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Soil microbial community and microbial residues respond positively to minimum tillage under organic farming in Southern Germany

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ABSTRACT

In a field trial comprising organic farming and minimum tillage management strategies in Scheyern, Germany, we evaluated the long-term (21-year) effects of organic farming (use of a diverse crop rotation with legume cover crop and without application of synthetic fertilizer or pesticides) and minimum tillage (6–8 cm depth) on the microbial community structure and microbial residues in Cambisols. Organic farming had a positive effect on microbial biomass, total phospho-lipid fatty acids (PLFA), Gram (+) bacteria, Gram (−) bacteria and the arbuscular mycorrhizal fungi (AMF) indicator PLFA 16:1ω5 and amino sugars. The increase in presence of Gram (+) bacteria when compared to integrated farming was also reflected by increased content of bacterial muramic acid (MurN), i.e. an increased formation of bacterial residues. Minimum tillage significantly increased microbial biomass N and the fungal PLFA 18:2ω6,9, averaging the values of upper (0–8 cm) and deeper (12–25 cm) soil, but had no effects on PLFA 16:1ω5. Minimum tillage generally resulted in a negative depth gradient of almost all microbial properties analyzed. The only important exception was fungal galactosamine (GlcN), which led to increases in the fungal C/bacterial C ratio and in the contribution of microbial residue C to SOC in the deeper soil. Significant second order tillage × management interactions indicated that minimum tillage effects on microbial biomass and PLFA indices (Gram (+) and (i15:0 + i17:0)/(a15:0 + a17:0)) were much stronger in the organic farming system than in the integrated farming system. Redundancy analysis (RDA) showed SOC and H_2O content predominantly affected the microbial community structure in the present study. Minimum tillage in combination with organic farming appears to be an effective agricultural strategy that enhances soil microbial biomass, microbial residues and bacterial and fungal abundances. The results indicate that the positive effects of minimum tillage on microbial community can be enhanced by organic farming. Microbial residues as a fraction of SOC respond faster to farming management than to tillage.

1. Introduction

The maintenance of viable, diverse populations and functioning microbial communities is essential to agricultural ecosystems (Kennedy and Smith, 1995), because soil microbial communities are critical to achieving many important ecological functions and services, to maintaining soil quality, to reflecting inherent soil fertility and to developing sustainable agriculture. However, it is subjected to the influence of agricultural management strategies and sensitive to soil perturbation and land use changes (Bending et al., 2004; Fließbach et al., 2007). Cropping system management strategy is one of the most significant anthropogenic activities that greatly alter soil characteristics, including physical, chemical, and biological properties (Jangid et al., 2008). Therefore, the development and implementation of sustainable agricultural strategies is necessary and it is important to understand the impacts of

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different cropping system management strategies on microbial communities in agricultural soils. Organic farming and minimum tillage are two alternative agricultural management strategies of intensive agriculture (Mäder et al., 2002; Kuntz et al., 2013).

The effects of organic farming, characterized by no use of synthetic fertilizer or pesticides and use of diverse crop rotations and manure, on soil microorganisms have been repeatedly analyzed (Mäder et al., 2002; Fließbach et al., 2007; Birkhofer et al., 2008). The application of cattle farmyard manure has usually positive effects on the soil microbial biomass (Heinze et al., 2010b), bacterial biomarkers (Bausenwein et al., 2008) and amino sugars (Scheller and Joergensen, 2008; Joergensen et al., 2010; Sradnick et al., 2014). Organic farming tends to shift the microbial community structure to bacteria, because of the application of farmyard manure (Joergensen et al., 2010), and bacteria respond most strongly to farming management compared with other microbial groups (Esperschütz et al., 2007). Also the effects of minimum tillage or reduced tillage on soil microorganisms have been repeatedly investigated (Heinze et al., 2010a; Jacobs et al., 2011). The use of a grubber instead of a soil-turning plough usually benefits fungi (Frey et al., 1999; Spedding et al., 2004), saprotrophic fungi due to an increased presence of organic residues in the deeper soil (Berner et al., 2008; Heinze et al., 2010b) and AMF due to decreased disturbance (Klein and Paschke, 2004; Kabir, 2005; Sale et al., 2015). Both organic farming and minimum tillage have potential to improve the soil microbial community, and thereby nutrient cycling. As minimum tillage is a management strategy that is rare in organic farming systems (Mäder and Berner, 2012; Armengot et al., 2015), limited information exists on the interactions of these two factors. This is especially true considering the confounding effects of climate and soil properties on tillage and management-induced changes in microbial properties (Six et al., 2006; Navarro-Noya et al., 2013). As most previous studies on the effects of agricultural practices have focused on active micro-organisms (Liang et al., 2008), limited knowledge exists on the changes in microbial residues caused by the combination of minimum tillage and organic farming.

