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Effects of agricultural practices on hydraulic properties and water movement in soils in Brittany (France)

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Abstract

The intensive agricultural use of soils in the Brittany region (western France) has increased the need for a better understanding of soil water dynamics. The aim of the present study is to compare quantitatively the differences produced by two agricultural practices on soil hydraulic properties (water retention curve and hydraulic conductivity) as well as the infiltration and drainage fluxes in the soils. This study was carried out on two experimental plots managed in the same way for 22 years. The two practices were continuous maize fertilized with mineral fertilizer, denoted as MX, and pasture within a ray-grass/maize rotation (3/1 year) with organic fertilization (pig slurry), denoted as PR. The study consisted of measuring soil physical properties in the laboratory and in the field, and estimating water infiltration in the soil of the two plots by recording water pressure heads after simulation of 2-h artificial rainfall with an intensity of 17 mm/h. We applied the van Genuchten model to describe the water retention and hydraulic conductivity curves ($\theta(h)$ and $K(h)$) for each soil horizon of the two plots. Hydrus-2D and ID softwares were used to construct a numerical model of water movement in the two soils. This model was used to quantify the infiltration rate, deep drainage and actual evaporation fluxes during the artificial rainfall experiment.

The vertical influence of agricultural practices in both plots appears to be limited to the uppermost 35 cm. Deeper in the B horizon, there are only very slight differences in the hydraulic properties between the two plots. In the top soil horizons (H1–H5 and H6), the two soil properties mostly affected by practices are the hydraulic conductivity and the α parameter of the van Genuchten model. At the lowest pressure head studied here (-1.5 kPa), hydraulic conductivity in a given horizon differs by more than one order of magnitude between the two plots. The model reproduces quite satisfactorily the observed pressure heads in plot PR at all depths, in the rainy period as well as in the water redistribution period (efficiency >0.77). Results are less good for the MX plot, with efficiency ranging from 0.49 to 0.84 depending on the horizon. The different sources of simulation errors are identified and discussed. For the MX plot, the soil water movement model succeeds in reproducing the infiltration excess runoff observed in the field, allowing us to calculate that it accounts for 9% of the applied rainfall. No surface runoff or ponding appears in the PR plot during the artificial rainfall experiment. In the PR plot, the simulated deep drainage flux increases more rapidly than in the MX plot. The lower hydraulic conductivity in the top soil horizon of the MX plot compared with the PR plot appears to reduce the infiltration rate as well as the deep drainage flux. It also decreases the upward flow of water to the soil surface when the water content in the top soil layer is depleted by evaporation flux. The model simulation could be improved by a more precise representation of the soil structure, particularly the location, size and frequency of clods as well as the variability of hydraulic properties. However, we need to strike a balance between improving the quality of the simulation even further and the practical constraints and efforts involved in measuring the soil hydraulic properties.

Keywords: Agricultural practices; Hydraulic parameters; Rainfall experiment; Water movement; Drainage; HYDRUS

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1. Introduction

Farming methods can alter soil structure and porosity, as well as the hydraulic conductivity and retention curves. In particular, tillage can have an impact on structural processes (Lamandé, 2003; Pagliai et al., 2004) such as fragmentation and compaction. This can create heterogeneity in tilled soil between compacted and uncompacted zones. Fragmentation can improve porosity when it is due to biological processes (Ehlers, 1975; Lamandé et al., 2003; VandenBygaart et al., 2000; Hallaire et al., 2004) and tillage (Ankeny et al., 1990). This is in contrast to compaction related to wheel-traffic, which diminishes the structural porosity (Guérif, 1987; Richard et al., 1999; House et al., 2001; Défossez et al., 2003; Czyz, 2004) and sometimes textural porosity as well (Grimaldi, 1986).

Green et al. (2003) have presented a thorough review of the advances in quantifying and predicting the effects of agricultural management (tillage, wheel-traffic compaction, crop residue management) on soil hydraulic properties. Mapa et al. (1986) were the first to perform controlled in situ and laboratory experiments to assess the effect of tillage and reconsolidation (following wetting and drying cycles) on hydraulic properties. However, tillage treatment studies in the literature have not always yielded consistent results, because of the major influence due to location in time and space, as well as the role of soils and experimental design (Ahuja and Nielsen, 1990; Logsdon et al., 1993; Van Es, 1993). Ahuja et al. (1998) have proposed a practical method for estimating the soil water retention curve for tilled soils, based on the curve for untilled soils. It is much more difficult to predict the temporal effect on soil structure caused by wetting and drying cycles. Nevertheless, some theoretical results have been reported in the literature (Or et al., 2000; Leij et al., 2002a,b).

Wheel-traffic patterns lead to variations in soil infiltration rates because the resulting compaction primarily destroys the large pores (Ankeny et al., 1990). Most authors report a 50% decrease in infiltration rate between traffic and non-traffic patterns. House et al. (2001) have shown that machine wheel traffic reduces the saturated hydraulic conductivity K_s and decreases the total porosity. However, the total weight transferred to the soil and the number of repetitions are the most important factors influencing soil physical properties (Startsev and McNabb, 2001; Défossez et al., 2003). Richard et al. (1999) have studied the long-term effect of traffic compaction on a loamy soil in northern France. They show a reduction of the structural porosity under wheel tracks (from 0.25 to $0\ m^3\ m^{-3}$) and a decrease in the percentage of compacted zones (from 100 to 0%).

Many studies have focused on the effects of management and tillage on soil physical properties, and especially on hydraulic properties such as hydraulic conductivity and water retention. However, few studies have been concerned with the consequences of agricultural practices on water infiltration and drainage in soils. In recent studies carried out by Coquet et al. (2005a,b), the flow and solute transport was modelled in a tilled soil by explicitly taking into account the soil heterogeneity created by tillage. The objective of the present study is to compare quantitatively the differences produced by two agricultural practices on soil hydraulic properties (water retention curve and hydraulic conductivity), as well as the infiltration and drainage fluxes in the soil. The two agricultural practices studied here are (i) continuous maize fertilized with mineral fertilizer, and (ii) pasture within a ray-grass/maize rotation (3/1 year). These two practices are representative of the agriculture of Western France (AGRESTE, 2004). The experimental site comprises a field where the two practices have been carried out for 22 years on two plots. The study involved measuring soil physical properties in the laboratory and in the field, and estimating water infiltration in the soil of the two plots by recording water pressure heads after artificial rainfall for 2 h. We constructed a numerical model of the water movement in the two soils to quantify infiltration rate, deep drainage and actual evaporation fluxes during the artificial rainfall experiment.

2. Site description and available data

2.1. The experimental site

The experimental site is located in western Brittany, France (latitude 47°57′N, longitude 4°8′W), at the experimental station of the Lycée Agricole de Kerbenez. This region is characterized by intensive milk production and rotation of maize and pasture in agricultural land. The climate is of temperate oceanic type, with an average annual rainfall rate of 1210 mm and a mean annual temperature of 11.5 °C (Lamandé, 2003). An automatic weather station, 50 m from the two studied plots, recorded hourly natural rainfall and other variables necessary to estimate the daily Potential Evapo-Transpiration (PET) from Penman's formula. Soils are made up of loamy-textured Humic Cambisols (FAO, 1998), with high concentrations of organic matter in the uppermost 25 cm (Table 1), and are developed on granitic saprolite. The particle-size distribution is homogeneous between the two plots (Lamandé et al., 2003).