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The impacts of no-tillage and conventional tillage on some hydraulic characteristics of topsoil in the Mediterranean Climate

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Abstract

Soil tillage is the guiding component of soil management and consequently has far-reaching implication for agroecosystems. Understanding structures and functions of soil under conventional tillage and no-tillage is an essential requirement for any future farming concepts. Tillage greatly affects soil structure in topsoil and, to a certain degree, in the subsoil. It can change soil behaviour at the topsoil with regard to infiltration, runoff, etc. Several methods have been developed to study hydraulic characteristics of topsoil. In this study Beerkan method, which is a simple in situ method using a single ring infiltration, was used to better understand tillage and no-tillage impacts on transmission properties of topsoil. This method depends on an algorithm namely BEST. This study was carried out at Lavalette experimental station in Montpellier in the South of France. Two different tillage measurement series were done. The first series was performed after harvest of durum wheat and the second one was performed after sowing. By using those two series as input data, BEST model can estimate saturated hydraulic conductivity, sorptivity, the mean characteristics of hydraulically functional pore size and capillary length. The results indicate that after harvest hydraulic properties of topsoil were not significantly different. However after sowing, saturated hydraulic conductivity was significantly higher ($p<0.05$).

Introduction

No-tillage (NT) is an ecological approach of soil management which has a higher efficiency than conventional tillage (CT) to improve soil properties. However, the response to NT depends largely on the climatic condition, mulch quantity on the soil surface and soil management. Tillage largely influences pore size distribution. Soils under CT generally have lower bulk density and associated with a higher total porosity within the ploughed layer than no tillage [1]. The relationships between soil pore structure induced by tillage and infiltration play an important role in water and solutes transport characteristics in soil. An important function of soil is transmission of water, which directly affects plant productivity and environment. In NT, greater infiltration rate was attributed to greater contribution of flow-active macro-pores made by soil microorganisms, worms, and roots of preceding crops [2]. As cited by Sasal et al., [3] such bio-pores are more effective for water and air movement and root growth, because they are more continuous, less tortuous, and more stable than macro-pores created during ploughing [4 through 7]. However the effects of soil tillage and

management on transmission properties are not uniform. The results of several study showed that no tillage as compared with CT had greater [8 through 11], similar [12] or lower infiltration rate [13 through 16]. Studying soil properties requires the determination of soil hydraulic parameters. This is important for understanding and characterizing the hydrological cycle and transfer of contaminants with water [17]. Different functional relationships have been proposed in literature to describe the relationships between soil water variables i.e. soil water content, θ, pressure head, h, and hydraulic conductivity, K. [18 through 20]. In this context, the Beerkan method, which is a simple *in situ* using a single ring infiltration, provides field soil hydraulic properties [17]. This method depends on an algorithm, BEST, which specifically relates to Van Genuchten's relation, for water retention curve, $h(\theta)$, with the condition of Burdine [21], and to Brooks and Corey's [19] relation for hydraulic conductivity, $K(\theta)$. The hydraulic characteristic curves, $h(\theta)$ and $K(\theta)$, were defined by their form and scale parameters. The BEST algorithm enables us to estimate those parameters from particle size distribution, dry bulk density and from modeling the experimental infiltration trials.
The aim of the research reported here was to determine whether or not NT system improves soil hydraulic parameters as compared with CT. The results of this study can help us to better understand the NT impacts on water and solutes transfer in soils.

Material and methods

A field experiment under irrigation condition was established at the experimental station of Lavalette (43° 40' N, 3° 50' E, altitude 30 m) at Montpellier (South of France). The average annual rainfall is 789 $mm.year^{-1}$ (1991-2006). Evaporation exceeds rainfall throughout the year under this Mediterranean climate. Those climate data were monitored at a weather station within the experimental station. Two different tillage treatments i.e. CT and NT have been applied for the last 7 years. The precedent crop residue was kept in the field. Retained residues were incorporated if tilled (CT), or left on the surface with NT. This paper deals with the two last cropping seasons. In CT plots, primary tillage for durum wheat with disc harrow was done to chop and bury the residues at the end of July 2005. Secondary tillage with plough was performed at the beginning of October. Depth of the tillage was close to 25cm in average. By using a harrow, seedbed was prepared and durum wheat sowing was performed using a seeder. Durum wheat was sown in both CT and NT in November 2005. In NT plots, a specific seeder for NT namely Semeato was used. After harvest in June 28, the experiment area was left completely fallow over summer. The first infiltration measurement series was performed from 17 to 23 July 2006 approximately one month after durum wheat harvest.
In October 2006, a mixed of oat, vetch and rape was planted in NT treatment as cover crop and was destroyed by glyphosat in April 2007 before sowing corn. In CT plots, at the end of July disc harrow was used to chop and bury the residues of durum wheat. At the middle of November tillage with plough was performed. Depth of the tillage was close to 25cm in average. Using a harrow, seedbed was prepared and corn sowing was performed by the specific seeder. In NT plot, after destroying the cover crop we used only the same seeder for NT. The second infiltration measurement series was done in May 2007 one month after sowing.
Infiltration measurements were performed in ten randomly selected sites of each plot. Soil samples were taken from the same sites to determine particle size and initial soil humidity. Soil bulk density (ρ_d) was determined using a gamma probe (Troxler 3440).
For the installation of the cylinder, the surface residue or vegetation is removed while the roots remain in situ. Then the cylinder is positioned at the soil surface and driven 1 cm into to the soil to avoid lateral losses of ponded water at the soil surface. A defined volume of water is added into the cylinder (15-20 cm of diameter) at time zero, and the time elapsed during the infiltration should be measured. When the first volume has completely infiltrated, immediately the second known volume of water is added, and cumulative time is recorded.

