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Impact of conservation tillage and organic farming on the diversity of arbuscular mycorrhizal fungi

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A B S T R A C T

Communities of arbuscular mycorrhizal fungi (AMF) are strongly affected by land use intensity and soil type. The impact of tillage practices on AMF communities is still poorly understood, especially in organic farming systems. Our objective was to investigate the impact of soil cultivation on AMF communities in organically managed clay soils of a long-term field experiment located in the Sissle valley (Frick, Switzerland) where two different tillage (reduced and conventional mouldboard plough tillage) and two different types of fertilization (farmyard manure & slurry, or slurry only) have been applied since 2002. In addition, a permanent grassland and two conventionally managed croplands situated in the neighborhood of the experiment were analyzed as controls. Four different soil depths were studied including top-soils (0–10 and 10–20 cm) of different cultivation regimes and undisturbed sub-soils (20–30 and 30–40 cm). The fungi were directly isolated from field soil samples, and additionally spores were periodically collected from long-term trap culture (microcosm) systems. In total, >50,000 AMF spores were identified on the species level, and 53 AMF species were found, with 38 species in the permanent grassland, 33 each in the two reduced till organic farming systems, 28–33 in the regularly plowed organic farming systems, and 28–33 in the non-organic conventional farming systems. AMF spore density and species richness increased in the top-soils under reduced tillage as compared to the ploughed plots. In 10–20 cm also the Shannon–Weaver AMF diversity index was higher under reduced tillage than in the ploughed plots. Our study demonstrates that AMF communities in clay soils were affected by land use type, farming system, tillage as well as fertilization strategy and varying with soil depth. Several AMF indicator species especially for different land use types and tillage strategies were identified from the large data set.

1. Introduction

Due to the growing demand for productive but sustainable agriculture, different farming systems have been developed. These include various ecologically sound management practices such as reduction or abandonment of soil tillage (so-called conservation or no-tillage systems, respectively), reduction or abandonment of synthetic crop protection products and/or of easily availably mineral fertilizers (so-called integrated production and organic farming systems, respectively), among several other options (Wezel et al., 2014).

To cultivate soils, mouldboard ploughing is traditional. However, in the last decades there was an effort to develop alternative strategies, such as different types of reduced tillage or no-tillage practices, both also denoted as conservation tillage practices. With such systems several advantages come along, above all in ecological as well as in economic aspects like higher biological

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activity, improved soil fertility, reduced soil erosion, less need of energy and labor (Peigné at al., 2007; Soane et al., 2012; Kuntz et al., 2013). On the other hand, the pressure of weeds and soil-borne pathogens are often enhanced in reduced tillage systems, and this might threaten the quantity or the quality of the harvests. This is especially a challenge in organic farming, because no synthetic pesticides, e.g. no synthetic herbicides, insecticides and fungicides, can be applied (Triplett and Dick, 2008; Carr et al., 2011).

Arbuscular mycorrhizal fungi (AMF) are obligate symbionts and associated with the majority of plant species. The fungi have several beneficial effects on their host plants, such as support of nutrient uptake, enhanced resistance against drought or root pathogens (Smith and Read, 2008; van der Heijden et al., 2015). In addition AMF can improve soil structure, soil aggregation and water infiltration and thus, can contribute to the prevention of soil erosion (e.g. Rillig and Mummey, 2006). Furthermore, it was shown that AMF diversity plays an important role for higher plant diversity and for the productivity of plant communities (van der Heijden et al., 1998).

AMF are influenced by farming practices such as soil tillage and fertilization strategy (Jansa et al., 2003; Oehl et al., 2003, 2010; Kabir, 2005). Extensive land use and low-input systems have usually positive effects on AMF, and therefore plants may benefit more from AMF in such agricultural systems (Mäder et al., 2000; Njeru et al., 2015). Several studies revealed that community structure and diversity of AMF in soils differ between tilled and reduced or no-tillage soils (e.g. Jansa et al., 2002; Yang et al., 2012; Köhl et al., 2014; Maurer et al., 2014; Wetzel et al., 2014). There was one study focusing on the intra-specific diversity of one AMF species, *Glomus intraradices* (Börstler et al., 2010), however, to our knowledge there has not been any study on AMF communities influenced by tillage intensity in organic farming systems.

AMF communities can be investigated by classical microscopic identification of spores extracted from the soil matrix or from inside the roots (e.g. Douds and Millner, 1999) and by modern molecular analyses in soils or in root systems (e.g. Verbruggen et al., 2012). Both methods have advantages and disadvantages (e.g. Oehl et al., 2004; Njeru et al., 2015), and, whenever possible, both methods should be combined, which has rarely been done in the past due to lack of time, knowledge and experience, respectively (Wetzel et al., 2014).

