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Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain

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ABSTRACT

Rainfall, runoff and soil loss from 6 m × 12 m plots were recorded during 7 years (2000–2006) in an experiment in which three different soil management systems were compared in a young olive grove installed on a heavy clay soil, near Cordoba, Southern Spain. The no-tillage (NT) system, kept weed-free with herbicides, had both the largest soil loss (6.9 t ha^{-1} year^{-1}) and the highest average annual runoff coefficient (11.9%). By contrast, a cover crop (CC) of barley, reduced the soil losses to 0.8 t ha^{-1} year^{-1} and the average annual runoff coefficient to 1.2%. Conventional tillage (CT), had intermediate values of soil loss (2.9 t ha^{-1} year^{-1}) and an average runoff coefficient of 3.1%. The different treatments were established 4 years after planting the olive trees, and a significant decrease in soil and runoff losses was observed with time as the olive trees grew and their canopies developed. Measurements at the end of the experiment showed a significant improvement in the topsoil properties of the CC treatment as compared to CT and NT. The soil under NT presented a significant degradation with respect to traditional CT management. Organic matter values were 2.0, 1.4 and 1.0%, and stability in water of macroaggregates was 0.452, 0.418 and 0.258 kg kg^{-1} for CC, CT and NT, respectively. These results indicate that the use of a cover crop can be a simple, feasible soil and water conservation practice in olive groves on rolling lands in the region. A key factor in its practical use is to establish it early enough to protect the soil in the critical initial years of the grove, when most of the soil is unprotected by the small olive canopy.

1. Introduction

Olive is one of the most emblematic crops in Spain, and especially in Andalusia, its southernmost region. Andalusia is the main olive cultivation area in the world as it produces 39% of the world's olive oil and 24% of the table olive production (average figures of the period from 2000 to 2003 given by Consejería de Agricultura y Pesca, 2006; International Olive Oil Council, 2006). This production is achieved in Andalusia by devoting 17% of its total area to the olive. The olive crop represents 25% of the value of the Andalusian agrarian production (CEH-JA, 2006). Although commercial olive cultivation has been present in Andalusia since Greek and Roman times (Semple, 1931, Chapter XIV), its current position as the most important single soil use in Andalusia has been reached through several eras of expansion, from the second half of the 16th century to the early decades of the 20th century (Guzmán, 2005). Historically, olive cropping has been concentrated on hilly lands, where olive trees had to adapt to shallow, stony soils, and to dry conditions, whereas herbaceous crops were cultivated in flat areas with more fertile soils. This explains why, despite a recent trend towards new, more intensive plantations in valley areas, most olive groves in Andalusia are rainfed and planted in sloping areas. To date, 31% of the olive acreage in Andalusia is located on very steep terrains, on slopes of above 15%; 38% of the acreage is on moderate slopes, in the 7–15% range; the rest on slopes of under 7%. Only 16% of the olive acreage in Andalusia is on slopes of below 5% (Consejería de Agricultura y Pesca, 2003). Traditional olive production is based on low tree densities, i.e. about 100 trees ha^{-1}, weed control via frequent tillage and canopy size limited by pruning, to ensure the productivity and survival of the plantation in a limited rainfall environment. These features contribute to understanding why olive production in the region has been associated with severe soil erosion problems (Gómez et al., 2003) accompanied by fertility depletion and loss of biodiversity (Beaufoy, 2001), that worsened with the arrival of farm mechanization in the early 1960s.

Alternative soil management practices to conventional tillage, hereafter CT, have been developed, partially encouraged by the

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concern raised by water erosion (Pastor et al., 1999). These alternatives consist basically of no-tillage with herbicides to maintain a bare, weed-free soil, hereafter, NT; or the use of a cover crop grown during autumn and winter, either sown in early autumn or obtained via regeneration of the natural vegetation after the onset of rains, hereafter, CC. The cover crop is controlled by tillage, mowing or spraying with herbicide in early spring to prevent competition with the olive tree for water and nutrients.

Several studies have reported the use of runoff plots to evaluate soil erosion in mature olive groves. Raglione et al. (1999), in Southern Italy, measured total soil losses of 0.36 and 41 t ha^{-1} $year^{-1}$ for CC and CT, respectively, in a 2-year plot experiment. Kosmas et al. (1996) measured annual soil losses between 0 and 0.03 t ha^{-1} $year^{-1}$ in semi-natural olive groves in Greece with 90% of the soil covered by vegetation. In a 2-year study in Andalusia, Spain, Francia et al. (2006) measured soil losses of 25.6, 2.1 and 5.7 t ha^{-1} from NT, CC and CT, respectively. Also in Andalusia, Gómez et al. (2004) reported average soil losses of 8.5, 1.2 and 4.0 t ha^{-1} from NT, CC and CT in a 3-year experiment on a heavy clay soil, and Gómez and Giráldez (2007) reported average soil losses of 21.5 and 0.4 t ha^{-1} for CT and CC in a different 4-year experiment. Bruggeman et al. (2005) measured average soil losses of 41.4 and 11.2 t ha^{-1} $year^{-1}$ in orchards under CT and CC, respectively, in Syria in an area with a slope of 24% for a 4-year period. Even though the results of all these trials support the use of CC over other soil management practices for reducing runoff and soil loss, many of them had a limited duration (4 years at the most).

