Toward Sustainable Agriculture: Soil Management and Hydraulic Properties

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Introduction

Sustainable soil management requires a continued evaluation of soil structural quality under conventional and alternative soil management practices to impede further depletion of soil resources. Furthermore, understanding of the temporal changes of soil hydraulic properties will improve the knowledge of soil-water management and modeling aspects. Evaluating the impact of agricultural practices on agroecosystems functions is essential to determine the sustainability of management systems (Liebig et al., 2001), which cover the productivity, economic, social, and environmental components of land use systems (Smith and Dumanski, 1995).

Soil tillage is the most important external forces considered as a guiding component in soil management. Conservation tillage methods are the most promising approach. Adoption of conservation tillage has revealed beneficial long-term effects on soil physical, chemical, and biological properties (Cannel and Hawes, 1994; Tebrügge and Düring 1999; FAO, 2000; Holland, 2004) compared with conventional tillage. Tillage has long been recognized as an important determinant of the infiltration-runoff relationship (Edwards, 1982). The hydraulic properties of near-saturated soil are very important for water and solute transport processes that normally occur with the highest rates near saturation (Bagarello et al., 2005; Wilson and Luxmoore, 1988).

Field measurements of *unsaturated hydraulic conductivity* $K(h)$ are used to indirectly characterize soil macrostructure under different soil management practices (White et al., 1992). The pore size distribution is highly influenced by soil tillage, creating a loose and fragmented macropore-rich soil structure which however is unstable and collapses with time (Hillel, 1998; Ahuja et al., 1998). Since soil management and tillage practices can dramatically change macroporosity (Ogden et al., 1999), disk tension infiltrometer is a valuable tool for indirect non-destructive soil structure measurement, which can be used for quantifying alteration in macroporosity and changes in infiltration properties (Perroux and White, 1988). The main objective of this study is to review the current soil management practices (tillage) in the Palestinian areas, and present results of a case study from Europe.

Methodology

Detailed soil properties and climatic conditions during the study period are presented in Daraghmeh et al. (2008 and 2009).However, the investigations were carried out on the topmost soil layer (0-3.5 cm) of a uniform sandy loam morainic Agrudalf soil grown with winter wheat. The soil had been subjected to two different tillage treatments for 7 years: (i) conventional tillage (CT) with annual mouldboard ploughing to about 28 cm followed by seedbed preparation, and (ii) reduced tillage (RT) including annual shallow tillage with a springtine harrow to about 10 cm.

Infiltrometer measurements were conducted in the trafficked and non-trafficked areas of conventional and reduced tillage treatments at 4 supply pressure heads *h* of -15, -30, -60, and -120 mm. Supply pressure heads were applied successively at the same topsoil position from high to low pressure to form a wet to dry sequence as used by others (Ankeny et al., 1991; Logsdon and Jaynes, 1993; Mohanty et al., 1994) as also reported in Daraghmeh, et al. (2008)).

Water retention curves at -1.75 to -150 cm pressure head were determined for each soil core using the hanging water column method (Dane and Hopmans, 2002). The water retention data were fitted to the van Genuchten model (vG-model; van Genuchten, 1980) for interpolation purposes and to the Brooks and Corey model (BC-model; Brooks and Corey, 1964) for estimating the air entry value (residual water content of both models = zero). The models were fitted to the experimental data pooling all replicates using RETC program (van Genuchten et al., 1991).

Effective porosity (ϕ_e, %) was calculated by applying the capillary rise equation in conjunction with Poiseuille's law as described by Watson and Luxmore (1986). Accordingly, the fractional volumes of three pore size classes (by radius) were determined from the infiltration measurements: Pore Class 1 (PC1), 1.0 to 0.5 mm; PC2, 0.5 to 0.25 mm; and PC3, 0.250 to 0.125 mm.

