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Near-saturated hydraulic conductivity measured on a swelling silty clay loam for three integrated weed management based cropping systems

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ABSTRACT

Integrated weed management (IWM)-based cropping systems included diversified agricultural practices (i.e., diversified crop rotations with diversified sowing dates, false seed-bed technique, delayed autumn sowing and mechanical weeding) to reduce the dependence to herbicide, some of these influencing soil hydraulic properties. The aim of our study was to assess the vertical and annual variability of the near-saturated hydraulic conductivity $K(h)$ for IWM-based cropping systems. The three cropping systems considered were classified as no-till cropping system S2 and moderate to intensive tillage cropping systems S4 and S5. The soil of cropping systems was a well-structured silty clay loam soil with shrink-swell behavior. Soil was studied at three depths (10, 20 and 50 cm) and during two or three annual measurement campaigns. The tension disc infiltrometer device was used to measure steady state flows at −5, −3, −2 and −1 cm pressure heads for all the cropping systems, horizons and measurement campaigns. The steady state flows were used to derive $K(h)$ at each pressure head applied as well as the effective macroporosity. No vertical variability was found on $K(h)$ for any of the cropping systems due to well-developed porosity networks throughout the soil profiles, confirmed by comparable average effective macroporosity values between all soil horizons and with the presence of non-equilibrium flows and water repellency behaviors at all soil horizons. The consequences for modeling the water flow of well-structured clayey soil imply taking into account comparable values of $K(h)$ for all soil horizons and considerably simplifies the work of modelers. The no-till cropping system S2 presented time-invariable $K(h)$ under different θ_i, which was in agreement with the equally time-invariable macroporosity results. For cropping system S4, $K(h)$ variability was found to be in agreement with θ_i variability, which was confirmed to be inversely correlated to $K(h)$. As expected, the $K(h)$ of cropping system S5 was found to be stable through time, in agreement with its comparable θ_i Moreover, our results allowed confirming the temporal stability of no-till cropping system S2 compared to superficially tilled cropping systems S4 and S5.

1. Introduction

Near-saturated hydraulic conductivity K (LT^{-1}) as a function of soil pressure head h (L), $K(h)$, provides valuable information on water transfer in the vadose zone (i.e., unsaturated zone), where key processes for water flow and solute transport take place (e.g., non-equilibrium flow, solute leaching). Thus near-saturated hydraulic conductivity was studied with applications varying from cropping system evaluation, mostly between no-till and conventionally tilled cropping systems (e.g., Castellini and Ventrella, 2012; Schwen et al., 2011a), the assessment of spatial and temporal variability (e.g., Bodner et al., 2013; Strudley et al., 2008), pedotransfer function development (e.g., Jarvis et al., 2013) and water flow and solute transport simulation (e.g., Fuentes et al., 2004). Consequently, different methods (e.g., pressure ring infiltrometer, tension disc infiltrometer, evaporation method) are available for determining $K(h)$ under laboratory and field conditions (e.g., Angulo-Jaramillo et al., 2000; Siltecho et al., 2014). The tension disc infiltrometer (Perroux and White, 1988) is a useful tool for field characterizations of $K(h)$, as proven by several studies (e.g., Jarvis et al., 2013,b; Vandervaere et al., 2000a,b)

Characterization of the hydraulic properties of well-structured clayey soils is still a challenge for soil science, especially when such soils present shrink-swell behaviors (i.e., variations of soil volume as a function of water content). Pores with equivalent diameters larger than 0.3 mm i.e., macropores (Jarvis, 2007) play an

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important role in water transfer in these soils and consequently in $K(h)$. Indeed, well-structured clayey soils are known to allow preferential flow and non-equilibrium flow (NEF) through macropores (i.e., macropore flow) which may accelerate solute transport to the saturated zone and increase groundwater pollution (Jarvis, 2007). Šimůnek et al. (2003) synthesized the definition of both phenomena as follows: preferential flow is the non-uniform wetting of the soil profile as a result of water moving faster in certain parts of the soil profile than in others and NEF is the flow regime in which infiltrating water does not have time to equilibrate with slowly moving resident water in the bulk of the soil matrix. NEF is characterized by the shape of the high nonlinear hydraulic conductivity function which typically shows dramatic increase with increasing water contents, particularly as the larger pores become active (i.e., close to saturation). Moreover, the occurrence of NEF depends on factors such as biological activity (earthworms), management practices (land use and soil tillage) and soil properties such as clay content (Jarvis et al., 2013). In addition, water repellency (WR) in well-structured clayey soils may result in preferential flow (Jarvis et al., 2008). WR is defined as the soil resistance to water infiltration (i.e., hydrophobicity) which is characterized by slow rates of water uptake at the beginning of infiltration. However, at close to saturation conditions, this resistance to water infiltration may turn into an increase of water uptake during infiltration and consequently in to faster infiltration rates under saturated conditions (DeBano, 2000).

