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No-tillage permanent bed planting and controlled traffic in a maize-cotton irrigated system under Mediterranean conditions: Effects on soil compaction, crop performance and carbon sequestration

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ABSTRACT

Under irrigated Mediterranean conditions, no-tillage permanent bed planting (PB) is a promising agriculture system for improving soil protection and for soil carbon sequestration. However, soil compaction may increase with time up to levels that reduce crop yield. The aim of this study was to evaluate the mid-term effects of PB on soil compaction, root growth, crop yield and carbon sequestration compared with conventionally tilled bed planting (CB) and with a variant of PB that had partial subsoiling (DPB) in a *Typic Xerofluvents* soil (Soil Survey Staff, 2010) in southern Spain. Traffic was controlled during the whole study and beds, and furrows with (F + T) and without traffic (F − T), were spatially distinguished during measurements. Comparisons were made during a crop sequence of maize (*Zea mays* L.)—cotton (*Gossypium hirsutum* L.)—maize, corresponding to years 4–6 since trial establishment. After six years, soil compaction was higher in PB than in CB, particularly under the bed (44 and 27% higher in top 0.3- and 0.6-m soil layers, respectively). Around this time, maize root density at early grain filling was 17% lower in PB than in CB in the top 0.6-m layer. In DPB, the subsoiling operation was not effective in increasing root density. Nevertheless, root density appeared to maintain above-ground growth and yield in both PB and DPB compared to CB. Furthermore, at the end of the study, more soil organic carbon was stocked in PB than in CB and the difference increased significantly with a depth down to 0.5 m (5.7 Mg ha^{-1} increment for the top 0.5-m soil layer). Residues tended to accumulate on furrows, and this resulted in spatial and temporal differences in superficial soil organic carbon concentration (SOC) in the permanent planting systems. In PB, SOC in the top 0.05-m layer increased with time faster in furrows than on beds, and reached higher stable values (1.67 vs. 1.09% values, respectively). In CB, tillage homogenized the soil and reduced SOC in the top 0.05-m layer (average stable value of 0.96% on average for beds and furrows).

1. Introduction

Maize is the most important irrigated cereal crop in southern Europe in terms of surface and production (IEEP, 2000). The development of sprinkler and drip irrigation has resulted in an expansion of maize cultivation on a hilly terrain and, with this expansion, the risk of soil erosion has increased thus becoming a major environmental concern. Conservation tillage and residue retention are expected to protect the soil and reduce its erosion (Brouder and Gómez-Macpherson, 2014). However, adoption of any form of conservation agriculture is minimal in irrigated cereal-based systems in Mediterranean environments, mostly because of soil compaction and difficulties in managing crop residues (Gómez-Macpherson et al., 2009). Irrigated, permanent bed planting (PB) is a form of conservation tillage that could help to manage the large amount of crop residues (Boulal et al., 2012). PB has been studied in Australia (Hulugalle et al., 2010), China (He et al., 2008), India (Ram et al., 2012), Mexico (Verhulst et al., 2011a,b) and Uzbekistan (Ibragimov et al., 2011; Devkota et al., 2013) although its impact on crop yield is not clear. In previous studies, positive, negative or no effects have been reported (Devkota et al., 2013; Boulal

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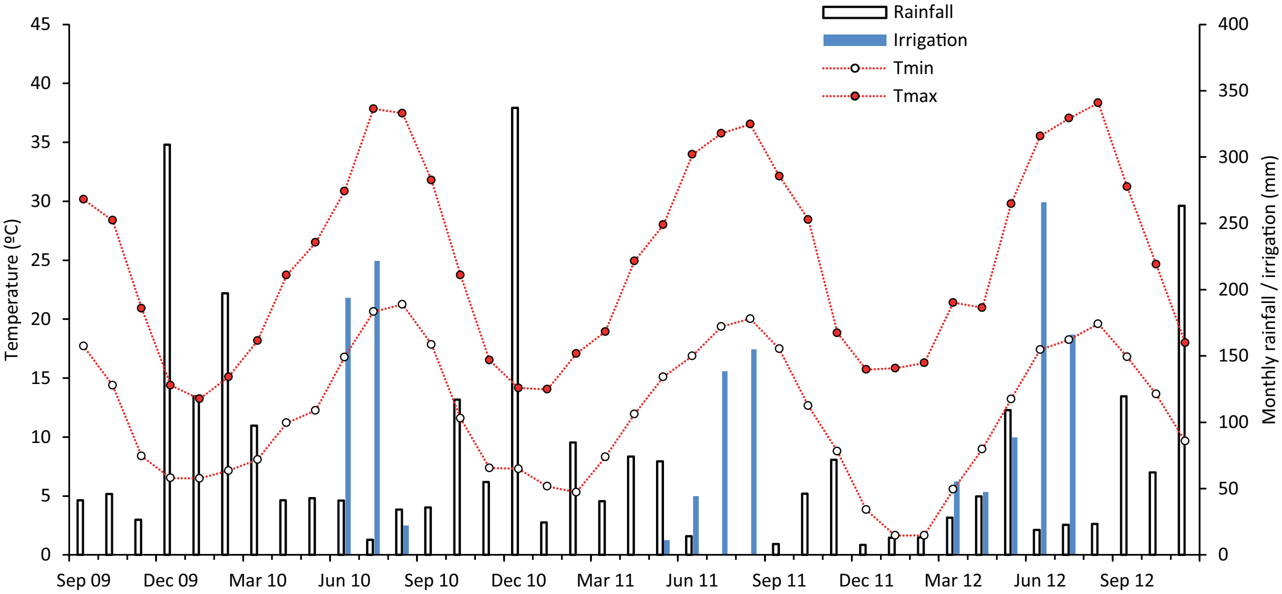

