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Effects of integrated weed management based cropping systems on the water retention of a silty clay loam soil

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ABSTRACT

Integrated weed management (IWM) based cropping systems employ a combination of agricultural techniques to manage weed communities. However, the effect of such a combination of agricultural techniques on soil hydraulic properties has received little attention. Main objective of our work was to evaluate the soil water retention of the superficial layer (3–15 cm depth) of 5 cropping systems of which 4 were based on IWM principles. Firstly, the effects of natural variability of soil properties on soil water retention were first evaluated for the 5 plots of the experimental site and then the effects of agricultural practices were investigated. To isolate the effects of soil properties from the effects of soil structure induced by agricultural practices on water retention, two different sample treatments (repacked and undisturbed samples) were set up. Significant differences between cropping systems in soil water retention were found for each soil sample treatment. For the repacked soil samples, significant differences were related to the slight spatial variability of clay content and the initial organic C gradient existing between cropping systems, whereas for undisturbed soil samples the significant differences observed were related to the combined effects of agricultural practices and higher clay and organic C contents. The highest water retention of undisturbed soil samples was found for the IWM-based cropping system without any herbicide and with a high frequency of shallow agricultural operations per year while the lowest values were found for the conventionally tilled cropping system. For the no-tillage cropping system low water retention values were found close to saturation, while high water retention values were found at the dry-end of the water retention curve. In conclusion, our work shows that, in the case of silty clay loam soil with shrinkage/swelling behavior, high clay and organic C contents and very frequent superficial tillage increased soil water retention.

1. Introduction

Reducing negative impacts on the environment such as soil erosion, river eutrophication and water pollution without compromising productivity is an important challenge for sustainable agriculture. In the case of water pollution, herbicides are the organic compounds most frequently found in groundwater and surface water. Hence, reducing the reliance of cropping systems on herbicides is one of the main objectives of sustainable agriculture and requires redesigning cropping systems by developing alternative agricultural practices. As a response, integrated weed management (IWM) proposes several agricultural techniques to manage weed communities, but these techniques must be combined in order to totally or partially substitute pesticides by mechanical treatments used to control weed infestations (Bastiaans et al., 2008; Debaeke et al., 2009; Munier-Jolain et al., 2008).

The main IWM techniques, as described by Pardo et al. (2010), are: (i) diversified crop rotations with diversified sowing dates to avoid selecting species with marked seasonality of emergence; (ii) superficial soil tillage in order to control the seed bank by managing the incorporation depth of seeds in the soil or repeated shallow cultivations (false-seed bed technique) to promote the emergence of seedlings and their destruction before crop drilling; (iii) delayed autumn sowing to avoid the emergence peak of a range of autumn-germinating species; (iv) competitive cultivars and competitive crop species sown at high densities and reduced row distance to maximize the competitive ability of the crop canopy, (v) in-crop mechanical weeding; and (vi) the use of pesticides with low toxic impacts. Such a combination of

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techniques might involve major changes in the nature of cropping systems (Bastiaans et al., 2008; Debaeke et al., 2009; Munier-Jolain et al., 2008).

Several studies have provided evidence of the influence of cropping systems on soil properties. They have focused on the evaluation and comparison of conventional tillage and conservation tillage (reduced and zero tillage) techniques (e.g. Alletto and Coquet, 2009; Hill, 1990; Hill et al., 1985), but the results are not always consistent across locations, soils and experimental designs (Green et al., 2003). However, few studies have focused on the evaluation of alternative agricultural practices such as mechanical weeding and/or intensive shallow cultivation on soil physical and hydraulic properties (e.g. Ugarte Nano et al., 2015). In the case of IWM, a key question is the assessment of the environmental risk of herbicide residue transport to other compartments of the environment (vadose zone, groundwater), due to the combination of several agricultural techniques and the application of herbicides (Deytieux et al., 2012). To answer this question, it is important to characterize soil hydraulic properties, especially the soil water retention curve (i.e. water content vs. water matric potential) which is an essential soil hydraulic property. Several applications of this soil characteristic in agronomy and hydrology can be mentioned, such as the determination of plant-available water capacity and the modeling of water flow and solute transport in the unsaturated zone. Indeed, soil water retention has been widely reported in the literature with studies aiming at: (i) the evaluation of the effect of agricultural practices on soil water retention, in which comparisons between conventional till, minimum or reduced-till and no-till cropping systems are the most frequently reported (e.g. Abu and Abubakar, 2013; Bescansa et al., 2006); (ii) the study of the temporal and spatial variability of soil water retention (e.g. Fuentes et al., 2004; Strudley et al., 2008); and (iii) the parameterization of soil water retention for applications such as water flow and solute transport modeling (e.g. Ippisch et al., 2006; Yates et al., 1992) and the comparison of different agricultural practices (e.g. Abu and Abubakar, 2013; Ndiaye et al., 2007). Concerning the effects of agricultural practices on soil water retention, several authors have agreed that the temporal and spatial variability of soil water retention as well as the natural soil variability of other soil main properties (e.g. texture, organic C among others) often mask the effects of agricultural practices on soil hydraulic properties such as soil water retention (Green et al., 2003; Strudley et al., 2008). Despite these masking factors, it is expected that after soil loosening by tillage, water retention will temporally increase and then decrease due to natural soil reconsolidation mostly over the wet rang (Ahuja et al., 1998; Mapa et al., 1986). Indeed, the detailed description of all the factors affecting soil hydraulic properties is necessary before any evaluation of the effects of agricultural practices (Green et al., 2003).

