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Long-term no-till as a means to maintain soil surface structure in an agroecosystem transformed into irrigation

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ABSTRACT

The aim of this study was to determine the most appropriate soil management to reduce the structural degradation of soils susceptible to crusting in Mediterranean areas recently transformed into irrigation. A long-term field experiment (LTE) under rainfed conditions was established in 1996 in NE Spain to compare three tillage systems (no-tillage, NT; reduced tillage, RT; conventional tillage, CT). The experiment was transformed to irrigated corn in 2015. In 2015, an adjacent experiment with the same layout was created (short-term experiment, STE) in an area previously managed under long-term NT. The study was carried out during the second corn growing season (i.e. year 2016). Soil samples were collected from 0 to 5 cm depth at different dates during corn season. Dry and water-stable macroaggregates and their C concentration, soil organic carbon (SOC) and labile C concentration, soil respiration, bulk density, penetration resistance (PR), water infiltration, macroporosity, microporosity, amount of crop residues and ground cover, corn development, aerial biomass, and grain yield were measured. In LTE and STE tillage led to a breakdown of dry sieved aggregates (of 2–4 and 4–8 mm size) in RT and CT, being slowly reconsolidated throughout the corn growing season. However, macroaggregate water-stability did not increase in CT and RT compared to NT due to a lower SOC concentration, making the soil more susceptible to its degradation by the action of water. SOC differences between treatments were more pronounced in LTE than STE given the long-term differential management in the first, which allowed greater accumulation of SOC under NT. In LTE, PR between corn rows was greater under NT than CT and RT and non-significantly different between treatments within the row. In the case of STE, PR increased over time after tillage (CT and RT) to match NT in the last sampling. Crop establishment was slower in CT than NT in LTE highlighting the impact of soil surface degradation on crop development. However, contrarily to the differences in corn yield in 2015, a careful planting in 2016 led to a lack of differences between tillage systems on corn yield. Our results indicate that in areas transformed into irrigation intensive tillage leads to greater susceptibility to soil structural degradation. Thus, in these areas the adoption of conservation agriculture practices such RT and NT enhances soil resilience to degradation processes and ensures an adequate development of the crop.

1. Introduction

Soil management practices affect both soil surface characteristics and crop productivity. Tillage exposes soil to erosive agents such as wind and water, inducing its degradation. Under severe erodible forces, soils are exposed to the impact of water-drops, either produced by irrigation or by rainfall. This last process results in the release of organic matter and, generally, in soil crusting (Awadhwal and Thierstein, 1985). In bare soils, structural crusts are a major problem facing many agricultural areas worldwide (Mbuvi et al., 2009). Structural crusts, developed on soil surface, negatively affect seedling emergence and reduce infiltration, favoring runoff and soil erosion (Fox et al., 2004). Furthermore, crusting is closely related to soil aggregation. In that sense, Bouaziz et al. (1990) found a linear relationship between soil aggregate size and the proportion of non-emerged wheat seedlings due to soil crusting.

In Mediterranean climate regions, an increasing number of rainfed areas are transformed into irrigation to stabilize or increase crop yields

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(Apesteguía et al., 2015). This conversion generates significant consequences in agroecosystems. Greater biomass production by irrigation leads to an increase in crop residues which can be returned to the soil. The increase of organic C inputs to the soil usually entails an increase in soil organic carbon (SOC) (Franzluebbers, 2005) and, concomitantly, an improvement in soil quality (Wick et al., 1998; Dexter et al., 2008). Moreover, C inputs play an essential role in the formation of soil aggregates, which physically protect SOC from microbial degradation (Beare et al., 1994) boosting SOC sequestration and climate change mitigation (Lal, 2011).

C-enriched aggregates are more stable to alterations such as rainfall, irrigation or tillage. Furthermore, crop residues protect the soil surface, preventing the formation of crusts (Jordán et al., 2010). Besides its importance in the Mediterranean climate regions, the impact of rainfed into irrigation transformation on soil surface characteristics (e.g., soil aggregation, soil organic carbon, bulk density, infiltration, penetration resistance and soil porosity) has been scarcely studied. Regarding to this, Apesteguía et al. (2015) observed an increase of the proportion of large macroaggregates under corn and wheat cropping systems managed under conventional tillage (chisel plow) when transforming a Mediterranean rainfed area into irrigation in north of Spain. Also, in Central Great Plains, Denef et al. (2008) found greater SOC storage in the surface soil layer (0–20 cm) in pivot-irrigated areas compared to dryland areas.

Tillage operations that incorporate crop residues into the soil increase soil susceptibility to degradation. When intensive tillage systems are adopted, soil remains bare until the next planting. Bare soils are more exposed to erosive agents and to drop impact promoting soil surface sealing and crusting and, at the end, water runoff (Pagliai et al., 2004). Tillage generally decreases soil bulk density compared to no-tillage (NT) (Lal, 1999) and it can negatively influence soil water infiltration, depending on soil type and properties (Dexter et al., 2004). For instance, Chan and Heenan (1993) and McGarry et al. (2000) reported lower infiltration rates under conventional tillage (CT) compared to NT. The adoption of NT systems has been identified as an optimal practice to reduce soil degradation and to improve soil aggregation in rainfed Mediterranean areas (Álvaro-Fuentes et al., 2009; Plaza-Bonilla et al., 2010). Moreover, it has been proved that long-term use of NT increases soil organic carbon (SOC) sequestration (Plaza-Bonilla et al., 2015). Similarly, Follett et al. (2013) showed that CT induced greater losses of old organic matter than NT in irrigated corn systems influencing soil physical properties. Soil organic matter plays a fundamental role in the formation and maintenance of aggregates, positively influencing the soil water retention capacity, water infiltration, and avoiding the formation of superficial crusts which improves seed germination and crop emergence.