Results and Discussions

Topsoil properties

Bulk density (ρ_b) in general, increased with time during the whole tillage year from October (Fig. 1). The overall pattern of variation in ρ_b and w_C was similar for the two tillage treatments, but with generally higher wetness and lower bulk density in the RT treatment as compared with CT. The seasonal variation of ρ_b may be ascribed to loosening and soil aggregate fragmentation effect of tillage (Oct) as reported by several authors (e.g. Shipitalo, 2000; Ghezzehei and Or, 2000) followed by collapsing of the generated unstable surface (Dec), soil resettling, and rainfall impact (Apr-Jun).

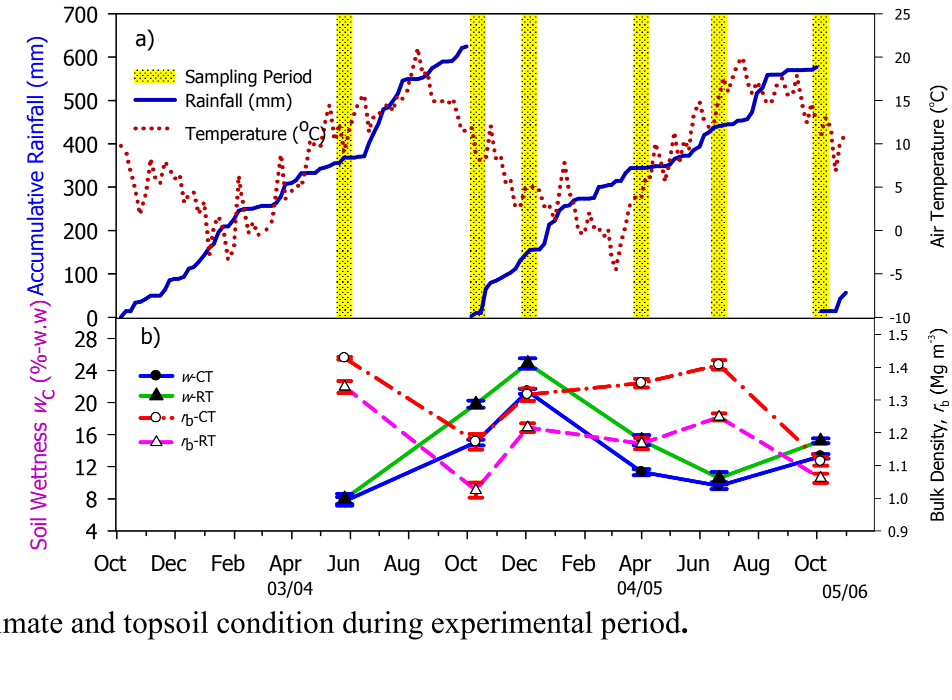

Fig. 1. Climate and topsoil condition during experimental period.

Soil hydraulic properties

Results indicated a substantial annual variation of infiltration rate (*i*) during the tillage year over the 4 supplied pressure heads (-15, -30, -60, and -120 mm; Fig. 2). The temporal changes *i* showed a large variability during the tillage year. Generally *i* at any *h* was higher shortly after tillage (Oct-04 and Oct-05) than at any other time during the tillage year as a direct result of soil loosening and fragmentation after tillage. Several factors could affect near saturated hydraulic conductivity during the tillage year, e.g. soil aggregate stability and the interactions with the natural processes as reported by Mapa et al. (1986) who found a high sensitivity to wetting and drying cycles subsequent to tillage.

