



Impact of conventional and minimum tillage on soil hydraulic conductivity in typical cropping system in Southern Italy

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ABSTRACT

Soil structure is one of the most important soil characteristics that can be modified by tillage practice due to the effects on porosity (shape, volume and continuity of pores) and soil hydraulic conductivity contributing to create optimal conditions to plant growth and crop establishment.

Continual soil inversion can in some situations lead to a degradation of soil structure, decreasing in available soil water, depletion of soil organic carbon, and increasing greenhouse gases emissions into the atmosphere.

The main objective of this work was to evaluate, under semi-arid Mediterranean conditions of Southern Italy, the effects of soil tillage on the soil hydraulic conductivity (K) evaluated for three consecutive years in a long-term research (over 20 years) regarding a cultivation of winter durum wheat.

The effects of soil tillage on hydraulic conductivity were evaluated by means of infiltration experiments carried out in 3 years on a clay soil submitted to conventional and minimum tillage. Starting of measurements of single values the K functions, effective porosity (as number and volume of pores per unit area) and contribution of macropores and mesopores were determined.

The bimodal two-line exponential functions were found to be adequate to describe K near saturation quantifying the water flux in the macro–mesopore system, with large increases in K observed for small increases in soil water pressure head regardless of tillage management.

Our results highlighted a significant equivalence of soil hydraulic properties between conventional and minimum tillage. Therefore, for the case study carried out for the typical cropping system of Southern Italy, the shallow soil tillage can be considered preferable to deepest plowing because of lower impact in term of cost and greenhouse gases emissions in the environment.

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1. Introduction

Tillage is the most common way to modify the soil structure due to the effects on porosity (shape, volume and continuity of pores) and soil hydraulic conductivity (Hillel, 1998) and, thus, it contributes to create optimal conditions to plant growth and crop establishment.

The term conventional tillage, CT, defines a tillage system in which a deep primary cultivation, such as moldboard plowing, is followed by a secondary cultivation to create a seedbed.

The impact of conventional and conservation tillage on near-saturated hydraulic properties has been well investigated using tension infiltrometer, from medium-textured (Moreno et al., 1997; Miller et al., 1998; Cameira et al., 2003; Moret and Arrúe, 2007a,b) to moderately coarse soils (Daraghmehe et al., 2008), but few works were carried out in fine texture soils (Miller et al.,

1998), probably because the preferential flow, that in general characterizes such soils is difficult to be described (Bouma and Wösten, 1984) and requires rather complex mathematical equations.

Hendrickx and Flury (2001) defined preferential flow as “all phenomena where water and solutes move along certain pathways, while bypassing a fraction of the porous matrix”. Thus, an important characteristic of preferential flow is that during wetting, part of the moisture front can propagate quickly (through shrinkage cracks, worm channels or old root holes) to significant depths while bypassing a large part of the matrix pore-space (Šimůnek et al., 2003).

The importance of macropore and mesopores to water flow in soils, particularly to infiltration and rapid movement of water, solute and pollutants through soils are well highlighted (Beven and Germann, 1982; Luxmoore et al., 1990; Ankeny et al., 1990). Macropore represents inter-aggregate porosity, characterized by a large degree of continuity structural. However, the mesopore system consists of inter-aggregate pores with less continuity and higher tortuosity (Messing and Jarvis, 1993).

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The choice of an effective size to delimit macropores is necessarily arbitrary and often related more to details of experimental technique than to considerations of flow processes (Beven and Germann, 1982). However, according to the soil pore classification (SSSA, 2008), macroporosity and mesoporosity represents those pores that drain at <3 cm and between 3 and 300 cm water tension, respectively (Luxmoore, 1981).

Watson and Luxmoore (1986) used the tension infiltrometer technique to estimate the concentration of effective macro- and mesopores on soil surface, but many other examples of similar applications can be found in the literature (Azevedo et al., 1998; Cameira et al., 2003; Bodhinayake and Si, 2004; Buczko et al., 2006; Carof et al., 2007; Moret and Arrúe, 2007b; Daraghmeah et al., 2008; Schwen et al., 2011).

For two agricultural soils with different textures (sandy loam and silty loam), for example, Buczko et al. (2006) showed values of effective macroporosity range for both sites between 0.001 and 0.2% and highlighted that these value are very similar to those determined in many other study (Bodhinayake and Si, 2004; Cameira et al., 2003; Watson and Luxmoore, 1986).

More recently, Daraghmeah et al. (2008) reported, for a sandy loam soil under long-term winter wheat cropping, a similar range of effective macroporosity (0.0017–0.0177%) whereas Schwen et al. (2011) found, for a silt loam soil, similar values of effective macroporosity (about 0.002–0.012%) over two consecutive years.

In every case, regardless to the specific characteristics of the considered agricultural soil (i.e. texture, soil tillage and land management), relatively small values of effective macroporosity (about 0.2%), represents a large part of the total saturated flux (about 70–80%).

