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Soil fertility after 10 years of conservation tillage in organic farming

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ABSTRACT

It has become commonplace to consider ploughing as an agricultural practice that destroys soil fertility. Organic farmers have traditionally used the plough to till their soil and control weeds. However, there is a growing interest in adopting tillage practices without ploughing to preserve long-term soil fertility and in the hope, subsequently, of increasing crop yields. The aim of this paper is to assess if conservation tillage treatments in organic farming did in fact improve long-term soil fertility, wheat rooting and yield in a long term field experiment (2004–2015). We compared the effects of conservation tillage treatments (superficial tillage – ST- with chisel at 15 cm depth and very superficial tillage – VST- at 5–7 cm depth) and conventional tillage treatments (traditional mouldboard ploughing- MP at 30 cm depth and shallow mouldboard ploughing – SMP- at 18 cm depth without skim coulter) during 10 years on a sandy loam soil in France. To assess soil fertility, physical (soil penetration resistance, visual soil profile observation), chemical (organic carbon – Corg, total nitrogen – Ntot and available phosphorus – OlsenP) and biotic (earthworms biomass, density and diversity) soil properties were measured in 2004-5 and 2015. The effect of soil fertility on wheat roots and crop growth was also measured in 2015. VST, and to a lesser extent ST, increased Corg, Ntot and OlsenP in the upper soil layer (from 0 to 15 cm) compared to ploughing treatments. On the contrary, soil compaction increased using conservation tillage treatments (VST and ST) during the 10 years of experiment, especially in the layers between 15 and 30 cm depth in comparison with ploughing treatments. This effect is not offset by an increase in earthworm abundance and activities in conservation treatments. Earthworm biomass and endogeic abundance were even higher in SMP compared to ST. Soil compaction limits roots, with less roots in depth with VST (from 12 to 30 cm and 48 to 70 cm) and ST (from 24 to 30 cm) compared to ploughing treatments. Conservation tillage treatments had positive effects on soil chemical components in the upper soil layer and contributed to the increase of wheat biomass until tillering stage. However, no wheat yield difference was found between treatments. Physical and biotic soil properties had not significantly improved after 10 years of conservation tillage. This could be due either to the insufficient duration of the experiment to foster a positive earthworm effect on soil porosity, or to the sandy soil, too sensitive to soil compaction in this organic cropping system (intensive mechanical weeding) and unfavourable for the development of the earthworm population.

1. Introduction

In organic farming (OF), the plough is traditionally used to prepare soil before seeding, for weed control, to bury intermediate crops, and incorporate organic fertilisers and amendments. However, due to soil fertility problems such as poor soil structure (compaction, soil crust) and the negative impact of tillage on soil organisms, organic farmers in Europe have shown interest in adopting conservation tillage (Casagrande et al., 2015). Conservation tillage includes many practices such as tillage with tined tools at depths down to 15–20 cm, or direct seeding without prior cultivation. Whatever the conservation techniques used, the first reason to stop ploughing is to protect the soil surface from crusting and erosion by leaving crop residues and organic matter at the soil surface. More water-stable aggregates are measured in the uppermost soil layer under conservation tillage compared to ploughing (Holland, 2004; Blanco-Canqui and Lal, 2007). In addition, several studies have shown that conservation tillage increases soil carbon stock (C) as well as the quantity, activity and diversity of soil microorganisms in the upper soil layers (Cookson et al., 2008). Conservation tillage also tends to increase earthworm biomass and diversity (Pelosi et al., 2014). It preserves their habitat (burrows), especially anecic burrows, which favour water infiltration and root penetration (Soane et al., 2012). It is also used to reduce labour time, energy consumption and machinery costs (Soane et al., 2012).

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The combination of conservation tillage advantages and organic farming specificities should be beneficial, as both types of agriculture aim at preserving soil fertility and increasing sustainable cultivation practices. However, to make conservation tillage a success in organic farming, many questions still remain (Peigné et al., 2007). Main difficulties regarding the use of conservation tillage in organic farming is weed management, as the plough is traditionally used to control weeds (Peigné et al., 2007). Several studies deal with weed infestation when conservation tillage are used in organic farming (Gruber and Claupein, 2009; Krauss et al., 2010; Vakali et al., 2011; Armengot et al., 2015; Peigné et al., 2014). Cooper et al. (2016) performed a meta-analysis on the effects of conservation tillage techniques in organic farming on weeds, yields and C stocks. Results on weeds show that conservation tillage increase weed incidence compared to ploughing systems by more than 50%. The statistical relationship between weed incidence and yield is less clear, even if yields decrease by 7.6% compared to deep ploughing. They state that other limiting factors, such as nutrient availability and soil structure, explain yield reduction when conservation tillage is used in OF.

Few articles clearly demonstrate the beneficial effect of combining conservation tillage and organic farming on soil fertility. According to Stockdale et al. (2002), soil fertility can be "defined as the ability of a soil to provide the conditions required for crop growth. It is a result of the physical, chemical and biological processes that act together to provide nutrients, water, aeration and stability to the plant…". Theoretically, the combination of conservation tillage and organic farming may increase soil organic matter content in the topsoil, preserve soil biology, which should then consequently increase overall soil fertility (Peigné et al., 2007). However, questions have been raised on the effect of conservation tillage on topsoil structure; could the risk of compaction increase with conservation tillage on weakly structured soils, such as sandy soil? (Peigné et al., 2007). The transition period from conventional tillage to conservation tillage is particularly prone to compaction, which in turn impedes water drainage and gas exchange, restricts crop emergence and leads to poorer root development (Peigné et al., 2007).

