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Study of sediment movement in an irrigated maize–cotton system combining rainfall simulations, sediment tracers and soil erosion models

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SUMMARY

Although soil erosion is one of the main threats to agriculture sustainability in many areas of the world, its processes are difficult to measure and still need a better characterization. The use of iron oxides as sediment tracers, combined with erosion and mixing models opens up a pathway for improving the knowledge of the erosion and redistribution of soil, determining sediment sources and sinks. In this study, magnetite and a multivariate mixing model were used in rainfall simulations at the micro-plot scale to determine the source of the sediment at different stages of a furrow–ridge system both with (+T) and without (−T) wheel tracks. At a plot scale, magnetite, hematite and goethite combined with two soil erosion models based on the kinematic wave approach were used in a sprinkler irrigation test to study trends in sediment transport and tracer dynamics along furrow lengths under a wide range of scenarios. In the absence of any stubble cover, sediment contribution from the ridges was larger than the furrow bed one, almost 90%, while an opposite trend was observed with stubble, with a smaller contribution from the ridge (32%) than that of the bed, at the micro-plot trials. Furthermore, at a plot scale, the tracer concentration analysis showed an exponentially decreasing trend with the downstream distance both for sediment detachment along furrows and soil source contribution from tagged segments. The parameters of the distributed model KINEROS2 have been estimated using the PEST Model to obtain a more accurate evaluation. Afterwards, this model was used to simulate a broad range of common scenarios of topography and rainfall from commercial farms in southern Spain. Higher slopes had a significant influence on sediment yields while long furrow distances allowed a more efficient water use. For the control of runoff, and therefore soil loss, an equilibrium between irrigation design (intensity, duration, water pattern) and hydric needs of the crops should be defined in order to establish a sustainable management strategy.

1. Introduction

Some irrigated agricultural areas in southern Spain have appreciable degradation problems caused by water erosion (Calleja et al., 2008; Cerdà and Doerr, 2007). The combination of periodic high intensity rainfall, common in the Mediterranean climate, steep and rolling landscapes, and inadequate soil management systems that leave the soil unprotected for part of the year trigger severe erosive processes.

In order to improve the soil's quality and reduce losses due to erosion, farmers are progressively shifting to ridge tillage systems, planting on the ridge shoulders, leaving residues in the soil and confining traffic paths to fixed furrow bottoms thus mitigating soil compaction by limiting wheel tracks to specific furrows (Hamza and Anderson, 2005; Tullberg et al., 2007). This soil management system has recently been evaluated in a sprinkler-irrigated farm in Southern Spain, where it was adopted to reduce erosion problems. The results obtained at the plot scale indicated that water infiltration into the soil was notably enhanced and soil losses were greatly reduced (Boulal et al., 2008; Boulal and Gómez-Macpherson, 2010).

The success of the ridge tillage management system in this region could be extended beyond the farm where it has been studied (Boulal et al., 2011a,b). Nevertheless, to fully explain the positive results on examining the erosive processes, one has to

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resort to additional research tools to describe the particle displacement of the soil, such as tracking methods and model analysis.

Sediment tracers have been widely used in water erosion studies. Guzmán et al. (2013a) made a thorough review of these tracing techniques, including fingerprinting. A recently developed technology for sediment tracing is the use of magnetic iron oxides. After a previous evaluation, Guzmán et al. (2010a) found a good correlation between measured and estimated soil losses through magnetic susceptibility measurements under controlled rainfall events at a laboratory scale. In the laboratory, Guzmán et al. (2011) explored a mixture of different iron oxides (magnetite, hematite and goethite) as sediment tracers using a combination of magnetic susceptibility and diffuse reflectance spectroscopy (DRS) measurements.

DRS measurements, widely adopted in soil formation studies, are often employed for the acquisition of remote sensing data at the laboratory and field scales, with the additional environmental advantage of not requiring chemical reagents. Cañasveras et al. (2009) proved the efficiency of DRS in discriminating soil zones according to surface sealing and water erosion susceptibility based on the estimation of soil aggregate stability.

Physically-based models integrate experimental information and, once properly calibrated, can be applied to explore the possible response of the system in different scenarios (Morgan et al., 2002). Even very simple models can assist in experimental research. A distributed erosion model based on the kinematic wave approach, KINEROS2 (Goodrich et al., 2012), a renewed version of KINEROS (Woolhiser and Smith, 1990), has been used recently by Ziegler et al. (2007) to characterize road erosion, Goodrich et al. (2012) coupled it with the SIG AGWA for modeling watershed erosion, and Guber et al. (2014) coupled it with a microorganism transport module, STWIR to detect surface water pollution. Therefore, this model could be useful for a broader analysis of different scenarios of the furrow–ridges system.

