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Three years of management with cover crops protecting sloping olive groves soils, carbon and water effects on gypsiferous soil

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ABSTRACT

Soils of olive grove are usually managed by tillage, leading to organic matter depletion and soil structure degradation. Cover crops to protect soils have been revealed as a sustainable land management practice for erosion control and remediation of degraded soils, but in some cases, water competition can be a problem, all these effects (particularly soil water) are site and climate specific. A trial in a rainfed olive grove in gypsiferous soils under semiarid Mediterranean climatic conditions has been set up in Central Spain.

Several parameters (plant cover, root density, organic carbon, organic nitrogen, aggregate stability, porosity, infiltration, water storage and soil penetration resistance) have been studied under different management practices: three types of cover crops, two annuals (legume and barley) and one permanent (*Brachypodium distachyon*); and minimum tillage. After three years of treatments, slight improvements in particulate organic carbon, aggregate stability, microporosity at 0–5 cm depth and soil water storage at 30 cm were found in cover crops; *B. distachyon* also increased organic carbon, and improved C/N ratio and available water. > 3 years of a sustainable land management are needed to recover olive groves soil quality in gypsiferous soils under semiarid climate. In this study, cover crops facilitated carbon stratification, higher SOC content in deeper layers are important in the context of carbon sequestration.

1. Introduction

In the Mediterranean Region the interactions between climate, topography, soil characteristics and human activity could led to short- and mid-term unsustainability of many land uses (García-Ruiz et al., 2013). Inappropriate agricultural practices are one of the main driving forces of soil degradation in Europe due to soil erosion and organic matter content decline (Gucci et al., 2012; Jones and Montanarella, 2003). The reconciliation of cultivation and soil conservation is sometimes difficult in Mediterranean environments (García-Ruiz et al., 2013), particularly in rainfed olive groves which are commonly cultivated on hillslopes and marginal lands (Gómez et al., 2009a; Zdruli, 2014). Soil productivity is compromised in these fragile areas where the scarcity and variability of water resources put the land in the limits of desertification, and make olive tree cultivation a potentially land degradation activity in most of Spain (Fernandez-Romero et al., 2016; García-Ruiz, 2010) mainly due to the traditional soil management based on frequent tillage (Xiloyannis et al., 2008). Soil erosion is the most visible sign of tillage (Fleskens and Stroosnijder, 2007; Gómez et al., 2009a). Moreover, this practice decreases soil organic matter content through increasing mineralization rates (García-Díaz et al., 2016; García-Ruiz, 2010), reduces infiltration capacity due to soil structure degradation (Palese et al., 2014), and also destroys olive roots in the plough layer reducing the tree water uptake capacity (Gómez et al., 1999).

Taguas and Gómez (2015) found that despite the use of different soil management techniques and the compliance of Common Agricultural Policy (CAP) agro-environmental regulations, unsustainable soil losses are still taking place. They concluded that the application of other conservation technologies in the agro-environmental requirements of CAP, like efficient use of cover crops, should be researched. Cover crops are one of the most effective sustainable land management (SLM) practice for erosion control and regeneration of degraded soil (Duran-Zuazo and Rodriguez-Pleguezuelo, 2008; Marques et al., 2016). Cover crops reduce runoff and soil erosion (Fleskens and Stroosnijder, 2007; Kairis et al., 2013; Gómez et al., 2014) by raindrops interception, favor autumn-winter rainwater storage in soil, improve soil structure (Palese et al., 2014) and increase soil organic carbon (SOC) content (Marquez-Garcia et al., 2013; Vanderlinden et al., 1998). Carbon sequestration in agricultural soils is also emerging as a simple and non-expensive tool to

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mitigate Global Climate Change (Lal, 2010; Vicente-Vicente et al., 2016); consequently, cover crops can be also a promising option to accelerate carbon sequestration (Pardo et al., 2017; Paustian et al., 2016).

In the last ten years, the use of cover crops in olive groves has been increased in Spain, prevailing spontaneous vegetation (Gonzalez-Sanchez et al., 2015). Nevertheless, cover crops set up, maintenance and efficiency are site-specific (Gomez, 2017). Even more, the establishment of effective ground cover in very steep areas, entails the need for additional investments or difficulties in terms of management operations (Gómez et al., 2014). Different circumstances may require different agronomic practices (Francia et al., 2006; Ruiz-Colmenero et al., 2013), and the literature shows that the use of cover crops can be controversial in semiarid areas due to water scarcity (Alcántara et al., 2011; Gómez et al., 2009b; Ruiz-Colmenero et al., 2011).

Gypsiferous soils are characterized by limited water availability, lack of plasticity and cohesion, structural deterioration, cemented and/or indurated layers, an imbalanced ion ratios, low organic matter content (van Alphen and Rios-Romero, 1971; Verheye and Boyadgiev, 1997). Gypsiferous soils are typically formed under arid or semi-arid climatic conditions covering approximately 100 million ha in the world (Verheye and Boyadgiev, 1997). This soil type appears in Mediterranean Region (Zdruli et al., 2010), mainly in Spain (Virto et al., 2015) and North Africa and the Midde East (Zdruli, 2014).

The Mediterranean Region is the largest olive production area worldwide with 9.7×10^6 ha from a total of 10.7×10^6 ha in the world (FAOSTAT, 2016). Most of the bibliography concerning cover crops in olive groves has been developed on calcic soils, e.g. Espejo-Perez et al. (2013), Gómez et al. (2009b) and Marquez-Garcia et al. (2013) in Spain, Kairis et al. (2013) in Greece and Palese et al. (2015) in Italy. The conclusions of researches in calcic soils might not be the same in gypsiferous soils due to the different soil properties.

