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Impact of recent conversion to organic farming on physical properties and their consequences on runoff, erosion and crusting in a silty soil

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ABSTRACT

The aim of this study was to assess the influence of a recent conversion to organic farming on the physical properties, particularly the aggregate stability, of soils that are prone to soil crusting, as well as their impact on runoff, soil erosion and soil crusting dynamics. Experiments were conducted in the area of Brie, France, in two agricultural fields separated by 400 m with similar slopes and soil types. They consisted of physical measurements of the soils as well as simulated rainfalls with different intensities. No significant differences were detected among the bulk density, soil water retention or saturated hydraulic conductivity. The aggregate stability, measured both under simulated rainfall and in a laboratory, was significantly higher in the organic management field (OF) than in the conventional management field (CM), indicating that CM soils are more prone to soil crusting than OF soils. The influence of this difference was quantified using rainfall simulations in the field. Within the CM field, runoff occurred with a runoff coefficient (RC) of 4.8% and 6.9% when the rainfall intensities were 25 and 40 mm h^{-1}, respectively, while in the OF field, no runoff was observed at these intensities. However, slight runoff was observed when the intensity was 50 mm h^{-1}. Soil losses followed the same trend. Depositional soil crusts were observed in the plots wherein runoff transpired. These results evidence the benefits of recent conversion to organic farming in silty soil to the aggregate stability and consequently soil crust dynamics, runoff genesis and soil erosion.

1. Introduction

Conventional agricultural farming methods, which include tillage, use of synthetic fertilization or synthetic pesticide, have led to various environmental problems identified by the European Commission and the FAO/ITPS as soil threats (European Commission, 2006; FAO and ITPS, 2015). These threats include soil compaction (Richard et al., 2001; Nunes et al., 2015), contamination by pesticides (Zhang et al., 2013) or trace elements (López et al., 2008; Schneider et al., 2016), the decline of organic matter (Bellamy et al., 2005; Riley and Bakkegard, 2006) and biodiversity (Gardi et al., 2009), and soil erosion (Le Bissonnais et al., 2001; Kirkby et al., 2004). The latter has been identified as a globally present primary threat (Van-Camp et al., 2004, FAO and ITPS, 2015). Indeed, soil erosion affects water quality (Lecomte et al., 2001), induces damage to cultivated soils, such as causing an exposure of the roots of some perennial crops, and results in sufficiently high quantities of soil loss that it may not be sustainable in the long-term (Jones et al., 2004).

Since soil is a non-renewable resource that provides essential support to life, soil degradation due to these threats, most notably soil erosion, must be slowed or altogether stopped. Soil surface conditions, such as the development of a surface crust as well as roughness and vegetation cover, influence runoff and soil erosion (Auzet et al., 1995; Morvan et al., 2014). In northern France, within the Paris Basin, large areas are covered by soils that are prone to surface crusting (Cerdan et al., 2004; Le Bissonnais et al., 2005; Augeard et al., 2005). This scenario resulted in an alarming level of soil erosion and runoff in terms of the rate and geographical extent among these soils (Boardman et al., 1994).

Soil degradation has led to the development of innovative agricultural practices such as organic farming management. That management, recommended by the FAO to enhance soil organic matter content (FAO, 2017), is defined by national and broader regulations (European Union, 2007; IFOAM, 2014). Fertility and soil biological activity should be maintained or increased through crop rotations, green manure cultivation, organic matter recycling and composting. In addition, organic production is based on the strict limitation of the use of synthetic chemical inputs (fertilizers and pesticides) except for a few exceptional cases (European Union, 2007). Even if particular studies did not suggest any benefits for the soil, many studies have highlighted environmental

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ameliorations due to the conversion from conventional to organic farming (Stolze et al., 2000). Hathaway-Jenkins (2011) evidenced little direct benefit on the chemical and physical properties of soil from organic management. These differences were influenced by the length of time following the conversion to organic farming, soil texture, and the complex interactions between the previous land use, cropping cycles and agricultural practices. Reganold et al. (2001) compared organic, integrated (denoting the reduction of the use of chemicals by integrating organic and conventional production methods) and conventional apple production systems. In the organic and integrated systems, the soil quality was better than in conventional farming. Erhart and Hartl (2009) reported the results of several studies comparing organic and conventional farming systems. The soil structures were positively affected by organic compared to conventional farming practices, demonstrating more stable macroaggregates, higher infiltration rates and an increase of the soil storage capacity. The main factors responsible for these benefits were larger inputs of organic matter, more diverse crop rotations (utilizing cover crops and green manure) and a longer time span of soil cover. Papadopoulos et al. (2009), Zhang et al. (2014) and Morugán-Coronado et al. (2015) demonstrated that organic management can enhance aggregate stability compared to conventional management. Papadopoulos et al. (2014), by comparing the soil physical quality of paired fields representative of organic and conventionally managed soils, demonstrated that organic farming can substantially improve soil structural conditions, organic matter levels, aggregate stability and porosity. Lotter (2003) specified that runoff genesis and soil erosion are substantially reduced within organic agriculture compared with conventional agriculture systems. Zeiger and Fohrer (2009) and Kuhn et al. (2012) also observed a decreased runoff while examining disturbed soils with different soil textures, but also noted earlier and more pronounced soil crusting signs in conventional farming soils under simulated rainfall conditions. In these two studies, only Kuhn et al. (2012) measured the aggregate stability, which is a parameter that can explain the runoff and soil loss differences (Le Bissonnais, 1996; Chappell et al., 1999). However, the method employed in their study did not characterize the soil behaviour relative to the different kind of rainfall, notably heavy rainstorms that can generate flooding and considerable damage (Cerdan et al., 2002). Furthermore, this kind of study has never been conducted on soils that are prone to soil crusting following a recent conversion to organic farming. Therefore, the purpose of this study is to fill in these gaps.