Studies, focused on soil fertility under conservation tillage in OF, often focus on the soil's biotic components (Berner et al., 2008; Kuntz et al., 2013) or chemical properties (Zikeli et al., 2013; Vakali et al., 2014; Cooper et al., 2016). Regarding physical soil properties, Vakali et al. (2011) show that conservation tillage (soil loosening up to 30 cm depth) tends to preserve soil aggregate stability, however few conclusions can be drawn regarding soil compaction as the working depth of the tested treatments was similar. Crittenden et al. (2015) studied the effect of conservation tillage *versus* conventional tillage (ploughing) in OF after 4 years of experiments, on physical soil properties and organic matter content in soils. They concluded that conservation tillage in OF had a potentially beneficial effect on soil fertility. But they also showed more soil penetration resistance using conservation tillage compared to conventional tillage. Thus, (i) the effect of combining conservation tillage and organic farming on soil fertility and (ii) the effect of soil fertility on crop development (root and shoot development) are not *a priori* clear, may not necessarily be beneficial and therefore have to be studied, especially over the long term.

After 10 years of experimentation on a sandy loam soil, the objective of this paper is to assess the effects of 2 conventional (traditional and shallow ploughing) *versus* 2 conservation tillage treatments (superficial tillage at 15 cm depth and very superficial tillage at 5–7 cm depth) on soil fertility and the resulting effect on crops. In light of the literature previously mentioned, the main questions of this paper are: (1) does the combination of organic farming and conservation tillage increase nutrients and soil carbon concentrations as well as the earthworm population? (2) Does biological porosity in conservation tillage remediate soil compaction as well as or better than mechanical porosity created by ploughing? And (3) how does the modification of soil fertility under conservation tillage affect root development and crop yields?

2. Materials and methods

2.1. Experimental design

The "Thil" trial (45°49′9.44″N and 5°2′2.62″E) was set up in 2004-5 in south-eastern France. The soil is a calcareous fluvisol developing on a recent alluvium. The soil texture is composed of 53% sand, 32% silt and 15% clay which corresponds to a sandy loam soil and the pH is 8.2. Below 60 cm, soil texture isn't spatially homogeneous due to heterogeneity in sands and gravels deposits. The climate is classified as semi-continental with Mediterranean influences; the mean annual temperature is 11.4 °C and mean annual rainfall is 825 mm. "Thil" cropping system – an irrigated system with spring crops (maize and soybean), winter wheat and legumes as cover crops – is representative of the organic stockless grain systems found in this region. The land conversion to organic farming (EU 2092/91) started in 1999. The crop rotation is based on Maize (*Zea mays* L.)- Soybean (*Glycine max L.)*- Winter wheat (*Triticum aestivum L.)* with cereal cover crops between maize and soybean and legumes cover crop between winter wheat and maize. Soybean and Maize are intensively irrigated each year (around 300 mm) while winter wheat is irrigated according to climatic conditions (from 30 mm to 100 mm). The experiment started with a maize crop in spring 2005 after 3 years of alfalfa (*Medicago sativa*, 2002–2005).

The experimental design consists in 4 tillage treatments replicated randomly 3 times. The experimental field of 1.5 ha contains 12 experimental plots, each measuring 80 × 12 m (length × width). The plots are separated by 2 m wide grass strips. All plots can be irrigated. The 4 tillage treatments were selected according to their expected effect on soil biology and soil structure: 2 ploughing treatments, *i.e.* mouldboard ploughing at 30 cm depth (MP) and shallow ploughing at 18–20 cm with no skim coulter (SMP), and 2 treatments without soil inversion, *i.e.* superficial tillage at 15 cm with a chisel plough (ST) and very superficial tillage at 5–7 cm with rotary and/or chisel tools (VST). In 2005 and 2008, direct sowing under rolled mulch was tested on VST plots (maize on rolled alfalfa in 2005 and soybean on rolled rye in 2008). The seedbed was prepared with a rotary harrow in all treatments. Weeds were mechanically destroyed by harrowing and hoeing in the row crops, and weed control was adapted to each tillage treatment (Fig. 1). Thus the number of weeding passes was adjusted according to the degree of weed infestation in each treatment. All the agricultural tools on wheat being 4 m wide, the wheel tracks were located on the same zones in 2015 as in previous years. However, as the tools used on maize and soybeans are 4.80 m wide, this, combined with harvesting operations, means that the entire area of a plot could have been suffered some compaction by the wheels over the last 10 years. Soil fertility was assessed between November 2004 and March 2005 on a 3 year alfalfa just before the beginning of the experiment (with a maize), to determine an initial point. Soil, weeds and crop measurements were performed after 10 years of experiment on a winter wheat in 2014-15 (at the end of the second crop rotation). The details of the crop management system and sampling scheme are illustrated in Fig. 1. In 2015, winter wheat was irrigated after the soil sampling period (35 mm the 30th of May, and 70 mm in June).

2.2. Soil fertility

2.2.1. Soil penetration resistance

The soil penetration resistance enables us to assess the state of soil structureat different depths and can be useful for understanding crop rooting. Soil penetration resistance was measured in May 2015 (Fig. 1) at wheat flowering stage. After choosing the most appropriate cone diameter (according to the compaction level), the penetrometer was pushed vertically into the soil at an approximate constant rate of 2 cm per second on each handle. Soil resistance pressure was measured every 5 cm until 50 cm depth. The recorded resistance was standardized