The procedure is repeated for a series of about 8 to 15 known volumes and cumulative infiltration is recorded. Finally, the data set is made up of a number of discrete points (t_i, I_i). At the end of the experiment, the saturated soil is sampled to determine the saturated volumetric water content (for more details refer to [17, 22, 23]. By those data as input, BEST, a 3D infiltration model can estimate saturated hydraulic conductivity, sorptivity, the mean characteristic of hydraulically functional pore size and capillary length.
Soil total porosity (TP) was calculated as the function of total volume not occupied by soil assuming a particle density (ρ_s) of 2.65 $Mg.m^{-3}$ using $TP=1-(\rho_d/\rho_s)$.
Treatment effects on measured variables were tested by analysis of variance (ANOVA), and comparisons among treatment means were made using the least significant difference (LSD) at $P<0.05$.

Results and discussion

Table 1 presents the particle size, texture, organic matter and organic carbon of soil at both plots. There is the same soil texture according to USDA soil classification system. There is more organic matter and organic carbon in NT plot as the long-term benefits of NT system.

Table 1. Soil physical and chemical properties at the Lavalette experimental station, Montpellier, France (all soil properties presented here are for 0-30 cm)

Plot	Clay (%)	Silt (%)	Sand (%)	Texture (USDA) (0-30 cm)	Organic matter (%)	Organic Carbon (%)
CT	18	42	40	loam	1.55	0.91
NT	17	39	44	loam	1.76	1.02

The average of bulk density, total porosity and three outputs of BEST i.e. sorptivity, capillary length (αh) and the mean characteristic of hydraulically functional pore size (λ_m) of soil surface, are shown in table 2. In 2007, one month after the planting date of corn, bulk density was significantly different, being the lowest among others. This is related to soil preparation before sowing. In NT, bulk density has being decreased from 1.44 in 2006 to 1.32 $Mg.m^{-3}$ in 2007. That can be associated with the cover crop effects, producing more bio-pore due to the decayed root channels or the macro-pore made by soil fauna. In 2007, one month after sowing, bulk density was not significantly different in CT and NT.
Sorptivity values, being indicative of soil water diffusivity and thus unsaturated hydraulic conductivity was higher in CT than NT; however the difference was not significant. These results should be considered as approximate values, since initial soil moisture content was not identical among all measurements. Sorptivity, which is water uptake by soil when there is no gravitational effect, is a good index of how the tillage treatments have influenced soil structure. It provides information on the soil absorption rate and varies with initial water content and structural stability.
In this study αh and λ_m were assessed in CT and NT. λ_m was not significantly different in CT and NT for both 2006 and 2007. In 2006, αh was not significantly different in CT and NT. But in 2007, it decreased and increases significantly in CT and NT, respectively. However the difference between CT and NT is not significant. The reduction of αh in CT can be related to decreasing in bulk density. In CT, decreasing in αh and increasing in λ_m reflect the changes in pore sizes and hydraulic conductivity due to soil loosening made by tillage. In NT 2007, the increase in αh can be due to a different pore size distribution in the surface layer.

Table 2. The average of bulk density, total porosity, sorptivity, capillary length (αh) and the mean characteristic of hydraulically functional pore size (λ_m) of soil surface measured at harvest of durum wheat (July 2006) and after sowing of corn (May 2007) in CT and NT treatments

Plot	Bulk density ($Mg.m^{-3}$)	Total Porosity (%)	Sorptivity ($mm.s^{-0.5}$)	αh (mm)	λ_m (mm)
CT 2006	1.35a*	49a	0.857a	67a	0.12a
NT 2006	1.47b	45b	0.741a	69a	0.11a
CT 2007	1.26c	52c	0.715a	49b	0.17a
NT 2007	1.32c	50c	0.563a	87b	0.12a

* Data within the same column followed by the same letter are not significantly different at the probability level $p<0.05$.

The difference in αh values should be interpreted resulting from differences in the soil pore system, which may have been induced by the tillage management. The differences in bulk density observed together with the greater macro-porosity probably induced by root or soil fauna in the surface layer.