The purpose of this study was to analyze the erosion processes and sediment movement within the ridge till systems. Three specific objectives were established: (i) the measurement of soil losses and sediment displacement under simulated rainfall using tracers and a multivariate mixing model, (ii) the calibration of a kinematic wave model simulating the behavior of the management system and (iii) the adoption of a distributed erosion model, KINEROS2 better fitted to the shape of the ridge till system to evaluate its performance under different slopes and furrow lengths, as well as several irrigation rates.

2. Materials and methods

2.1. Field site

The field was located in Córdoba, in the south of Spain, at the Alameda del Obispo experimental farm (latitude 37°53′N 4°46′W, elevation 110 m). The climate is true Mediterranean according to Aschmann (1984), with average annual rainfall and reference evapotranspiration of 595 mm and 737 mm, respectively. For this study, only one plot 144 m long, 9 m wide with a slope of 0.8%, was chosen. The soil of the subgroup *Typic Xerofluvent* (Soil Survey Staff, 2010) was formed on the recent alluvium of the Guadalquivir, which flows at a distance of less than 200 m away from the plot. The 10 cm deep topsoil was composed of 10% clay, 42.6% sand and 47.4% silt measured, after dispersion with an ultrasonic probe, with a Beckman Coulter LS-230 (Beckman-Coulter Co. Brea, CA) as described by Guzmán et al. (2010b), with no particles coarser than the maximum sand size, and a low organic matter content, 1.3%. The ridge till system adopted in the plot consisted of ten 0.85 m spaced ridges, each one 0.59 m wide and 0.25 m high. Machinery traffic was restricted to the same furrows. Therefore, furrows with (+T, 5–9 passes), and without wheel ruts (−T) alternated in the plot. The crop rotation was cotton (*Gossypium hirstium* L.) first, followed by maize (*Zea mays* L.), and, later, cotton again since 2007 with a bare fallow intercrop period. Fig. 1 shows the time line of the agricultural operations during the course of the

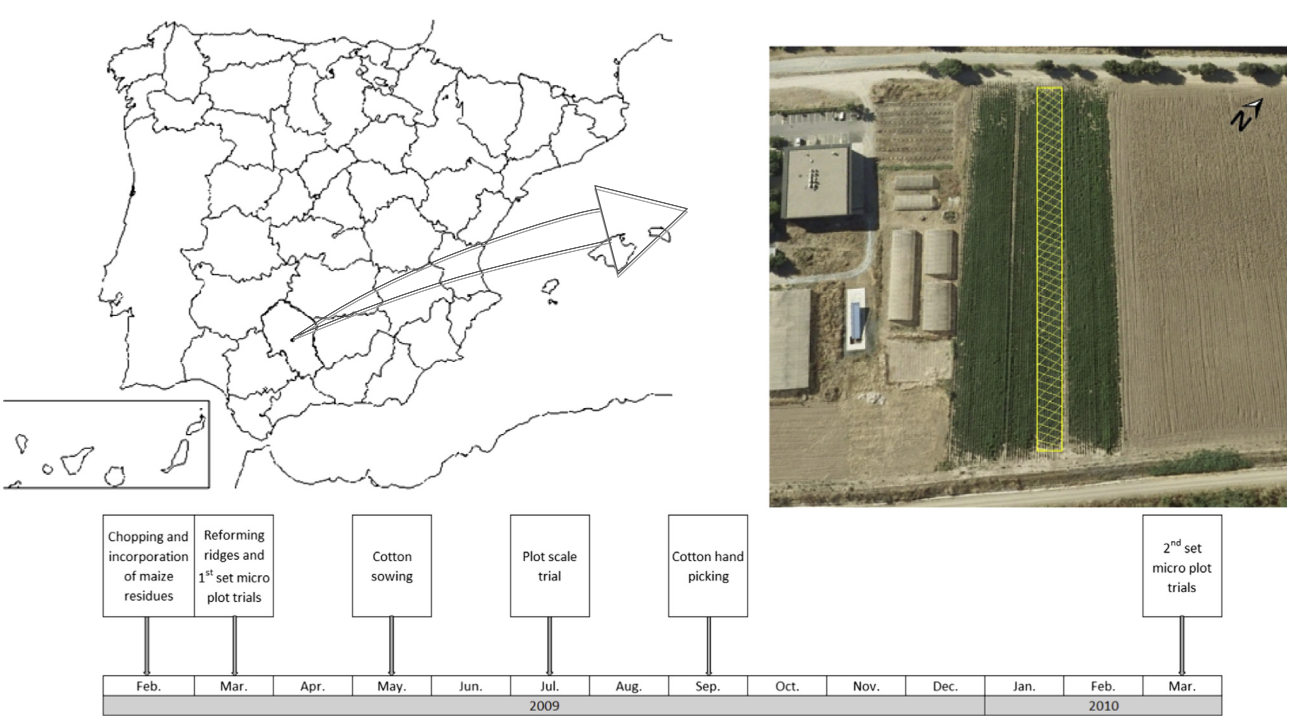

Fig. 1. Location and time line of management practices in the field site.