Soil recovery after disturbance is a slow process in semiarid areas. Acin-Carrera et al. (2013) stated that > 4 years were needed to observe signs of recovery for calcic soils after the cessation of tillage. Gypsiferous soils make more difficult soil improvement, e.g. Bienes et al. (2016) found little changes in soil quality after 11 years of land abandonment and spontaneous growth of herbaceous vegetation or shrubs. Therefore, local climatic and edaphic conditions play a critical role to establish the nature and speed of soil changes. The current study can provide valuable information to assess the effects of cover crops under harsh conditions that can be transferred to rainfed olive growers in semiarid areas in order to foster the use of cover crops in gypsiferous soils.

The aim of this paper was to compare three types of cover crops in a rainfed olive grove under semi-arid climatic conditions, two of them annually seeded and one permanent compared to minimum tillage and evaluate their effects of on carbon sequestration and different soil properties after three years of management in: organic carbon and nitrogen and theirs fractions, root density, aggregate stability, soil porosity, bulk density, infiltration, water content and penetration resistance.

2. Materials and methods

2.1. Site description and climatic parameters

This study was performed in an experimental olive grove (*Olea europaea* L.) located in Central Spain, in southern Madrid (UTM 30N, ETRS89: X = 455,654, Y = 4,435,959). The elevation is c.a. 540 masl, and the slope ranges from 9 to 12%. The soil is classified as *Haplic Gypsisol* (IUSS Working Group WRB, 2014), with a *xeric* moisture regime. A soil pit was opened at the beginning of the study; the main characteristics are reported in Table 1. A high silt percentage was measured in all the horizons, with a moderate to low cation exchange capacity (CEC), moderate to high electrical conductivity (EC) and low soil organic carbon and total nitrogen contents.

The climate is Mediterranean semiarid, with long hot summers and cold winters. The mean annual temperature is 13.6 °C, with a thermal oscillation of 21 °C between January and July and reference evapotranspiration (ET_0 Penman-Monteith) is 1112 mm. The annual precipitation is approximately 390 mm with high inter and intra-annual variability. During the study period the mean annual precipitation was 284 mm and the ET0 was 1200 mm with a drier period between April and September (Fig. 1).

The olive plantation was established in 2004 with trees at $6 \times 7\ m^2$ spacing, covering an area of approximately 3 ha. The cultivar is *Cornicabra*, the most widely grown cultivar in Central Spain, drought tolerant and cold resistant (Rallo et al., 2005). This is a rainfed olive orchard since 2007, and no emergency irrigation has been applied during the study period. The mean yield was around 1400 kg ha^{-1} with the expected alternate bearing, typical of *Cornicabra* cultivar.

2.2. Experimental design

Before the trial starts, in November 2010, the whole area was tilled with a chisel at 0.25 m depth following the traditional management. The tillage was performed in 6 m-wide inter-rows. The treatments consisted of the following: 1) barley (*Hordeum vulgare* L.) annual cover, that was seeded each autumn (seed dose of 70 kg ha^{-1}); 2) sainfoin (*Onobrychis viciifolia* Scop.) a legume that was seeded each autumn (seed dose of 42 kg ha^{-1}); 3) purple false brome (*Brachypodium distachyon* L. P. Beauv., hereafter Brachypodium), a permanent grass cover seeded only the first year (seed dose of 40 kg ha^{-1}); and 4) minimum tillage (hereafter control) consisted of one pass per year with a chisel at 0.15 m deep in mid-November, to control weeds. Seed doses were settled to obtain similar ground cover between treatments. Each of the four treatments was performed in 3 consecutive inter-rows (Fig. 2). All treatments were mechanically mowed once in the spring (during the first fortnight of May), except in 2013, when the vegetation was mowed twice (the second cut was at the end of May) because of high vegetation growth resulting from the abundant rains of that spring. Plant debris was left on the surface like a mulch; the cut straw covered the soil but was also prone to be carried down by runoff during rains.

2.3. Plant cover

Plant and ground cover (%) were measured bimonthly, using quadrats $25 \times 25\ cm^2$, the resulting plant cover was the average of coverage judged by six trained observers.

2.4. Physical-chemical topsoil parameters up to 10 cm deep

2.4.1. Soil organic carbon and nitrogen

Three composite samples per treatment were taken in the inter-rows at two depths: 0–5 and 5–10 cm. Sieved samples (2 mm) were separated to analyze particulate organic-matter fraction (POM) and mineral-associated organic-matter fraction (MOM) following Cambardella and Elliott (1992).

Organic carbon (SOC and C-MOM) and total nitrogen (soil nitrogen (SN) and N-MOM) were determined by wet oxidation (Walkley and Black, 1934) and Kjeldahl digestion (Dewis and Freitas, 1970) respectively. The stock values of SOC and SN, given to a specific thickness, was obtained as follows:

$$Stock = conc. \times BD \times d \times (1 - \delta 2mm) \times 10^2 \quad (1)$$

where *Stock* is the stock of C or N (Mg ha^{-1}); *conc.* is the concentration of C or N (%); BD is the bulk density (Mg m^{-3}); *d* is the thickness (m); and *δ2mm* is the proportion of gravel larger than 2 mm.

C-MOM and N-MOM fractions were calculated by multiplying the dry mass of each fraction by the respective C and N concentration following Eq. (1). Soil carbon in POM fraction (C-POM) and total