A possible limitation of infiltrometric techniques is that it assumes that the soil is rigid, homogeneous and isotropic, which is not true for a vertic clay soil. Nonetheless, these techniques are commonly applied in real soils notwithstanding that they are not perfectly rigid, homogeneous and isotropic (Bagarello et al., 2010a). For example, Gómez et al. (1999) used Wooding's analysis to analyze steady-state tension infiltrometer data collected in a vertic soil, but many other examples can be found in the literature, including those by Messing and Jarvis (1993), Potter et al. (1995), Reynolds and Zebchuk (1996), Miller et al. (1998), Ventrella et al. (2005), and Das Gupta et al. (2006).

For a clay soil, Lin and McInnes (1995) recommended the tension infiltrometer technique in order to characterize the effects of non-uniform flow (bypass or macropore flow) on hydraulic properties. However for the clay soils, the presence of cracking, both superficial and subsurface, usually makes difficult, if not impossible, to use the tension infiltrometers both for measuring the soil infiltration and for the estimation of the hydraulic conductivity through the solution of Wooding's analysis. In fact, in such cases a very fast depletion of infiltrometer water reserve can occur making impossible the water infiltration rate determination.

In any case, the hydraulic conductivity obtained by an infiltrometric technique, when it is feasible, should be considered as an equivalent conductivity, i.e. the conductivity of a rigid, homogeneous and isotropic porous medium characterized by infiltration rates that are the ones actually measured on the real soil (Bagarello et al., 2010a).

Numerical models for uniform water flow are usually based on the Richards equation, for variable saturated water flow. Porous media is viewed as a series of impermeable soil particles (or soil aggregates), separated by pores through which flow takes place. The Richards equation, that requires knowledge of the unsaturated soil hydraulic properties, specifically $\theta(h)$ and $K(h)$ relationships, has been combined with other mathematical expressions to yield alternative approaches accounting for different forms of nonequilibrium preferential flow (Durner, 1994).

Preferential flow in structured media can be described using a variety of models taking into account dual-porosity, dual-permeability, multi-porosity and/or multi-permeability (Šimůnek et al., 2003).

Dual-porosity models assume that water flow is restricted to macropore (or inter-aggregate pores and fractures) and that water in the matrix (intra-aggregate and soil matrix) does not move at all. This conceptualization induces to consider a two-region model that divides the liquid phase into mobile (flowing, interaggregate) and immobile (stagnant, intraaggregate) regions. Therefore, water can move from the main pore system into the soil aggregates and vice versa, but not directly between themselves.

However, in real situations, water moves directly between soil aggregates. Because of this reason, dual-porosity models were proposed, they assume that the porous media consists of two overlapping pore domains, with water flowing relatively fast in one domain (often called the macropore, fracture or crack), active when the soil is close to full saturation, and slowly in the other domain (often called the micropore or matrix). Like dual-porosity model, dual-permeability models permit the transfer of water between the two pore regions (Šimůnek et al., 2003).

Multi-porosity and/or multi-permeability models are based on the same concept, but include additional interaction pore region (Šimůnek et al., 2003).

Undisturbed soils may exhibit retention curves with more than one inflection point, due to specific particle-size distributions or be due to the formation of secondary pore systems (multimodal pore size distribution). Hence, the bimodal soil system has two inflection points, whereas multimodal soil system has more than two (n) inflection points.

Closed-form van Genuchten type models (van Genuchten, 1980) for the soil water retention and hydraulic conductivity, however, appear to be inaccurate when the soil has a bimodal or multimodal pore size distribution (Mohanty et al., 1997).

Different composite retention and hydraulic conductivity functions, for two overlapping porous media, were suggested by Othmer et al. (1991), Smettem et al. (1991), Durner (1994), Mohanty et al. (1997), Ross and Smettem (2000) among others. For example, Othmer et al. (1991) described the bimodal retention and the conductivity curves as the superposition of two van Genuchten–Mualem type curves, concluding that a two-domain model is the best for describing the bimodal water fluxes in the soil. Mohanty et al. (1997) used a van Genuchten–Mualem model for the capillary-dominated flow and an exponential function to account for the non-capillary-dominated flow domain, whereas Jarvis and Messing (1995) used a more simple two exponential function of the Gardner type (Gardner, 1958) that accounts for a rapid increase in hydraulic conductivity near saturation (Caron and Elrick, 2005).

The main objective of this work was to determine, under semi-arid Mediterranean conditions of Southern Italy and for a clay soil, the effects of soil tillage (minimum and conventional) on the soil hydraulic conductivity evaluated for three consecutive years, in a long-term research (over 20 years) regarding a cultivation of winter durum wheat.

2. Materials and methods

2.1. Field site

The infiltration experiments were carried out in Foggia (41°27' latitude N, 15°32' longitude E, 90 m above sea level), in a typical flat area of Southern Italy, the “Apulian Tavoliere”, at the Experimental Farms of the Agricultural Research Council – Research Unit for Cropping Systems in Dry Environments.

The soil is a Vertisol of alluvial origin, classified as fine, mesic, Typic Haploxerert (USDA) with the surface layer (0–40 cm)

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