In our work, our main objective was to study the effect of cropping systems (i.e. 4 based on the principles of IWM and one standard reference) on water retention of the superficial soil layer (Ap1, i.e. first 15 cm). Our study was based on two hypotheses:

Hypotheses 1. IWM-based agricultural practices have no effect on soil properties involved in the studied cropping systems. In order to test this hypothesis, we proposed to compare, at plot scale, the soil properties variability characterized at the beginning of experimentation with those obtained after 12 years of experimentation;

Hypotheses 2. IWM-based agricultural practices have an effect on soil water retention. To evaluate this second hypothesis, a more homogeneous soil area was delimited in each experimental plot to reduce the spatial variability of soil physical and chemical characteristics which may mask effects of cropping systems on soil water retention. In that case, soil water retention curve from the 5 cropping systems were compared by using 2 different types of soil sample treatment: (i) repacked soil samples with homogeneous and equivalent soil structure between cropping systems in order to study the possible remaining effects of soil properties differences despite the choice of a homogeneous area, and (ii) undisturbed soil samples with heterogeneous soil structure in order to check the induced effects of the different cropping systems studied on soil structure which may in turn influence soil water retention.

2. Materials and methods

2.1. Experimental location

The experimental site is located at the INRA Dijon experimental unit, eastern France (47°20′N, 5°2′E), in a region with a semi-continental climate with an average annual rainfall of 770 mm and a mean annual temperature of 10.5 °C. The silty clay loam soil, classified as Cambisol (Hypereutric) (Iuss Working Group WRB, 2006), is developed on an alluvial coarse deposit and its thickness is close to 0.77 m (±0.13 m). The soil vertical stratification according to the FAO classification (Iuss Working Group WRB, 2006) includes 3 soil layers: superficial tillage layer Ap1 (0–15 cm), plough layer Ap2 (15–30 cm) and structural layer Bm (30–80 cm).

2.2. Experimental design

The experimental design is composed of 5 experimental plots of 1.7 ha (80 × 210 m) and each plot corresponding to a cropping system (two replicates). The main components of the 5 cropping systems were described by Chikowo et al. (2009) and are summarized in Table 1. Briefly, the first cropping system (S1) is the standard reference based on farming practices in the region of the experimental site. It is designed to maximize financial returns

Table 1
Main components of the 5 cropping systems.

Cropping system	Description
S1	Reference system designed to maximize financial returns. Use of chemical herbicides to control weeds. Moldboard ploughing each year. Choice of herbicides according to recommendations of extension services. Crop rotation: oilseed rape/winter wheat/winter barley
S2	System with IWM. Reduced tillage between 2000 and 2007. No-tillage since 2008. Time-consuming operations such as ploughing, harrowing and mechanical weeding excluded. Treatment frequency index[a] reduced by 50%
S3	System with IWM. Ploughing and other tillage operations allowed when necessary for weed seedbed management but mechanical weeding is excluded. Treatment frequency index reduced by 50%
S4	System with IWM. Ploughing and other tillage operations allowed when necessary for weed seedbed management including mechanical weeding. Treatment frequency index reduced by 65%
S5	System with IWM. Use of any herbicides excluded. Only non-chemical practices are allowed to contain weed infestation

[a] Amount of pesticides spread per ha expressed in percent of the standard approved dosages of pesticides per ha.