The effect of soil management on soil properties in olive orchards has been assessed in a few studies conducted in commercial farms (e.g. Álvarez et al., 2007, 2008; Milgroom et al., 2007; Soria et al., 2005; Hernández et al., 2005; Gómez et al., 1999; Vanderlinden et al., 1998). In general, these studies detected an improvement in the infiltration rate and in the organic matter content in the top soil of groves under CC management.

Despite the work described above, long-term studies that evaluate simultaneously the effects of different soil management on soil properties and on soil and runoff losses in olive groves are, to our knowledge, lacking. The results of a 7-year study in which the effects of three soil management methods on soil properties and on runoff and sediment losses were measured in a commercial olive orchard are presented here.

2. Methods

In 1999, a field experiment was established at "La Conchuela" farm, at 10 km west of Cordoba, Spain, 37°48′54″N 4°53′53″W and at 147 m above sea level. The plantation was installed in 1993 with trees at 6 m × 7 m spacing, although about 40% of the trees had to be replanted after a severe infection by *Verticillium dahliae*, associated with prolonged soil waterlogging in the spring of 1996. The trees were drip-irrigated. The average annual rainfall is 655 mm with 77% concentrated in the October–March period. The soil, formed on Miocene marls, has been classified as Typic Haploxerert (Soil Survey Staff, 1999), or Vertisol according to the FAO classification. It has an Ap horizon 0.45 m deep, with 49% clay and 47% silt content and 1.07% OM in 1998 (Ramírez, 1998), with a very fine granular structure. The subjacent horizon is an AC horizon, 0.45–1 m deep, with 46% clay and 46% silt and 0.5% OM with a prismatic structure. The C horizon from 1 m downwards has 44% of clay and 45% of silt and 0.3% OM. These soils are highly plastic when wet, and crack as they dry.

Nine closed runoff plots were established. Each plot was 6 m wide and 12 m long with the long side along the direction of the maximum slope. Each plot enclosed two trees that were aligned along the direction of the maximum slope in the centre of the plot. Both trees were 3 m away from each of the two longest (12 m) plot edges, with the first tree 3 m away from the outlet, and the second 9 m away from the same outlet. The average plot slope was 13.4%. The particle size distribution of soil in the nine plots was homogeneous. All the plot soils belonged to the silty clay texture class.

The runoff generated on each plot was collected and measured with a system of tipping-bucket gauges similar to that of Barfield and Hirschi (1986) with a 1-min resolution. A barrel located upstream of the tipping buckets acted as a sediment trap and the sediment concentration of the runoff collected in the barrels was used to calculate soil loss. Rainfall was measured with two gauges; one connected to a data-logger that recorded intensity at 1 min intervals, while the other, a cup-shaped gauge, measured total rainfall. The experiment was set up during 1999 and early 2000 when the different soil management treatments were established. Regular collection of runoff and sediment started on 1 September 2000. Since 1 September 2003, the average sediment concentration in the runoff downstream of the sediment traps was measured using a collection system based on that of Khan and Ong (1997) that collected runoff samples from each plot. After installing this system, the efficiency of the sediment traps was estimated by Eq. (1) (Gómez et al., 2004). The correction in Eq. (1) was applied to the soil loss measured for the period prior to September 2003,

$$SL_T = 1.4\,SL_{st} \qquad r^2 = 0.88 \tag{1}$$

where SL_T is the total sediment loss (calculated adding the sediment in runoff to the sediment in trap) and SL_{st} sediment loss calculated using the sediment trap. The efficiency of the traps was similar for all the plots and treatments. Runoff and sediment measurements ended in February 2006, because normal farming operations interfered with the maintenance of the runoff plots.

The experiment design consisted of three soil management systems replicated three times in a completely randomized block. The three soil management treatments were no-tillage, conventional tillage, and cover crop. NT consisted of maintaining the soil weed-free and bare with herbicide applications. The herbicide applied was glyphosate (Piton^{TM}, 0.36 kg a.e. L^{-1}, Dow AgroSciences^{TM}) at 2.1 kg a.e. ha^{-1} using a backpack sprayer that delivered a spray volume of 350 l ha^{-1}. This was done depending on the weed growth all through the season, and added up to between 3 and 5 applications per year, mostly concentrated in fall and spring. Conventional tillage, consisted of three to four passes, 0.15 m deep, with a rotary tiller (5.5 h.p.) per year, starting after the first rain in late September or early October to control weeds in the whole plot. The crop cover consisted of two strips (2 m wide and 12 m long each) of barley sown in October and killed with herbicide in early April, leaving the crop residue on the surface. The barley strips were sown parallel to the plot's longest edges, while a 2 m wide central strip across the plot (where the two trees were located) was maintained with bare soil using the same herbicide applications as in the NT treatment. Every year, a 0.1-m deep rotary tiller cultivator pass prepared the seedbed before sowing the barley. Soil management operations were maintained in the three treatments until June 2006.

In the second half of June 2006 soil samples were collected at two points at two different depths (0–5 and 5–10 cm) from each plot, always outside the tree canopy area. They were air dried, crumbled and passed through a 2-mm sieve for the determination of nine chemical and physical properties, two in the field and seven