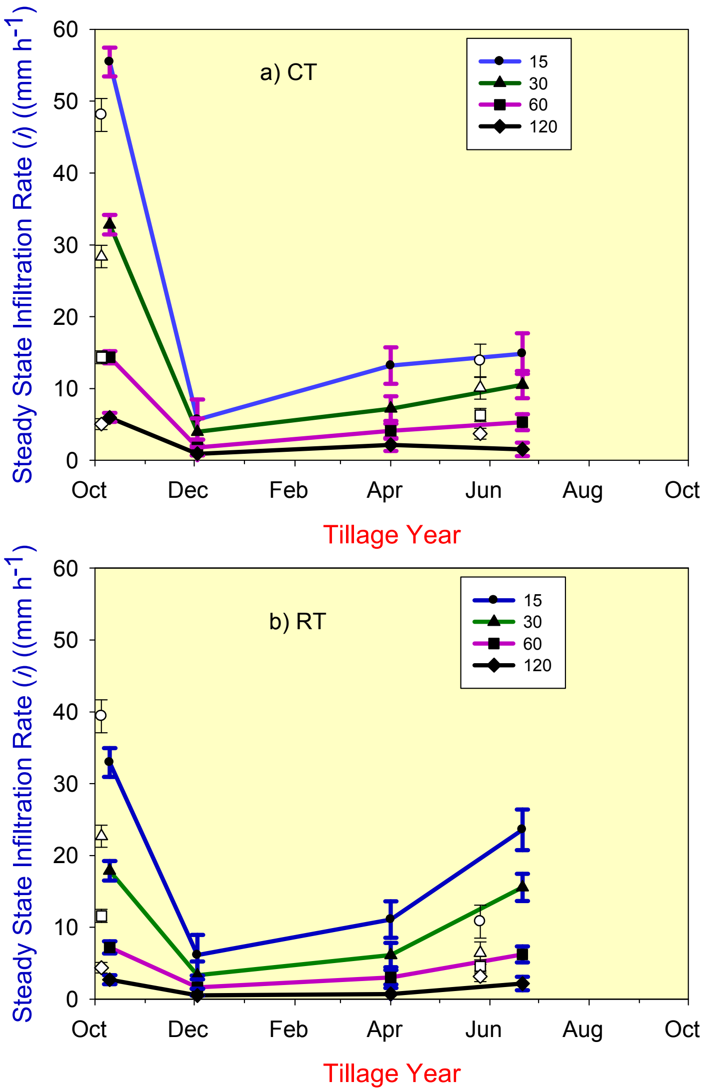

Fig. 2. Steady state infiltration rate (with standard error bars) during the tillage year 2004/05. a) conventional tillage. b) reduced tillage. (Open symbols, May-04 and Oct-05).

Tillage had a significant effect on the measured *i* values during the tillage year. Infiltration rate decreased more under CT than RT with decreasing supply pressure heads, indicating the importance of large pores in water transmission in CT shortly after tillage (Oct-04 and 05). This may indicate that soil under CT had a well connected and structured pores network, whereas RT had higher void volume as indicated by the lower bulk density but possibly these pore with less connection resulting in lower *i* after tillage. All treatments showed one order of magnitude of reduction in *i* over the range in *h* as a result of successively excluding large pores participating in water transmission, a long all the sampling occasions, with the greatest reduction at sampling shortly after tillage.

In addition to the water transmission properties, soil water retention characteristics were also evaluated under the different treatments and during the study period (Fig. 3). Studying soil water retention is fundamental to quantify the flow of water and dissolved substances in the subsurface (Haverkamp et al., 2005). Parameters of Brooks-Corey model (pore size distribution index, λ and air entry pressure heads, h_a) varied during the tillage year. Clear variations in h_a were obvious under the different treatments with a generally decrease in h_a with time and higher in RT than CT. Soil water content varied between the tillage practices during the tillage year and was generally, higher under RT than CT. RT had significantly λ, than CT, over the sampling times except the one shortly after tillage (Oct-05) where insignificant values were recorded. It appears that improvement in soil aggregation processes due to the increase in SOM under RT (Daraghmeh et al., 2009) lead to this improvement in pore space and hydraulic conductivity under non-trafficked RT. This confirms the model of Elliott and Coleman (1988) regarding concurrent formation of soil aggregates and pore space. The development of pore sizes is mentioned in more detailed in Daraghmeh et al. (2008).

The effective porosity in the macro-meso range of 1 to 0.125 mm pore radius, dynamically determined from the infiltration flux, was highest shortly after tillage and lowest in winter followed by the restructuring in spring and early summer (Fig. 4). Compared with CT, the effective porosity under RT was lower shortly after tillage but higher in early summer after the recovery.

