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No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils

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ABSTRACT

Many soils in the semiarid Mediterranean Ebro Valley of Spain are prone to physical and chemical degradation due to their silty texture, low organic matter content, and presence of carbonates, gypsum or other soluble salts. Rainfed agriculture on these soils is also hindered by the scarcity of water. No-tillage can increase plant-available water and soil organic matter, thus helping overcome most factors limiting crop production in this area. Our objective was to determine how conventional- and no-tillage practices affected soil physical quality indicators and water availability in an on-farm study in the Ebro Valley. Soil samples were collected from 0 to 5-, 5 to 15-, and 15 to 30-cm depth increments within adjacent farmer-managed conventional- and no-tillage fields in 2007 and 2008. Both fields were managed for continuous barley (*Hordeum vulgare* L.) production. The soil at both sites is a silt loam (*Haplic Calcisol*). Aggregate-size distribution and stability, soil water retention characteristics, organic carbon, and total carbonates were determined in 2007. Pore-size distribution was estimated from the water retention curve. Penetration resistance, soil bulk density and field water content during the entire crop growing season were measured for both fields in 2008. Aggregate dry mean weight diameter and stability in water were 1.2 and 2.2 times greater, respectively, under no-tillage than conventional tillage due to reduced mechanical disturbance and increased soil organic carbon content. Bulk density was 1.12 times greater ($P < 0.1$) under no-tillage only in the 0–5-cm depth. Two times greater penetration resistance to a depth of 15 cm in this treatment was related to bulk density and aggregates stability. Field water content was greater with no-tillage than conventional tillage during the driest months in 2008. The volume of equivalent diameter pores (0.2–9 μm) was 1.5 times higher under no-tillage. This increased plant-available water content and doubled barley production under no-tillage in 2008, which was a very dry year. We conclude that despite the greater penetration resistance under no-tillage, increased water availability as a result of improved structure characteristics was more important for crop yield. This suggests that producers should seriously consider adopting no-tillage practices for soil conservation in semiarid degraded areas like the one studied.

1. Introduction

Soil physical properties strongly influence soil function and determine potential land uses. This is of special importance in the Ebro Valley of Spain, where they affect both plant-available water content and land degradation processes. Water frequently limits rainfed crop production in this area because of low precipitation (<450 mm) and an uneven interannual distribution. To mitigate that stress it is crucial to enhance plant-available water content which is directly affected by soil structure. This enhancement can be difficult, however, because soils of the Ebro Valley are usually characterized by silty texture, low organic matter content, localized accumulations of both geological and secondary gypsum and other soluble salts; factors affecting soil structure and resulting in a high potential for physical and chemical degradation.

Chisel-ploughing is one management practice that has been introduced for dryland production in the Ebro Valley during the last 20 years to decrease damage to soil structure (Angás et al., 2006). No-tillage is not used as much (10–30% of the land) even though it may be a better option to prevent soil degradation and increase plant-available water. The most widely used practice (i.e. conventional tillage in the area) is reduced vertical tillage with a chisel-plough.

To evaluate effects of management on soil physical quality, aggregate-size distribution, water stability of those aggregates,

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Table 1
General soil characteristics and particle size distribution under no-tillage (NT) and conventional tillage (CT) in 2007.

Tillage treatment	NT			CT		
Soil depth (cm)	0–5	5–15	15–30	0–5	5–15	15–30
Particle size distribution USDA (g/kg)						
Sand (50–2000 μm)	160.5	147.3	141.6	171.4	147.9	139.2
Silt (2–50 μm)	579.4	582.6	574.0	572.4	609.4	607.2
Clay (<2 μm)	260.0	270.3	284.3	256.2	242.6	243.6
Organic carbon (g/kg)	12.55	9.68	9.32	10.17	9.63	8.45
$CaCO_3$ (g/kg)	356	362	353	353	349	353
pH (water, 1:2.5)	8.39	8.51	8.50	8.35	8.47	8.50
Electrical conductivity (1:2.5) (dS/m)	0.15	0.13	0.12	0.24	0.13	0.16
Cation exchange capacity ($cmol_c$+/kg)	12.41	15.22	13.33	10.98	15.10	11.50

compaction, water retention and porosity have been widely used as soil quality indicators and are often referred to as dynamic physical quality indicators. Collectively assessing multiple indicators such as these, along with those reflecting biological and chemical properties and processes can be useful for quantifying changes in soil quality due to various management practices (Karlen, 2004).