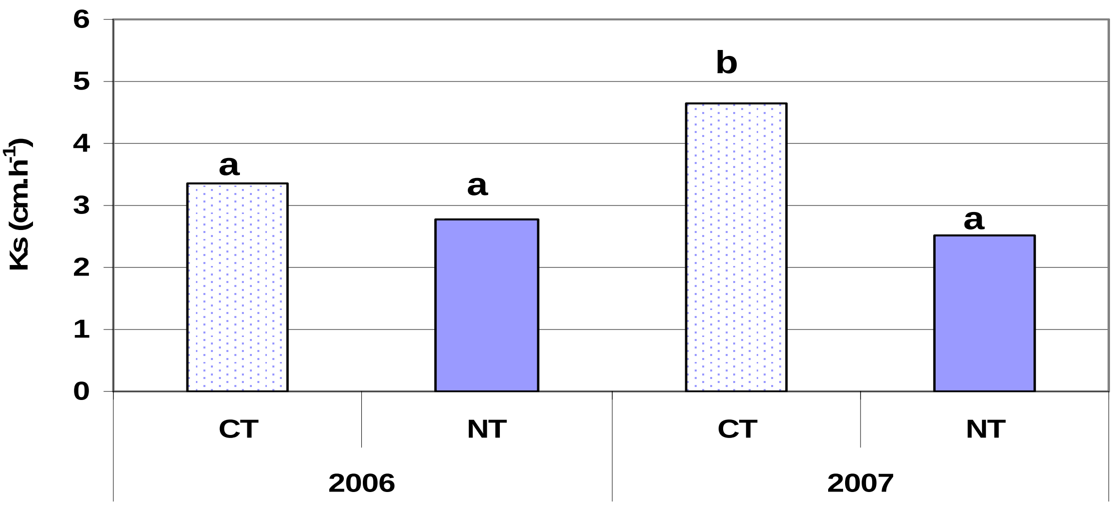

Fig. 1: The average of saturated hydraulic conductivity in the soil surface measured after harvest of durum wheat (July 2006) and after sowing of corn (May 2007) in CT and NT treatments. Different letters within tillage systems indicate significant differences ($p<0.05$).

Saturated hydraulic conductivity (Ks) in both CT and NT treatment are shown in Fig. 1. Ks was not significantly different in CT and NT treatment in 2006, however Ks was higher in CT. That can be due to a higher plant density in CT, having more decayed root channels. Ks was significantly different in 2007, being higher in CT than NT. This can be related to soil preparation in CT treatment before planting resulting in a lower bulk density. In contrast, Ks was not significantly different in CT treatment for 2006 and 2007, however Ks was higher in 2007 (4.66 in 2007 as compared with 3.35 $cm.h^{-1}$ in 2006). For NT treatment, the difference was not significant for 2006 and 2007. However, Ks was higher in 2006 (2.79 in 2006 as compared with 2.51 $cm.h^{-1}$ in 2007). In spite of expected increase of Ks, due to soil decompaction i.e. decreasing bulk density from 1.47 in 2006 to 1.32 $Mg.m^{-3}$ in 2007, Ks decreased in NT 2007. The Ks diminution could be due to a different pore size distribution and their orientation rather than to total porosity in the surface layer. Ks depends not only on total porosity but also, and primarily, on the size of the conducting pores. Cracks, worm holes, and decayed root channels may affect flow in different ways. It is possible that differences in organic matter and organic carbon caused the differences in Ks in CT and NT as attested by some pedo-transfer functions [24].

Conclusion

Soil tillage is defined as mechanical or soil-stirring actions exerted on soil to modify soil conditions for the purpose of nurturing crops. Results of various investigations from almost all world climatic zones suggest that plowing often reveals common soil-related problems such as soil compaction, soil erosion, deteriorated water percolation, and high energy and time requirement [25]. As a response to those problems, conservation tillage, including no-tillage (NT) was proposed. This system has often higher efficiency than conventional tillage (CT) to improve soil properties. To better understand this system, a study has been carried out at Lavalette experimental station in Montpellier in the South of France. There were two tillage systems i.e. CT and NT. Characterization of topsoil layer is essential to better understand water dynamic in these two systems. Modifications of soil structure by soil tillage cause changes in conductivity and permeability characteristics for water and solute transport in soils and their spatial distribution. The objective of study was the assessment and comparing hydraulic characteristics of topsoil in both systems. Beerkan method which depends on an algorithm namely BEST was employed to determine hydraulic parameters. Two measurement series were performed; the first one after harvest and the second one after sowing. The results indicated that, after harvest sorptivity, capillary length, the mean characteristic of hydraulically functional pore size, and saturated hydraulic conductivity (Ks) were not significantly different in CT and NT. After sowing, Ks was significantly different in NT and CT, however other parameters were not significantly different. Using tillage resulted in increasing some hydraulic characteristics of topsoil, however these effects of tillage are short lived. So that in the environmental point of view there is higher risk of pollution transport in CT system especially after soil operation. The differences in CT and NT can be related to different soil layer which exist in the topsoil of NT which can cause a spatial heterogenity of hydraulic properties of the porous media while tillage has the homogenization effects in the topsoil of CT system. More study is necessary to better understand the porous media under NT system especially over the growing season, this is the subject of our oncoming study.

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