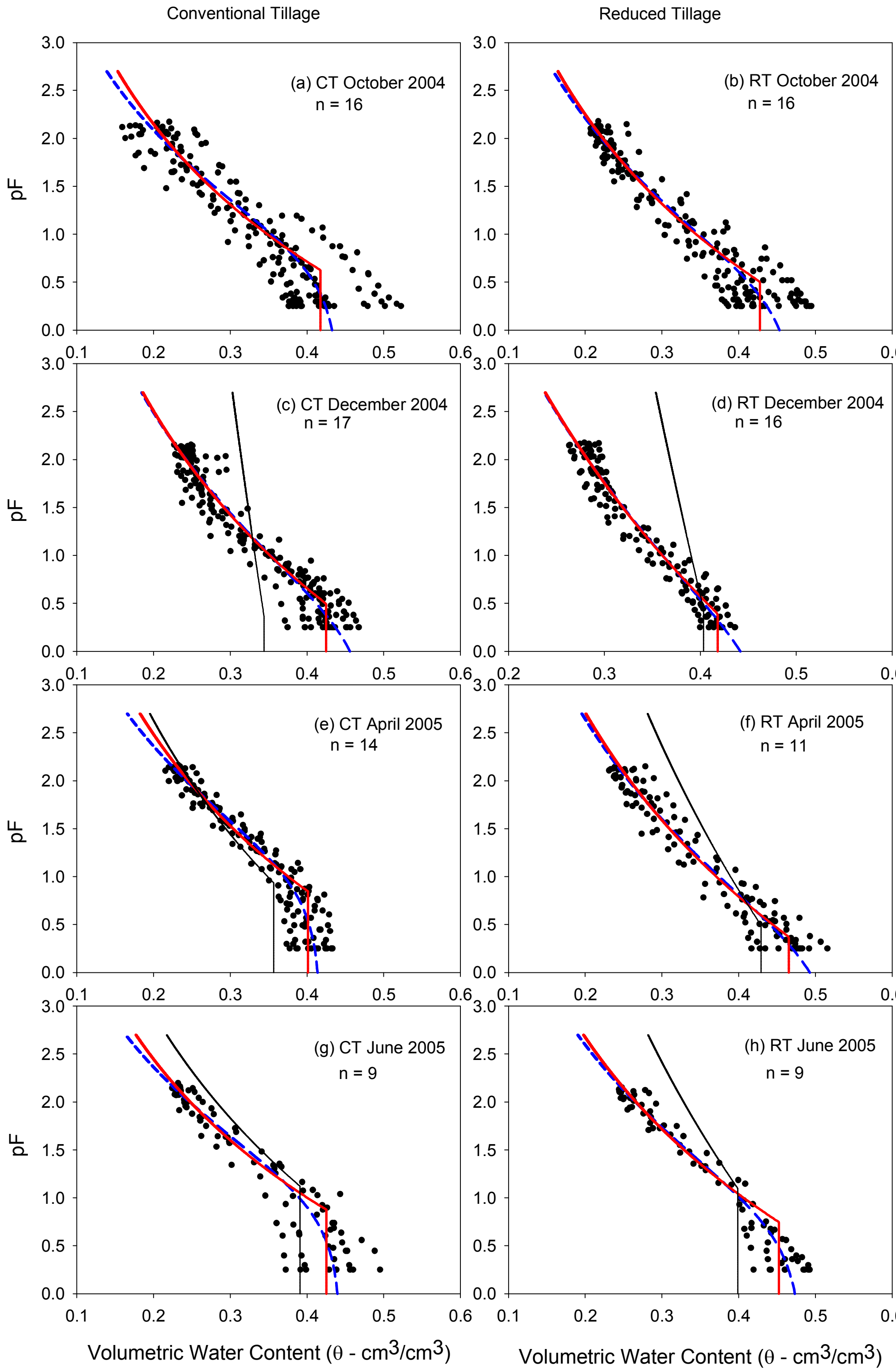

Fig. 3. Soil water retention under conventional (CT) and reduced (RT) tillage at sampling time during the tillage year 2004/05.

