Available online at www.sciencedirect.com
ScienceDirect
Soil & Tillage Research 96 (2007) 103–113
Soil & Tillage Research
www.elsevier.com/locate/still

Research paper

Dynamics of soil hydraulic properties during fallow as affected by tillage

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Received 10 August 2006; received in revised form 13 March 2007; accepted 9 April 2007

Abstract

There is limited information on the effects of tillage practices on soil hydraulic properties, especially changes with time. The objective of this study was to evaluate on a long-term field experiment the influence of conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) on the dynamics of soil hydraulic properties over 3 consecutive 16–18 month fallow periods. Surface measurements of soil dry bulk density (ρ_b), soil hydraulic conductivity ($K(\psi)$) at −14, −4, −1 and 0 cm pressure heads using a tension disc infiltrometer, and derived hydraulic parameters (pore size, number of pores per unit of area and water-transmission porosity) calculated using the Poiseuille's Law were taken on four different dates over the fallow period, namely, before and immediately after primary tillage, after post-tillage rains and at the end of fallow. Under consolidated structured soil conditions, NT plots presented the most compacted topsoil layer when compared with CT and RT. Soil hydraulic conductivity under NT was, for the entire range of pressure head applied, significantly lower ($P < 0.05$) than that measured for CT and RT. However, NT showed the largest mean macropore size (0.99, 0.95 and 2.08 mm for CT, RT and NT, respectively; $P < 0.05$) but the significantly lowest number of water-conducting pores per unit area (74.1, 118.5 and 1.4 macropores per m^2 for CT, RT and NT, respectively; $P < 0.05$). Overall, water flow was mainly regulated by macropores even though they represented a small fraction of total soil porosity. No significant differences in hydraulic properties were found between CT and RT. In the short term, tillage operations significantly increased K ($P < 0.05$) for the entire range of pressure head applied, which was likely a result of an increase in water-conducting mesopores despite a decrease in estimated mesopore diameter. Soil reconsolidation following post-tillage rains reduced K at a rate that increased with the intensity of the rainfall events.

Keywords: Tillage management; Hydraulic conductivity; Fallow period

1. Introduction

In Central Aragon (NE Spain), the traditional cereal/fallow rotation is the most common cropping system, which includes a fallow period 16–18 months long. Mouldboard ploughing during the early spring followed by repeated shallow tillage operations, remains the commonest form of fallow management. Tillage alters the structure of the topsoil layers and consequently their hydrophysical properties thus modifying the soil water regime. In order to define sustainable fallow management practices, knowledge of the dynamics of soil bulk hydraulic properties during fallow under field conditions thus appear to be of paramount importance.

With regard to the effects of tillage on the soil hydraulic properties under well-structured soil conditions, results for the different tillage treatments are not always consistent across locations, soils and experiment designs (Green et al., 2003). Chan and Heenan (1993)

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0167-1987/$ – see front matter
doi:10.1016/j.still.2007.04.003

and McGarry et al. (2000) observed higher values of hydraulic conductivity (K) under no-tillage relative to tilled treatments due to a greater number of macropores (Logsdon et al., 1990), increased fauna activity and the litter of residues formed by accumulated organic matter (Logsdon and Kaspar, 1995). Other researchers found, however, similar (Sauer et al., 1990) or lower (Miller et al., 1998; Evett et al., 1999) values of K under no-tillage treatment. In other studies where reduced tillage was compared with mouldboard ploughing, minimum tillage provided the highest values of K (Logsdon et al., 1993; Moreno et al., 1997), due to a different pore size distribution in the surface layer rather than to changes in total porosity (Moreno et al., 1997). In general, the water flow for structured soils is mainly conducted by macropores even though they constitute only a very small fraction of the total porosity (Sauer et al., 1990; Reynolds et al., 1995; Angulo-Jaramillo et al., 1997; Cameira et al., 2003).

In spite of the large number of field studies conducted to evaluate tillage effects on the hydraulic functioning of structured soils, the information available in the literature about short-term tillage-induced effects on the hydrophysical properties of agricultural soils and their dynamics over the fallow period is very scarce (Green et al., 2003). Results from studies on this subject have shown that the loosening of surface soil by tillage operations increases the total soil porosity (Logsdon et al., 1999; Miller et al., 1998; Green et al., 2003). On the other hand, although a destruction of macropores and macropore continuity is probable after tillage (Malone et al., 2003), an increase in K has commonly been observed in recently tilled soils (Messing and Jarvis, 1993), probably as a consequence of an increase in the number of active mesopores. Tillage operations, however, have a transitory effect on soil physical characteristics because of the impact of rain on the freshly tilled soil, which promotes a steady breakdown of soil structure (Green et al., 2003). Soil structural changes in recently tilled soil caused by precipitation and associated wetting and drying cycles thus lead to a decrease in K (Cameira et al., 2003; Schwartz et al., 2003), which can be attributed to a reduction in the fraction of conductive mesopores (Messing and Jarvis, 1993) in conjunction with a concomitant increase in bulk density (Mellis et al., 1996). However, as a recent review by Green et al. (2003) has made clear, further research is needed to improve current knowledge of the influence of tillage on the soil hydrophysical properties of freshly tilled soils.

The present work is part of a long-term conservation tillage experiment initiated in 1989 to assess soil and crop responses under different tillage systems in a dryland semiarid cereal-growing area of Central Aragon. The study aimed (i) to evaluate the effect of conventional and conservation tillage systems on soil bulk hydrophysical properties after 8–10 years of trials; (ii) to quantify the dynamics of these soil properties over 3 long-fallow periods.

2. Materials and methods

2.1. Experimental site and procedures

The site is located at the dryland research farm of the Estación Experimental de Aula Dei (CSIC) in the province of Zaragoza (latitude 41°44′N; longitude 0°46′W; altitude 270 m). The climate is semiarid with an average annual precipitation of 390 mm and an average annual air temperature of 14.5 °C. Soil at the research site is a loam (fine-loamy, mixed thermic Xerollic Calciorthid) according to the USDA soil classification (Soil Survey Staff, 1975). Particle size distribution for the plough layer (0–40 cm) averages 25% clay, 47% silt and 28% sand. Selected physical and chemical properties of the soil for this layer were given in López et al. (1996).

The study was conducted on two adjacent large blocks of plots, which were set up on a nearly level area (slope 0–2%) of land in 1991 (Field 1) and 1992 (Field 2) within a long-term conservation tillage experiment initiated in 1989. The two fields were in a winter barley (*Hordeum vulgare* L.)-fallow rotation, with each field cropped in alternate years. This study was conducted when both fields were in the long-fallow phase of this rotation, which extends from harvest (June–July) to sowing (November–December) the following year. Field measurements were made during three fallow seasons: 1999–2000 and 2001–2002 fallows in Field 2, after 8 and 10 years of the trial, and the 2000–2001 fallow in Field 1, after 10 years of the trial (Fig. 1).

Three different fallow management treatments were examined: conventional tillage (CT), reduced tillage (RT) and no-tillage (NT). The CT treatment consisted of mouldboard ploughing of fallow plots to a depth of 30–40 cm in late winter or early spring, followed by secondary tillage with a sweep cultivator to a depth of 10–15 cm in late spring. In the RT treatment, primary tillage was chisel ploughing to a depth of 25–30 cm (non-inverting action), followed, as in CT, by a pass of the sweep cultivator in late spring. The dates of the primary and secondary tillage operations, which were the same for the CT and RT treatments, were 25 April 2000, 10 April 2001 and 13 March 2002 for primary