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Permanence of soil surface crusts on abandoned farmland in the Central Ebro Basin/Spain

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Abstract

Surface crusts are frequently found on fallow land in the semi-arid Ebro Basin (Spain) and are an important factor in land degradation. Soil surface sealing leads to a decrease in infiltration rates and a consequent increase in runoff, thereby accelerating sheet wash and rill erosion. Thin sections were used to analyse the development and structures of the different crusts found across the ridge/furrow field pattern. Rainfall simulations experiments and infiltration measurements show the runoff generation and the soil erosion rates on the crusts. The spatial distribution of crusts was documented using large-scale aerial photographs, taken from a remote-controlled hot air blimp.

Splash and slaking cause structural crusts to form on the ridges, while eroded material leads to a build-up of sedimentary crusts in the furrows. A platy structure as well as vesicles then develop in these crusts, depending on the amount of time that has elapsed since ploughing and the frequency of wetting and drying cycles. Alluvial fan crusts develop on material accumulated at the end of erosion rills. The increase in the runoff of up to 81% and the decrease in infiltration rate up to 4.6 mm h-1 on surface crusts were quantified.

Keywords: Soil crusting; Abandoned fields; Thin sections; Rainfall simulation; Land degradation

1. Introduction

1.1. Objectives

In the traditional dry farming system (Spanish: *año y ves*, *cultivo al tercio*) in the semi-arid parts of Spain, arable land lies fallow as bare fallow for up to two years, is ploughed several times for complete infiltration of precipitation, and is harrowed and rolled after rainfall in order to minimise evaporation loss. With the water stored in the ground wheat or barley can be grown in the second or third year. The EU Commission responded to the overproduction of agricultural products (in the European Union) with set-aside programmes. Consequently, since the beginning of the nineties in the semi-arid parts of Spain the number of abandoned fields has increased constantly supported by subsidies up to 45% of all rainfed land (Marzolff et al., 2003). The fields are left fallow during the next years or decades and are used for sheep grazing. This young fallow land displays very complex geomorphodynamics. When the former arable land is no longer ploughed, harrowed and rolled regularly, as was usual in the traditional dry farming system, soil crusts that heavily reduce local infiltration capacity develop on the silty soils. The vegetation cover decreases from 55% in the second year to up to 25% in the fifth year after set-aside (Lasanta et al., 2000, pp. 269). Soil surface crusts have a negative effect on the vegetation succession with annuals in various ways: firstly the surface transport of seeds can barely find any grip on the crusts, secondly because of the high temperatures on the crust, the shoots dry out easily, and thirdly crusts represent a mechanical obstacle to seedling emergence. They “cement” the *seed bank* and have a retarding influence on the germination behaviour as a result of diminished gas exchange and low soil water balances in and below the crust. This explains why the seedling emergence rate is low, despite the surprisingly large number of seeds, and why the survival of shoots is rare (García-Fayos et al., 1995, pp. 694; Cerdà and

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García-Fayos, 1997, p. 88; Guàrdia et al., 2000, pp. 198). High runoff coefficients on these crusts reflect high sheet wash rates, and induce rill and gully erosion on and downstream from the fields. Alluvial fans develop from material accumulated at the end of erosion rills.

Neither the development process of soil crusting in this area nor its influence on soil erosion is investigated up to now. Nevertheless these processes are highly relevant, because of high erosion activity visible in form of sheet erosion up to deep gullies (*Spanish barrancos*). The political changes described above which interfere these processes and are not adapted to the regional conditions. Therefore the object of our research is to investigate the interaction of soil crusts, their development, structure and distribution with geomorphodynamics, vegetation cover and land use. The distribution of crusts on the abandoned fields is as relevant as to quantify the site-specific erodibility of the soil in the test area Val de las Lenas in the Central Ebro Basin.

Aim of the study is to show the consequences of crust formation on areas of fallow land on the surface runoff and soil erosion. Therefore the occurrence and structure of soil crusts on abandoned fields has to be visualized. The role of time and thus of alternating drying and wetting processes in the development of different layers subsequent to the sedimentation processes can be demonstrated. A further aim is to support a regional differentiated political programm to give consideration to natural and social conditions in this area, which can hinder further erosion processes or at least a further increase of erosion areas.

