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Maximising Water Availability of Rainfed Treecrops and its Impact on Land Degradation; an Example from the Semiarid Part of Spain

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Résumé

Les vergers non irrigués en milieu semi aride sont très vulnérables à l'érosion à cause leur faible couverture au sol. D'autant plus que le sarclage fréquent cause une redistribution de sol importante. Cet article étudie la variabilité spatiale des caractéristiques du sol et l'impact sur le bilan hydrique pour un bassin versant couvert de vergers d'amandiers. La surface sujette à l'érosion est plus importante (53 %) que celle qui subit la sédimentation (34 %). Dès lors les sols deviennent progressivement plus minces et caillouteux. L'évaporation du sol nu entre les arbres espacés représente la perte la plus importante du bilan hydrique de ces vergers. Cependant ces pertes (33 % de la pluie) ne suivent pas la variabilité des caractéristiques des sols. Malgré la perte de sol, le sarclage reste crucial en tant que stratégie de conservation d'eau pour les arbres espacés.

Abstract

Rainfed permanent crops in semi arid regions provide a very low soil cover and hence soils are vulnerable to water erosion. Keeping the soil bare requires frequent tillage resulting in important soil redistribution. This paper investigates the systematic variation in soil properties of a small catchment cultivated with almonds and its impacts on the water balance. The area suffering from erosion (53 %) is larger than the area undergoing sedimentation (34 %). Hence, the soil in a large part of the catchment becomes thinner and stonier. Since the widely spaced trees have a well-developed root system penetrating below the plough layer, evaporation from bare soils can be considered the main loss in the water balance. These losses are similar for all soil profiles at c. 33 % of the rainfall. Therefore, keeping the soil bare is an important strategy supplying extra water to the widely-spaced tree crop.

Introduction

Rainfed permanent crops such as almonds, olives and vines cover important areas in the drier parts of the Mediterranean. The acreage of almonds has expanded rapidly into marginal soils of the hillslopes of southeast Spain. This expansion starting in the 1970s was reinforced by the subsidies under the EU Common Agricultural Policy since the late 1980s (Beaufoy, 2003). Permanent crops provide a very low soil cover throughout the year and hence soils are vulnerable to water erosion. However, recently it has been demonstrated that soil

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redistribution by tillage can be an even more important cause of degradation. This paper investigates the systematic variation in soil properties as a result of soil redistribution by tillage of a small catchment converted to almond groves in the late 1970’s. Furthermore, the impacts of the spatial variation in soil properties on the water balance of the almond cropping system are evaluated.

Materials and Methods

A 21 ha agricultural catchment to the north of La Paroquia (1°56’W, 37°41’ N, Murcia Region) in south east Spain was selected. The hilly area of the Sierra de Torrecilla is underlain by slates and phyllites. This catchment has been converted to almond groves c. 25 years ago. The sandy loam soils (62% sand, 32% silt and 6% clay) are weakly developed Eutric Leptosols and Calcaric Regosols with very high rock fragment contents (66 %). The climate is semi arid with mean annual precipitation of 275 mm and mean annual temperature of 17°C.

The soil redistribution as a result of tillage was predicted by the WATEM model (Van Oost et al., 2000). This model simulates the diffusion of soil material by ploughing for three dimensional landscapes. A digital terrain model as well as a map of the parcel boundaries create the spatial patterns. The model requires a bulk density (1582 kg m^{-3}), a tillage depth (15 cm), the number of tillage operations (2 per year) and a tillage transport coefficient (139 kg m^{-1}). These values were derived from tracer experiments on the same site by Poesen et al. (1997). We surveyed breaks in slope along field borders, created by accumulation and removal of soil material, using an automatic theodolite. Furthermore, retention dams and the sediment behind these dams were also surveyed. Validation of the WATEM model consisted of comparing the observed removal and accumulation of sediment along field borders with the model output for 110 sites.

The PATTERN model (Mulligan, 1996) is conceived to quantify the water balance of marginal and stony soils in the Mediterranean. This model was parametrised to run on two soil profiles: a relatively thick soil in the valley bottom and a thin soil on the hillslope. Two undisturbed soil columns of 30 cm diameter were transported to the laboratory and underwent four wetting (rainfall simulator) and drying (UV lamps and fan) cycles. The soil moisture content (electronic balance), drainage (tipping bucket rain gauge), radiation, temperature and relative humidity were monitored at 10 minutes intervals. The model parameters to describe evaporation from bare soils were derived using the pedotransfer functions described in Campbell (1985). The model results were compared to daily values of soil moisture content (m^3 water / m^3 soil), evaporation and drainage measured for both columns. The model was calibrated by adjusting the so-called b-value, quantifying the matrix potential, soil moisture relationship. The model was then used to simulated the water balance of three soil profiles representing the range of stoniness and soil depth using meteorological data from 1992 with a yearly rainfall of 295.4 mm. The thin soil (15 cm) on the convexities contains 0.47 m^3 m^{-3}, the soil on the hillslope (27 cm) 0.40 m^3 m^{-3} and the soil in the valley bottom (47 cm) 0.53 m^3 m^{-3} of rock fragments.