In Mediterranean irrigated agroecosystems, typical soil management strategies include intensive tillage with deep subsoilers and mouldboard ploughs. However, unlike in irrigated systems, in Mediterrenan rainfed areas an increasing adoption of reduced tillage (RT) or NT techniques has been taking place over the last 30 years (Lampurlanés et al., 2016). In Mediterranean irrigated areas, the limited knowledge associated to the use of MT or NT systems, makes farmer adoption difficult and jeopardizes the soil quality benefits attained with long-term NT. As a consequence, the aim of this study was to determine to what extend soil management practices affect soil surface characteristics and crop establishment when transforming a rainfed area into irrigation in Mediterranean conditions.

2. Materials and methods

2.1. Experimental design

A field experiment was conducted in Agramunt, NE Spain (41°48′ N, 1°07′ E, 330 m asl), where the soil was classified as *Typic Xerofluvent* (Soil Survey Staff, 2014). Soil characteristics are presented in Table 1.

Table 1
Soil characteristics of Ap horizon (0–28 cm) at the beginning of the field experiment (1996).

Soil characteristic	
pH	8.5
$EC_{1:5}$ (dS m^{-1})	0.15
Organic matter (g kg^{-1})	9
P Olsen (ppm)	12
K (ppm)	155
Water retention (−33 kPa) (%) (g g^{-1})	16
Water retention (−1500 kPa) (%) (g g^{-1})	5
Sand (%)	46.5
Silt (%)	41.7
Clay (%)	11.8

The climate is semiarid Mediterranean with a mean annual precipitation of 430 mm and a potential evapotranspiration of 855 mm. Mean annual air temperature is 13.8 °C.

A rainfed long-term field experiment (LTE) was established in 1996 to compare three tillage systems (no-tillage, NT; reduced tillage, RT; conventional tillage, CT) under barley monocropping (Angás et al., 2006). In 2015 the LTE was transformed into irrigation by installing a fixed sprinkler irrigation system with a 18 × 18 m spacing and a maximum flow rate of 2.07 m^3 h^{-1} coming pressurized from the Segarra-Garrigues channel, and corn (Zea mays L.) monoculture as cropping system. The experimental design in LTE consisted of randomized blocks with three replications and a plot size of 50 × 6 m. After the transformation into irrigation, the LTE maintained the same tillage treatments (NT, RT and CT) and the same experimental layout as the previous rainfed experiment. At the same time, in 2015, a new tillage experiment was set up adjacent to the LTE (separated by a 15-m corridor). The layout of this new experiment (so called short-term experiment, STE) was exactly the same as the LTE (same tillage treatments, spatial arrangement and cropping system) but with different historical tillage management. For the last 20 years, the entire surface occupied by the STE consisted of a rainfed NT winter cereal system.

In LTE and STE, the CT treatment was implemented according to the traditional practices of the area for corn cultivation. It consisted of one pass of rototiller to 15 cm depth followed by subsoiler to 35 cm depth and to finish one pass of a disk plough to 20 cm depth with almost 100% of the crop residues incorporated into the soil. The RT treatment consisted of one pass of a strip-till implement on the corn planting row to 30 cm depth reducing the total area tilled to ca. 20%. Finally, the NT consisted of weed control with a non-selective herbicide (i.e. glyphosate) at 1.5 L ha^{-1} without no soil disturbance. Planting was carried out with a pneumatic row direct drilling machine equipped with double disc furrow openers (model Prosem K, Solà, Calaf, Spain) in the three tillage systems (NT, RT, and CT). Rotary residue row cleaners were installed to clear the path for the row unit openers. In this work we evaluated the second year after conversion into irrigation in LTE and STE. Tillage operations were conducted at the end of March and beginning of April 2016 (Table S1). Planting of corn (cv. Kopias) was performed on 22 April, at a rate of 90.000 seeds ha^{-1} with the rows 0.73 m apart. Mineral N fertilization was split in one pre-planting application of 50 kg N ha^{-1} with urea (46% N), on 12 April, and two top-dressing applications of 75 kg N ha^{-1} with calcium ammonium nitrate (27% N), on 31 May and 5 July, respectively. P and K fertilization consisted of 154 kg ha^{-1} P_2O_5, and 322 kg ha^{-1} K_2O applied at pre-planting, respectively. Irrigation was supplied to meet the estimated evapotranspiration (ET) of the crop minus the effective precipitation. Reference ET was computed with the FAO Penman–Monteith method from meteorological data obtained from an automated weather station located near the experimental site. Crop coefficients (Kc) were estimated as a function of the thermal time (Martínez-Cob, 2008). Weekly corn evapotranspiration was calculated from the corresponding weekly values of ET and Kc. Irrigation began on 19 April and ended on 14