Research over the last 3 decades on clayey soils has provided information on $K(h)$ for temporal (i.e., seasonal and annual) and spatial (i.e., horizontal and vertical) variability. Different studies suggest an increase of $K(h)$ for clayey tilled soils shortly after tillage followed by a considerable decrease during winter and, finally, by an increase during spring/summer due to enhanced soil macroporosity (i.e., cracks, root development, earthworms channels) (Messing and Jarvis, 1993). These studies allowed identifying the key factors involved in the general temporal dynamics of $K(h)$, such as initial soil water content (e.g., Das Gupta et al., 2006 Zhou et al., 2008), porosity network (e.g., Buczko et al., 2006; Schwen et al., 2011b), crusting (e.g., Vandervaere et al., 1997, 1998), crop and cropping periods (e.g., Castellini and Ventrella, 2012; Rienzner and Gandolfi, 2014) and tillage treatments (e.g., conventional tillage, reduced tillage, no-till) (e.g., Daraghmeh et al., 2008; Fuentes et al., 2004). However, less attention has been paid to the assessment of vertical variability compared to horizontal variability (Schwen et al., 2014).

The interests of Integrated Weed Management (IWM)-based cropping systems are to reduce the need for chemical treatments with herbicides. Their strategy consists in combining several agricultural practices to partially or totally replace herbicide application (Debaeke et al., 2009; Munier-Jolain et al., 2008). The combination of agricultural practices includes diversified crop rotations with diversified sowing dates, the false seed-bed technique, delayed autumn sowing and mechanical weeding (Pardo et al., 2010). As a result, due to the increasing number of factors to be taken into account, the assessment of agronomical, economic and environmental impacts has become more complex. At present, little is known about the impact of IWM-based cropping systems and the induced-effects of their individual agricultural practices on soil hydraulic properties.

In order to assess the evaluation of IWM-based cropping systems, our main objective was to study the vertical and annual variabilities of $K(h)$ values for a well-structured silty clay loam soil under different IWM-based cropping systems. Our first hypothesis suggests the vertical differentiation of $K(h)$ as a result of: (i) the long term effects of cropping systems, (ii) the natural variability of soil properties, and (iii) the weather conditions. Our second hypothesis suggests the annual variability of $K(h)$ as a function of factors such as tillage operations, cropping periods (i.e., beginning or end of cropping period, fallow period) and initial soil water content. Consequently, annual stability is expected under comparable factors through time. Since the complexity of the IWM-based experiment considered in our study design made it difficult to isolate the effects of particular factors for their evaluation, three characterization campaigns involving three IWM-based cropping systems were taken into account. The characterization campaigns were chosen in order to evaluate the influence of tillage operations, soil initial water content, crops and cropping periods on $K(h)$ values in contrasting situations: (i) with no-tillage treatment and comparable cropping periods but different initial soil conditions, (ii) after superficial tillage operations and different initial soil conditions, and (iii) with comparable cropping periods and initial soil conditions.

2. Materials and methods

2.1. Site and soil description

The study was performed at the Institut National de la Recherche Agronomique (INRA) experimental farm in Dijon, eastern France (47°20′N, 5°2′E). The climate of the region is semi continental with an average annual rainfall of 770 mm and a mean annual temperature of 10.5 °C. Three IWM-based cropping systems

Table 1
Main soil properties of the three cropping systems.

	Clay[a] (<2 μm) g kg^{-1}	Silt[a] (2–50 μm) g kg^{-1}	Sand[a] (50–200 μm) g kg^{-1}	Organic C[a] g kg^{-1}	pH[a]	Bulk density[b] g cm^{-3}	Porosity[b] cm^3 cm^{-3}
S2 IWM system – reduced tillage then no till							
Ap1 (0–15/16 cm)	348	581	71	16.3	6.7	1.45 ± 0.05	0.44 ± 0.02
Ap2 (15/16–35/40 cm)	459	475	66	6.7	6.8	1.57 ± 0.04	0.40 ± 0.02
Bm (35/40–75/80 cm)	536	403	61	3.3	7.0	1.46 ± 0.05	0.44 ± 0.02
S4 IWM system – moderate to intensive tillage							
Ap1 (0–15/16 cm)	360	581	59	14.5	6.9	1.47 ± 0.06	0.44 ± 0.02
Ap2 (15/16–35/40 cm)	384	568	48	11.4	6.8	1.43 ± 0.09	0.45 ± 0.04
Bm (35/40–95/100 cm)	528	423	49	4.8	7.5	1.40 ± 0.08	0.46 ± 0.03
S5 IWM system – moderate to intensive tillage							
Ap1 (0–15/16 cm)	355	581	64	15.1	6.6	1.55 ± 0.05	0.41 ± 0.02
Ap2 (15/16–35/40 cm)	426	527	47	10.9	6.6	1.58 ± 0.03	0.39 ± 0.01
Bm (35/40–60/70 cm)	498	448	54	4.9	7.5	1.40 ± 0.02	0.46 ± 0.01

[a] Soil characterization was performed during the 2012 measurement campaign.
[b] Values are mean ± standard deviation for all measurement campaigns (9 replicates for S2, 6 for S4 and S5).