Results and discussion

The results of a spatially distributed tillage erosion model, WATEM, are validated by a topographic survey of accumulation and removal of soil along field borders (root mean square difference (RMS) = 0.66 ton $ha^{-1}y^{-1}$). On the hillslopes, soil loss by tillage erosion amounts to

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26.6 ton $ha^{-1}y^{-1}$ while sedimentation occurs at a rate of 21.1 ton $ha^{-1}y^{-1}$. The difference between erosion and sedimentation on the hillslopes results in a net transport of sediment towards the valley bottom, where the sediment is retained behind 17 earthen dams. Overall, these currently store 156.5 tons ha^{-1} which is about half their total capacity. The area suffering from erosion is larger (53 %) than the area undergoing sedimentation (34 %) or the area undergoing a change within the accuracy of the model prediction (13 %). Hence, soils in a large part of the catchment become gradually thinner and stonier. When we assume that at the time of planting the soils were ripped open to a uniform depth of 30 cm, the soil depth resulting from tillage erosion can be estimated. Predicted soil depth after 25 and 50 years was compared to 248 measurements of soil depth in the same area (Fig. 1; Boer et al., 1996; van Wesemael et al., 2000). The increase in the area of shallow soils (< 20 cm) after 25 years of tillage is remarkable. The increase of the area of deep soils is much more restricted and probably confined to concavities and zero order valleys. Furthermore, the comparison between the modelled and the observed soil depths reveals that shallow soils already existed, but that soil redistribution by tillage increases the areas of both very thin (<10 cm) and deep soils (> 60 cm).

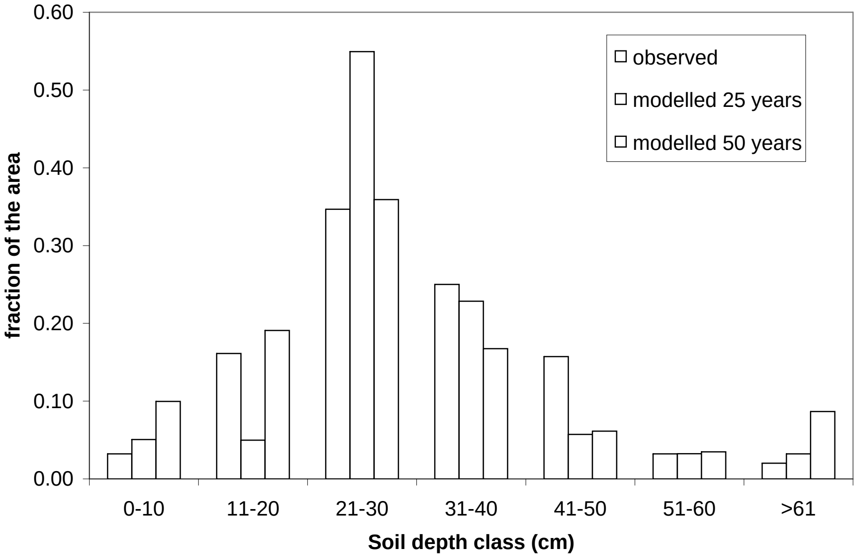

Fig. 1. Spatial distribution of soil depth classes in the slate area of the Sierra de Torrecilla (Boer et al., 1996; van Wesemael et al., 2000) compared to modelled soil depth assuming 25 and 50 years of tillage operations starting from a uniform soil depth of 30 cm.

The results of the PATTERN model that the variation in soil moisture content in thin soils is much larger than in thicker soils. Thin soils tend to saturate after rainfall and dry out quickly by drainage and evaporation, since these processes are driven by the concentration of water in the soil rather than its quantity. Plants relying on the available water in these thin soils would suffer severely from water stress in the periods between rainfall which are frequently longer than one month. However, soils are kept bare by frequent ploughing within these almond orchards and therefore, roots of the almond trees are forced to penetrate to a depth below 15 cm in the regolith and the cracks of the bedrock. The growth of the almond trees therefore does not respond to the soil moisture evolution in the topsoil. Since the tree canopies only cover less than 25 % of the surface, the roots benefit from the surplus water in the bare areas between the canopies. This means either the moisture stored in the topsoil or the water drained from the very thin soils and tapped into by the roots of the almond trees at

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some depth. The water balance for 1992 with 295 mm rainfall demonstrates that no runoff occurs due to the very stony nature of the soils with high macro porosity (Table 1). Furthermore, evaporation losses are comparable at the different sites, but are limited to c. 30 % of the annual rainfall.

The modelling of the water balance demonstrates that erosion creating a marked spatial variability in soil properties does not influence the water stress of the almond trees for these stony soils. This explains the uniform planting scheme. Keeping the soils bare is a strategy which supplies important amounts of water to the treecrop even on the marginal soils. However, the frequent ploughing causes important erosion rates which reduce the soil thickness of the majority of the area and have already filled up half of the storage behind retention dams in 25 years time. The application of cover crops which do not influence the drainage from the soil profile will be further investigated.

Table 1. Water budget for the soil profiles in different hillslope positions for 1992 with 295.4 mm rainfall

	Infiltration (mm)	Evaporation (mm)	Drainage (mm)	Soil moisture increment (mm)
Convexity	295.4	92.8	197.5	5.1
Hillslope	293.6	94.7	197.3	1.6
Valley	295.4	94.4	172.1	28.9

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