Fig. 1. Monthly cumulative precipitation (rainfall and irrigation) and average maximum and minimum temperature from September 2009 to September 2012 at the experimental site in Córdoba (Spain).

et al., 2012; Ibragimov et al., 2011; Govaerts et al., 2005; Ram et al., 2012).

Compared to conventional systems, where crop residues are baled, burned or buried during soil preparation, managing the large amount of residues produced in irrigated PB systems is a challenge, particularly at sowing. On one hand, crop residues decrease soil temperature at emergence and may result in poorer crop establishment (Ibragimov et al., 2011; Ram et al., 2012). On the other, the maintenance of residues is a key element in conservation tillage systems because crop residues directly protect the soil and reduce soil erosion (Boulal et al., 2011b) while promoting SOC accumulation (Verhulst et al., 2010), which, in turn, may increase soil carbon sequestration (Palm et al., 2014). Some authors have argued, however, that incorporating crop residues into the soil in conventional systems would result in increasing SOC in deeper soil layers, and, thus, deeper samplings are needed to detect differences between tillage systems (Baker et al., 2007; Blanco-Canqui and Lal, 2008; Govaerts et al., 2009). In Spain, most studies on soil carbon sequestration have been carried out under rainfed conditions and for shallow horizons (Álvaro-Fuentes and Cantero-Martínez, 2010; González-Sánchez et al., 2012). Nevertheless, differences would be expected in irrigated systems because of the larger amount of crop residues produced and the higher soil moisture and temperature during summer.

PB may also result in greater soil compaction (Verhulst et al., 2011b; Ram et al., 2012) although, when combined with controlled traffic, compaction can be confined successfully to certain furrows (Chamen et al., 1992; Li et al., 2007). Controlled traffic results in spatial variations in soil water infiltration and other soil properties (Blanco-Canqui et al., 2010; Gasso et al., 2013; Cid et al., 2013) but it is not clear how soil properties will evolve in the long-term and how these properties will affect crop performance (Botta et al., 2007). Soil compaction may reduce root growth without affecting above-ground growth or yield (Busscher and Bauer, 2003; Moreno et al., 2003), provided water and nutrient availability is adequate and there is a minimum root density (Guan et al., 2014). Other authors, however, suggest that soil strength directly induces a hormonal signal that reduces shoot growth without decreases in water or nutrient availability, at least in early stages (Masle and Passioura, 1987)

PB combined with controlled traffic in an irrigated maize-cotton rotation has resulted, in the short-term, in being a successful practice for protecting the soil and increasing superficial SOC, while maintaining crop yields (Boulal et al., 2012). Our working hypothesis is that this success can be sustained in the mid-term and, in the case of carbon sequestration, confirmed with deeper soil sampling. Although PB planting systems have been developed and tested around the world, we have not identified any studies under Mediterranean conditions, and we are not aware of any example in which PB has been associated with controlled traffic. The objective of this study was, therefore, to compare mid-term effects of PB and conventional bed plantings, both combined with controlled traffic, on soil compaction, SOC, and on below- and above-ground crop performance. Additionally, a decompaction treatment in PB was also evaluated as a complementary management practice for the system.

2. Materials and methods

2.1. Experimental site, planting systems, and farming operations

The study was conducted at Alameda del Obispo experimental farm (37°51′ N, 4°47′ W; altitude 110 m), in Córdoba, Spain. The climate is Mediterranean with a mean annual temperature of 17.6 °C and mean annual rainfall of 536 mm, most of which is concentrated between late autumn and early spring. Fig. 1 shows daily temperature and precipitation (rainfall and irrigation) during the study. The soil is a loamy alluvial, *Typic Xerofluvents* (Soil Survey Staff, 2010), of negligible shrinkage and without any apparent restriction to root growth to a depth of 3 m. Particle-size distribution consisted of 390, 470 and 140, and 470, 410 and 120 g kg^{-1} sand (0.05–2 mm), silt (0.002–0.05 mm) and clay (<0.002 mm), in the 0–0.5 m and 0.5–1.0 m soil layers, respectively. Estimated water storage at field capacity was 0.24 $m^3\ m^{-3}$, and at wilting point, 0.12 $m^3\ m^{-3}$.

This study was conducted during three years (2010–2013) as part of a long-term trial set up in 2007 to compare no-till bed planting (conservation tillage) and mulch-till conventional-bed planting systems (ASABE Standards, 2005), both combined with controlled traffic, in a maize–cotton rotation. Details of land previous history