1.2. Soil crusting

Soil sealing occurs when the soil surface is unprotected against the effects of precipitation and when rapid wetting of aggregates occurs. When this happens, the impact forces of the raindrops lead to consolidation of the soil near the surface as a result of pressure and the splash erosion of soil particles (Roth, 1992, pp. 43). Aggregates are crushed into individual soil constituents or micro-aggregates. So called “structural crusts” occur through processes resulting from raindrop impact and the rapid wetting of the soil surface (Chen et al., 1980; Onofiok and Singer, 1984; Bresson and Valentin, 1994; Bielders and Baveye, 1995).

The formation of a structural crust leads to surface flow due to the reduced infiltration capacity of the soil. This serves as a medium for transporting soil particles detached by the impact of the rain, and these particles are deposited in another place as “sedimentary crusts” (Arshad and Mermut, 1988; Valentin, 1991; West et al., 1992). The extent of the sedimentation depends on the micro-relief, the flow velocity of the surface water and the amount of eroded material in suspension (Bresson and Valentin, 1990, p. 239).

Despite their low thickness (usually only a few millimetres) the soil crusts have a significant effect on the physical properties of the topsoil. The consequences of sealing are: a reduction in water conductivity, the promotion of surface flow, impairment of the gas exchange, and a mechanical obstacle for seedlings. Consolidation near the surface of the soil causes considerably diminished saturated water conductivity with the result that any sealing is to be regarded as a fundamental cause of the formation of surface flow on unprotected arable land (Roth, 1992; Herrmann et al., 1993). On the one hand sealing affects the water balance of the soils, and on the other it represents an important part of the process of water erosion (Auerswald, 1986; Roth et al., 1988). With the sealing of the soil surface and the reduced porosity, the gas exchange in the soil is reduced (Frede, 1986). According to its thickness and hardness, the crust represents a considerable mechanical obstacle for seedlings. In later stages of growth plant cover obstructs crust formation with increasing soil cover (Hanks and Thorp, 1957; Czeratzki, 1957).

2. Materials and methods

2.1. Test area

The Central Ebro Basin is characterised by a semi-arid climate with an annual precipitation of 320 mm and an annual water deficit of up to 2000 mm. It is one of the driest regions in Europe. The Val de las Lenas is situated on an eastern tributary of the Huerva river. Flat-lying Miocene gypsum, marl and clay series with interbedded limestone and sandstone build up the highly dissected slopes (ITME, 1998), which turn sharply into scree-covered glacis. The slopes are covered by low scattered matorral of *Rosmarinus officinalis* and *Thymus vulgaris*, the glacis are scattered with *Lygeum spartum*. Both, slopes and glacis, show indicators of heavy land degradation owing to deforestation of the natural vegetation (*Junipereto-phoeniceo-thuriferaesigmetum*) and grazing activities during the last centuries (Braun-Blanquet and De Bolòs, 1987; Rivas-Martínez, 1987). The soil surface is covered by stone pavements, which are the result of intensive sheet wash: on these surfaces, runoff coefficients can be as high as 57% (Ries, 2002). Owing to high bioturbation, soil crusts cannot be found on these surfaces and the infiltration capacity with 9.4 mm h^{-1} is surprisingly high in comparison with those on the abandoned fields (see Fig. 1).

The flat valley bottoms (Spanish val) are infilled with Quaternary alluvial sediments. This part carries the agricultural land. They are usually incised by deep gullies. The material delivered from the Miocene sediments is very rich in carbonate (33.0% to 46.8%,). Towards the valley sides the grain size of the valley fill increases (Andres et al., 2002).

On young fallow land vegetation succession is slow owing to the semi-arid climate with six arid months and a total precipitation of 320 mm per year. The rainfall activity is characterised by a low amount of precipitation with heavy rain storms occurring primarily in spring and autumn but can also occur in the usually precipitation-free summer months. With the course of weather from late winter to early summer sparse therophyte vegetation (*Hordeum murinum*) grows leading to low vegetation cover. Ries (1995, pp. 9f.) found a very low vegetation cover (5–25%) on the young fallow land of the test area after five years. A vegetation cover of over 50% is reached only after six to eight years (Marzolff, 1999, pp. 108). The