The objective of the present study was to investigate the influence of soil tillage and type of fertilization on AMF communities in an organically managed long term field experiment running since 2002 (Berner et al., 2008). While approximately the same amount of nutrients was applied to all plots, there were two fertilization types per tillage strategy: one fertilization regime was mainly with farmyard manure complemented by slurry, while in the other regime only slurry has been applied. In order to compare the AMF communities established in the treatments of the experiment with those communities occurring in the same area in less and more intensively used agricultural soils, one extensively managed permanent grassland subjected to organic farming, and two intensively managed cultivated sites subjected to conventional farming in so-called Integrated Production systems (IP) were also included in our study.

In view of our laboratory research history and the large number of samples (seven treatments/sites and four soil depths per treatment/site, with four field soil replicates per treatment and soil depth) we focused on morphological spore identification and spore quantification. Based on earlier findings obtained in conventionally managed arable fields (e.g. Jansa et al., 2002; Wetzel et al., 2014), we hypothesized that also under organic farming intensive soil tillage, and intensive conventional farming will negatively affect the AMF communities and AMF diversity due to vulnerability of the AMF mycelia networks by specific soil cultivation techniques. There is little knowledge about AMF spore populations in different soil depths, even from sites of different soil use and cultivation, or from organic farming systems (e.g. Oehl et al., 2005). We hypothesized that AMF diversity decreases with soil depth, and that this decrease varies among different farming and tillage systems. With more than 100,000 AMF spores isolated and more than 50,000 spores identified, the present study has been one of the most extensive AMF diversity studies based on spore morphology presented so far.

2. Materials and methods

2.1. Study sites

For this study, seven sites were selected, all situated in the Sissle valley between the neighbored municipalities Frick and Oeschgen (Canton Aargau, Switzerland) in close vicinity to each other (47°30–31′N; 8°01′21–25″E). According to IUSS Working Group WRB (2014, International Union of Soil Sciences), the soils (with about 45% clay content) are all Vertic Cambisols having developed on alluvial and colluvial Jurassic sediments. Mean annual temperature is about 9.0 °C and mean rainfall is about 1000 mm per year. Four sites, located at 47°30′42″N; 8°01′25″E, constituted four treatments of a long-term field experiment of the Research Institute of Organic Agriculture (FiBL), in which reduced tillage and conventional tillage systems under organic farming (RO and CO systems, respectively) have been compared since 2002 (e.g. Berner et al., 2008; Börstler et al., 2010; Krauss et al., 2010; Sans et al., 2011; Gadermaier et al., 2012; Kuntz et al., 2013; Armengot et al., 2015 for further details). One other site was a permanent, organically managed grassland (GL) at the southern end of the field experiment (47°30′38″N; 8°01′25″E), while two additional cultivated sites were conventional farming systems managed according to the guidelines of Swiss proof of ecological performance and Swiss integrated production (IP). The latter two sites (IP1 and IP2) were located in the North of the field experiment (at 47°30′55″N; 8°01′25″E and 47°30′59″N; 8°01′20″E, respectively). All sites had about 400 m distance to the Sissle river.

The field experiment was designed as a split strip plot (Gadermaier et al., 2012), four times replicated with tillage and fertilization as factors. One fertilization regime was mainly with farmyard manure (M) complemented by slurry, while in the other regime only slurry (S) has been applied (Berner et al., 2008, Table 1). In two of the treatments, reduced tillage (RO; Reduced tillage under Organic farming) was practiced (5–7 cm depth soil pealing by Skim plough or by overlapping wide chisel sweeps, or 15 cm depth soil loosening by narrow tines of a chisel, depending on the crop in the rotation) to incorporate the harvest residuals and to control weeds, while in two treatments of conventional tillage (CO; Conventional tillage under Organic farming) a mouldboard plough was used (tillage depth 15 cm). For details about the tillage practices in the past, see Gadermaier et al. (2012). The previous crops had been 2004 sunflower, 2005 spelt, 2006–07 grass-clover, 2008 maize, and at sampling time in 2009 winter wheat was grown (Table 1). Seedbed preparation was the same in the reduced and conventionally tilled treatments performed with a rototiller (5 cm depth). In IP1, the ploughing depth was 18–20 cm and a rotary harrow was used before seeding. For the IP2 field, a seeding combination with rotary harrow was used. Depending on the crop, either plough (16–18 cm) or rototiller (5 cm) was chosen to cultivate the soil, which represents another kind of reduced tillage practice by reducing the number of ploughings per crop rotation. Under wet soil conditions, rototiller was replaced with a rotary harrow. The principal agricultural practices, like land use type, farming system, fertilization type and level, crop rotation, standing crop at sampling