In this context, the first objective of this study was to compare the physical properties of soil with a focus on aggregate stability in soils that are highly sensitive to soil sealing with two different farming management styles: one represented by a recent conversion to an organic farming system and a conventional farming system. The aggregate stability was measured under simulated rainfall conditions with different intensities and with methods characteristic of a gentle rain or heavy rainstorm in order to study the influence of rainfall characteristics on the formation of soil crust. The second objective was to assess the influence of these physical parameters, especially aggregate stability, on runoff genesis, soil erosion and soil crusting dynamics in the field. Accordingly, rainfall simulations were performed in two fields in the area of Brie, France.

2. Material and methods

2.1. Study site

The study was conducted throughout two agricultural fields in the Orgeval experimental catchment in the Brie area, located 80 km east of Paris, France (Fig. 1). In this catchment, during the measurement period spanning 1972–2012, the average annual air temperature was 9.7 °C, the annual mean rainfall was 696 mm and the annual mean evapotranspiration was 592 mm. Based on a data set comprised of 40 years of rainfall recorded at a five minute time-step, Intensity-Duration-Frequency rainfall (IDF) curves were calculated (Fig. 2). These curves illustrate the synthetic relationship between a return period, the duration of a rainfall event and the information regarding the rainfall height.

The two fields under investigation belong to the same farmer. Their coordinates are latitude 48°50′N and longitude 3°06′E. They are separated by 400 m (Fig. 1) and demonstrate similar slopes ranging between 1 and 2°. The soil type of the two fields is a luvic cambisol (IUSS WRB, 2015), which was developed from loess material. Prior to the conversion of one of these fields to organic farming, the agricultural managements were the same throughout the two fields in accordance with the different crops (Appendix A). The first field was in the third year of conversion to organic farming (OF). To obtain the certification “organic farming”, a conversion period is necessary. From the beginning of the conversion, the only new practice in this field, to comply with the specifications of organic farming, was to stop using synthetic pesticides and synthetic fertilizers. In addition, during the year preceding the study, horse manure was applied. The previous crops were wheat, flax and triticale. A green cover crop (mustard) was sown in August 2011 and harvested in January 2012, just prior to tillage. In May 2012, two false seed beds were performed before mechanical weeding using harrow and bean seedlings. The second field was cultivated using conventional management (CM). The previous crops were wheat, peas and wheat. In August 2011, after the harvest of wheat, sugar beet vinasse was applied and green cover crops (mustard and oats) were cultivated until December, following which vinasse and green cover crops were incorporated into the soil with tillage. Sugar beet was sown in April 2012. Subsequent to sowing, four chemical weeding treatments were applied preceding the experiments.

2.2. Soil characterization

Six topsoil samples of the A horizon from each field were collected at depths of 0–15 cm, dried at 105 °C in an oven and sieved with a 2-mm mesh to separate out the finer fraction from the coarser elements. To characterize the 2 horizons, particle size analyses were performed using the NF X31-107 method (AFNOR, 2004), following which the carbonates, total organic carbon (OC) content and pH of the soil measured in the water were determined employing the NF ISO 10693, the NF ISO 14235 and NF ISO 10390 protocols, respectively. The soils from the two fields exhibited a similar pH as well as a particle size distribution, and they were not calcareous (Table 1). Based on the soil guidelines of the FAO (2006) for soil determination, the soil texture of the two fields were classified as silt.

In each field, 10 bulk density measurements were acquired in the first 5 cm of the soil using cylinders of 100 cm^3.

Soil water retention data for separate surface horizons may be different since they are individually affected by soil texture, soil structure, the amount of OC and the type of clay present (Hathaway-Jenkins, 2011). These data were measured on a pressure plate apparatus for 7 matric potential values between 0 and 15,850 hPa using the method described in both Bruand and Tessier (2000) and in Bruand et al. (1996). To assess the variability within each matric potential, measurements for each horizon were performed on 12 clods of approximately 10 cm^3. These clods were separated by hand from a large undisturbed sample in order to preserve the soil structure. A paste of kaolinite allowed for hydraulic continuity between the clods and the surface of the pressure plate. For each matric potential, the clods remained in pressure cells for one week until equilibrium was reached, following which the gravimetric water content was measured for each clod.

The saturated hydraulic conductivity (Ks) was measured for each field using a Guelph permeameter (Soilmoisture Equipment Corp., Santa Barbara, CA, USA). The Guelph permeameter method is described and discussed in Reynolds and Elrick (1986). It consisted of a modified Mariotte bottle that maintained a constant water level within a well dug