One reason for suppression of tillage is that it temporarily alters soil structure, breaking apart the largest soil aggregates and disrupting their formation and stabilization cycles (Six et al., 1999). Most of the studies on this topic have been conducted on carbonate-free, neutral to acidic soils, as in Rasmussen (1999) for Scandinavian soils, Castro-Filho et al. (2002) for a Brazilian latosol, Zhang et al. (2007) for an Australian oxisol, and many others. They generally observed a higher mean weight diameter for dry aggregates and a greater percentage of water stable aggregates as tillage intensity decreased. Studies quantifying tillage effects on aggregation in calcium-rich soils, such as those in the Ebro Valley, where calcium plays an important role in the aggregate cycle (Muneer and Oades, 1989), are more scarce in the literature. Recently, Álvaro-Fuentes et al. (2007) observed that organic matter enrichment under no-tillage also enhanced aggregate stability in a loam calcic soil under similar semiarid conditions.

Tillage is often justified because without it compaction can lead to higher bulk density and increased penetration resistance, especially in the top few centimetres of soil. Many authors have found that semiarid no-tillage sites have greater bulk density and penetration resistance than reduced-tillage sites (e.g. Mahboubi et al., 1993; Lampurlanés and Cantero-Martínez, 2003). Such compaction is often characterized by a reduction in size distribution and stability of aggregates; two soil structure factors that provide resistance against external forces (e.g. wheel traffic).

Tillage and the resultant soil structure also influence soil water retention and its availability to plants. This is especially critical for crop production and temporal yield stabilization under semiarid conditions. No-tillage has been shown to increase soil water content through greater infiltration and reduced evaporation (Blevins and Frye, 1993; Cannell and Hawes, 1994; Lampurlanés et al., 2001), and by increasing the proportion of smaller pores (Arshad et al., 1999; Bescansa et al., 2006).

We hypothesized that no-tillage can provide an opportunity to improve soil structure and increase plant-available water content in soils that have lost in some degree of ability to sustain crop production, as a result of decreased physical and/or biochemical quality, under the semiarid conditions in the Mediterranean Ebro Valley of Spain. Our objectives were to quantify soil physical quality indicators and water retention characteristics for two, adjacent farmer-managed fields, one conventional- and one no-tillage, where rainfed barley was being grown. Through this analysis, we wanted to quantify the sustainability of no-tillage for this semiarid area where soils have a little structure development and high potential for degradation due to their physicochemical properties, and where water is the most limiting factor for crop production.

2. Materials and methods

2.1. Site description and experimental design

This study was conducted at two adjacent on-farm sites in the Ebro Valley following 7 years of either conventional- or no-tillage practices near the municipality of Santacara (42°23′44″N; 1°32′32″W; altitude 342 m a.s.l.) in the southern portion of Navarre. Conventional tillage (CT, consisting of chisel-ploughing to a depth of 15 cm) has been practiced for decades in the area. No-tillage (NT, using direct-seeding) was implemented in one of the fields in 2000, 7 years before this study was conducted. Both fields were managed for continuous barley (*Hordeum vulgare* L.) production, using the same seeding rate (160 kg/ha) and fertilizer treatments. The soil at both sites is a silt loam *Haplic Calcisol* (Word Reference Base, FAO, 2003) with high calcium carbonate content. Organic carbon content in both fields is low and decreases with depth. The slope is negligible in both fields. Additional details for both sites are given in Table 1.

Climate in the area is semiarid Mediterranean with an autumn/winter rainfall pattern and dry, hot summers. The average (30 years) annual precipitation is 448 mm with an evapotranspiration of 775 mm. Averages for the growing season (October to July) are 389 and 553 mm, respectively. During the two seasons that this research was conducted, (October 2006 through July 2008) mean rainfall was 494 and 338 mm, respectively (Table 2).

Fields for each tillage treatment were selected randomly within the same soil unit and treated as experimental units based on the model of Wander and Bollero (1999). Within each field a 12 m × 12 m grid was established. The main treatment was the tillage system (CT versus NT). Samples were collected at the four grid corners within each field, for three depth increments (0–5, 5–15, and 15–30 cm) in 2007 and 2008.

2.2. Soil sampling, laboratory analyses and field measurements

Soil organic carbon content (SOC) and total carbonate content were analysed in composite samples previously air-dried and sieved to pass a 2-mm sieve, in 2007. Due to the elevated carbonate

Table 2
Long-term average and seasonal rainfall and evapotranspiration at the study site in the Ebro Valley of Spain.

	Annual average (30 years)	Growing season (average)	Growing season 2006–2007	Growing season 2007–2008
Rainfall (mm)	448	389	494	338
ETP[a] (mm)	775	553		

[a] ETP, potential evapotranspiration (Thornthwaite).