The biomass, i.e. the active fraction of microorganisms, can be estimated by fumigation extraction (Brookes et al., 1985; Vance et al., 1987) and the phospholipid fatty acids (PLFA) as cell membrane components give additional information on the biomass of functional microbial guilds (Zelles and Bai, 1993; Gattinger et al., 2002), such as Gram (+) and Gram (−) bacteria and saprotrophic and arbuscular mycorrhizal fungi (AMF) (Joergensen and Wichern, 2008).

Microbial cell wall-derived amino sugars are routinely used as biomarkers for microbial residues (Liang et al., 2013; Sradnick et al., 2014), with muramic acid and glucosamine being highly specific for bacteria and fungi, respectively (Joergensen and Wichern, 2008). Another important component of microbial residues is the glomalin-related soil protein, produced by AMF (Burrows, 2014), closely related to soil organic C (SOC) sequestration and to aggregate stabilization (Rillig et al., 2002; Baez-Perez et al., 2010; Singh et al., 2013).

Long-term agricultural field experiments are particularly valuable for detecting effects of management or tillage systems on soil (Widmer et al., 2006). In the current field trial, we evaluated the effects of long-term (21-year) implementation of organic farming and minimum tillage on the microbial community structure and microbial residues. Our investigations are based on the following hypotheses (1) Organic farming increases microbial biomass, especially bacterial biomass, leading to an increased contribution of microbial residues to SOC. (2) Minimum tillage increases microbial biomass, especially fungal and AMF biomass. (3) The combination of organic farming and minimum tillage would be the most effective management strategy, resulting in maximum contents of microbial biomass, with strongest effects on AMF and only intermediate effects on bacteria and saprotrophic fungi.

2. Materials and methods

2.1. Field experiment

Field experiments have been carried out at the Scheyern Research Farm (TERENO site) located 40 km north of Munich, Germany (48.50°N, 11.45°E) since 1992. The altitude of the farm ranges between 445 and 500 m a.s.l. The mean annual precipitation and mean annual temperature are 803 mm and 7.4 °C, respectively (Schröder et al., 2002). The central part of the research station was divided into two parts: organic and integrated systems, each striving for ecological and economical sustainability. Moreover, detailed studies on management-induced changes were carried out in plots sub-divided into integrated and organic farming (Schröder et al., 2002).

On the organic and integrated sites, plot experiments studying tillage-induced changes to the systems were set up. Two farming managements (Integrated (I) and Organic farming (O)) and two tillage systems (Plough tillage (PL) and Minimum tillage (MT)) were arranged in full factorial plot design. The tillage systems in the study represent two possible tillage intensities under the existing soil and climate conditions. PL as a conventional tillage system means tilling the soil with a moldboard plow (25–30 cm). MT in the study means cultivating soil with a chisel plow in the first 6–8 cm of soil. Therefore, there are four treatments in the present study in total and each has three replicates. Namely, 1) organic farming + plough tillage (OPL); 2) organic farming + minimum tillage (OMT); 3) integrated farming + plough tillage (IPL); 4) integrated farming + minimum tillage (IMT). The assignments of the treatments to the plots have been kept constant since 1992. The IF plots are 12 × 12 m in size and the crop rotation is potato (*Solanum tuberosum* L.) + mustard (*Sinapis alba* L.) as catch crop, (2) winter wheat (*Triticum aestivum* L.), (3) maize (*Zea mays* L.) + mustard as catch crop, and (4) winter wheat. The OF plots are 12 × 12 m in size and the crop rotation is a seven-crop rotation: grass–clover–alfalfa (GCA) (*Lolium perenne* L. + *Trifolium pratense* L. + *Medicago sativa* L.), (2) potato + mustard as cover crop, (3) winter wheat, (4) sunflower (*Helianthus annuus* L.) + GCA as cover crop, (5) GCA, (6) winter wheat, and (7) winter rye (*Secale cereale* L.) + GCA as cover crop. The soil types are sandy to loamy Cambisols, derived from tertiary sediments. The soil in both field trials has a soil texture of silty loam (USDA) and the soil texture of top soil is 22% sand, 58% silt and 20% clay (Flessa et al., 2002; Kolbl and Kögel-Knabner, 2004).

In the IF system trial, N fertilization was done with UAN (50% urea N, 50% ammonium nitrate N), with a modified boom sprayer with tubes to conduct the solution directly to the soil surface. Fertilizer rates were fixed for the cultivated crops (135 kg N ha^{-1} for winter wheat, 105 kg N ha^{-1} for maize and 100 kg N ha^{-1} for potato), irrespective of credits due to effects of previous crop cultivation or mineralization in the soil. In the OF system trial, cattle farmyard manure was applied at a rate of 30 t ha^{-1} a^{-1} dry weight.

2.2. Sampling and soil properties

Three composite samples (20 augers, 5 cm in diameter) were separately collected at two soil depths (0–8 cm-upper soil and 12–25 cm-deeper soil) in April 2013 from each experimental plot. Soil moisture (WC) was determined by oven-drying fresh soil at 105 °C to a constant weight. Soil pH was measured in a soil-0.01 M $CaCl_2$ suspension (1:2.5 v:v). SOC and total N were measured using