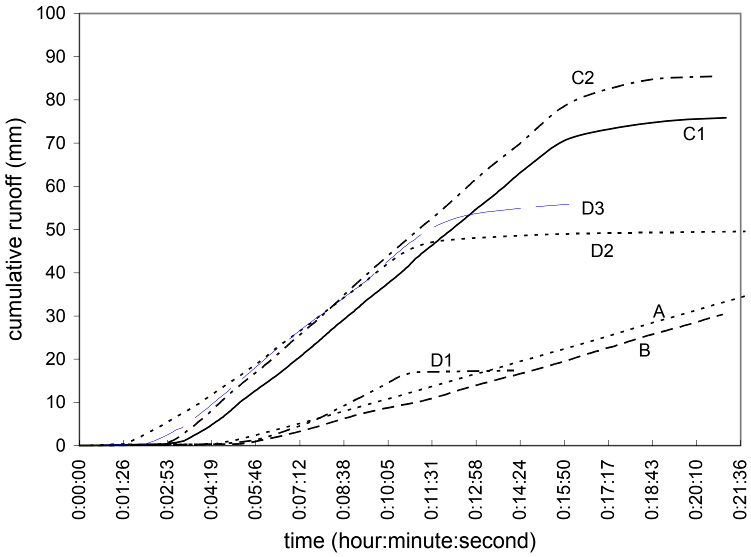

Figure 7.- Cumulative runoff for all rainfall simulations

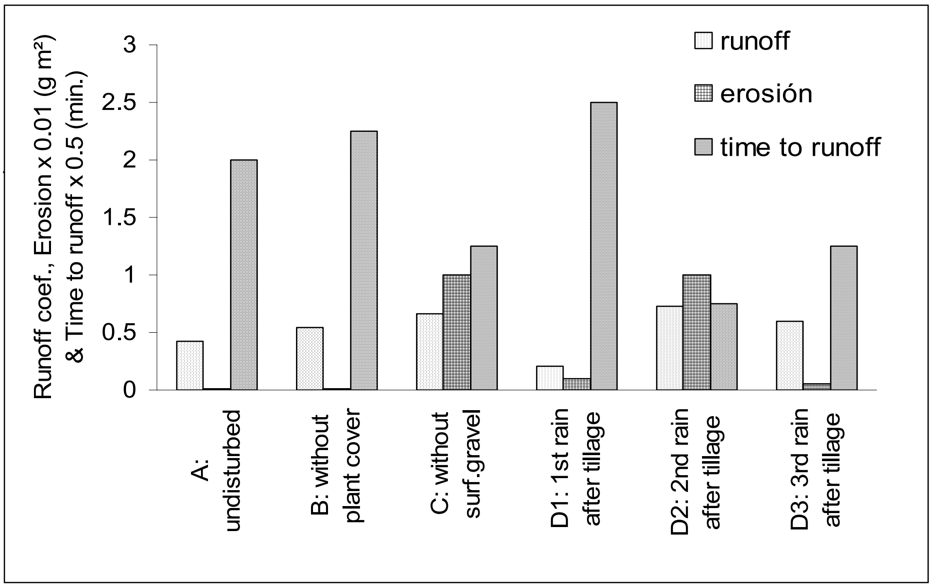

Figure 8.- Time to runoff, runoff coefficient and erosion obtained with similar rainfall simulations over different soil surface types and conditions of a same runoff-erosion plot

DISCUSSION AND CONCLUSIONS

Rambla Honda alluvial soils have developed from mica schist, have a sandy loam texture, a poorly developed structure, a relatively high infiltrability and a quite high saturated hydraulic conductivity. Under non-tillage land use, a stony pavements armours the soil surface and is responsible for the high infiltration, low runoff and almost negligible erosion. However, when this rock fragment cover is absent, and no plant cover is present, i.e. in tilled soils, this soil is very vulnerable to surface crusting and erosion.

In the first stage of a rainfall event after the land has been tilled, runoff and erosion are very reduced because the newly created structure absorbs most of the water and the energy of raindrops progressively brake down poorly stable aggregates and clods, and detached particles are washed through the highly porous surface horizon and accumulate below. This process is the start of an horizon differentiation into very thin layers formed by progressively finer grains downwards, the whole known as a *sieving crust*.

In the subsequent stage, some minutes after the rainfall started, a physical surface crust develops and the sealed surface causes a progressive increase in runoff and erosion. At the same time, most of the fine earth is transported downslope and a residual rock fragment cover starts to develop, through which more fine particles can be washed out, contributing to the accumulation of a washed-in layer.

As rainfall continues, in a third stage, about ten minutes later, the progressive removal of fine particles from the surface has left a residue of rock fragments (> 2mm), and runoff and erosion decrease. The causes: increased infiltration along with the armouring effect of the stony pavement (Poesen and Lavee, 1994; Poesen et al, 1994).

As a consequence of this process, the tillage of these soils is responsible that runoff and erosion exert an impoverishment in fine particles which ends as soon as a stony pavement has been reconstructed. Successive tillage deteriorates this type of soil across slope gradient at valley sides. However, the valley floor is enriched in silts but clays are mostly transported out of the catchment, as also found in Niger by Valentin (1991) in soils with sieving crusts.

Under the present environmental conditions, which can be summarised as low pressure grazing and ephemeral agriculture, the soil surface morphology of the extensive alluvial fans from the southern versant of Filabres Range, is quite stable and quickly recovers from any perturbation, after a few rainfall events (this has been precised for 3 events of 65 mm/h during 10 minutes each). This relatively small rainfall amount has been enough to reproduce a similar stony pavement and sieving crust as those observed in neighbouring abandoned lands.

Measurements of the soil surface micro-relief with a portable laser instrument proved to be of great use to know the patterns of soil erosion and soil sedimentation as a result of plant cover removal, tillage and crusting.

Rainfall simulations over an experimental runoff plot allowed to conclude that the protective effects of a bare stony pavement are comparable to those of a mixed cover: annual plant cover and a stony pavement, suggesting that the role of the plant cover alone might be secondary in relationship to the stony pavement.

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