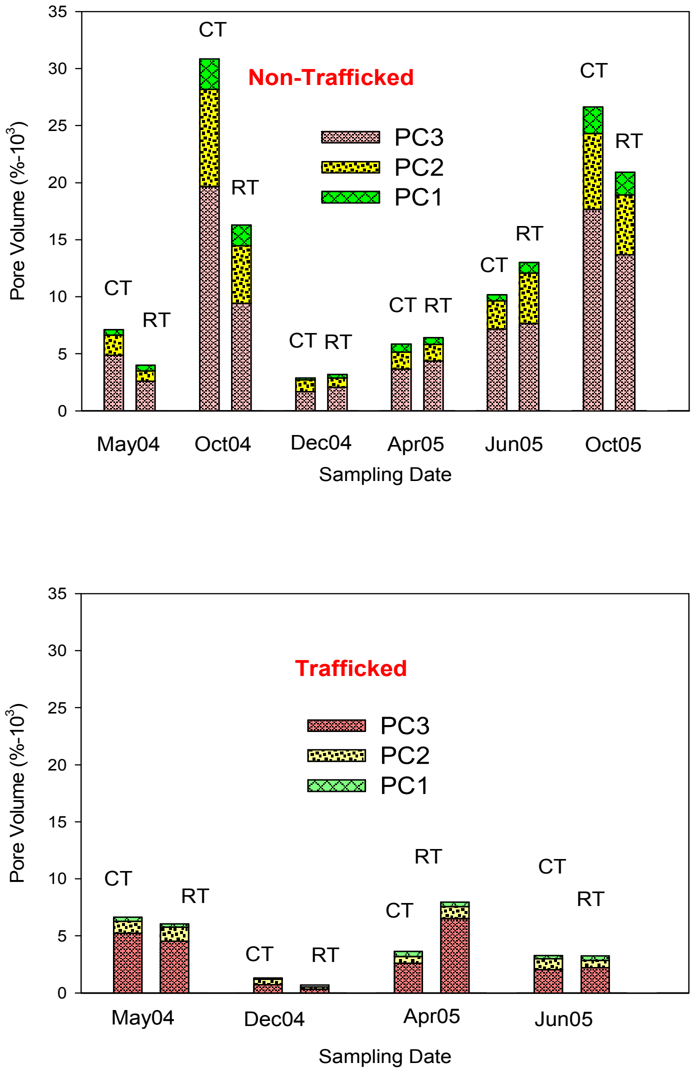

Fig. 4. Effective porosity of the pore classes indicated during the tillage year 2004/05 in non-trafficked (a) and trafficked (b) areas under conventional (CT) and reduced (RT) tillage.

Conclusions and general implications

Hydraulic topsoil properties at near-saturation, including water retention determined in the laboratory and infiltration and hydraulic conductivity determined in the field, were found to vary significantly over the year, influenced by a combination of tillage system and natural processes. The temporal changes over the tillage year were generally characterized by the hydraulic conductivity (*K*) being relatively high shortly after tillage, steeply decreasing during late autumn and early winter (Oct-Dec), being low during the winter (Dec-Apr) and followed by an increase during spring and early summer (Apr-Jun). The effective porosity in the macro-meso range of 1 - 0.125 mm pore radius was highest shortly after tillage and lowest in winter followed by the restructuring in spring and early summer. Compared with CT, the effective porosity under RT was lower shortly after tillage but higher in early summer after the recovery.

The general implications of the findings for the assessment and choice of tillage practice are:

(i) The soil resilience seem to be improved under RT, as the recovery of soil structure in spring and summer, was enhanced under RT relative to CT;

(ii) RT is likely to improve crop water availability relative to CT, because of the long term increase in porosity and soil organic matter content under RT.

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