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Diversifying crop rotation increased metabolic soil diversity and activity of the microbial community

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ABSTRACT

Agricultural intensification has increased food production by reducing crop diversity and increasing fertilization and crop protection. Unfortunately, intensification has also reduced soil ecosystem services. Diversifying crop rotations could be a feasible alternative to promote positive feedbacks between soil biota and soil properties. Here, we investigated the impact of diversifying crop rotations on functional composition and diversity of the heterotrophic soil bacterial communities. We studied three frequent rotations with a total number of crops ranging from two to four. Before the experiment, all plots were cultivated with soybean. In the first experimental year, the crop sequences were (1) fallow/soybean, (2) barley/soybean, and (3) field pea/maize. In the second year, all plots were subjected to a wheat/soybean double crop. The experiment was replicated in three locations of the Rolling Pampa (Argentina). Soil and plant sampling took place immediately after the soybean harvest, in the second year. The most diverse rotation (field pea/maize, wheat/soybean) showed the highest standing biomass and litter and the most metabolically diverse and active soil microbial community ($P \leq 0.05$). In turn, metabolic diversity was positively associated with plant and litter biomass ($r^2 = 0.7$) and with soil pH ($r^2 = 0.72$). Our results revealed that crop rotation affects soil metabolic bacterial diversity and activity ($P \leq 0.05$). The most diverse rotation (four different crops) had also the most diverse and active soil microbial biota, concomitantly with a higher plant biomass production and soil pH. Because soil microbial activity and metabolic diversity detected in specific rotations potentially contribute to soil aggregate formation and other soil properties intimately related with nutrient cycling and plant production, the negative effect of agricultural intensification could be attenuated by designing specific and more diverse crop rotations.

1. Introduction

Sustainably increasing crop production is critical for modern agriculture. Agricultural intensification fragments farmed landscape by enlarging field size and decreasing crop diversity to a handful of species. Because the expansion of cropland area is unlikely, increasing crop yields and using double crops are essential parts of agricultural intensification (Andrade et al., 2015). Therefore, modern agroecosystems provide more food, but depend more on external inputs and lose self-regulation capacity (Foley et al., 2005). In particular, intensification may dramatically affect soil properties responsible for residue decomposition, nutrient re-cycling, and soil formation (Zak et al., 2003; McDaniel et al., 2014a; Lange et al., 2015).

Feedbacks between plants and soil microbes represent an important dimension of ecosystem regulation, which has been addressed in different contexts and scales (Zak et al., 2003; Lange et al., 2015). In agricultural landscapes, land use (e.g. crops, pastures, woodlands, grasslands) alters carbon cycling and soil organisms (Guo and Gifford, 2002). Woody patches show lower litter decomposition than the cultivated matrix in which they are embedded because of their production of large amounts of recalcitrant tissue. Therefore, they accumulate more soil carbon and sustain more diverse soil microbial communities than surrounding cropped areas (D'Acunto et al., 2014, 2016). Within cropped areas, long-term crop rotations also accumulate more soil carbon and microbial biomass than monocultures, particularly when rotations include cover crops (McDaniel et al., 2014a; Tiemann et al., 2015; Venter et al., 2016). Mechanisms for this influence involve variation in litter chemistry, soil pH and nutrient contents (Zak et al., 2003; Fierer and Jackson, 2006; Lauber et al., 2008, 2009; Wickings et al., 2012; Venter et al., 2016).

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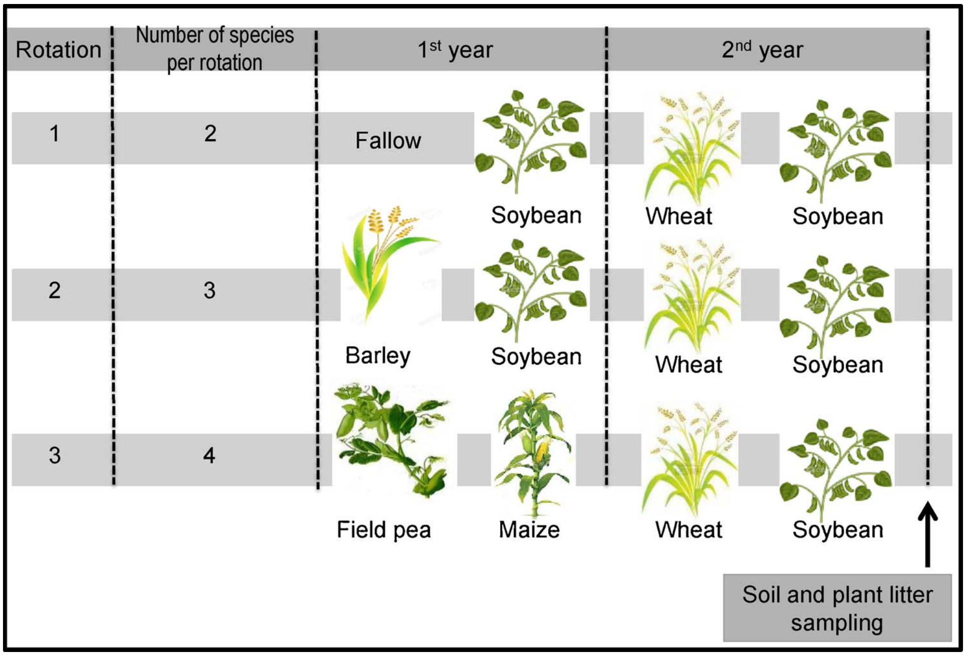

Fig. 1. Experimental design and sampling. Crop rotations differed in the composition and total number of different crop species (fallow/soybean,wheat/soybean, 2 species; barley/soybean, wheat/soybean, 3 species; and field pea/maize, wheat/soybean, 4 species). The same experimental design was replicated in three different locations (Junín, Pergamino and San Pedro) along a SW-NE 100-km transect in the Rolling Pampa (Argentina).

While the benefits of particular crop rotations in terms of yields, resource use, and pest control have been well established, those related to soil microbial organisms are less understood (Altieri, 1999; Liebman and Dyck, 1993; Govaerts et al., 2007; Andrade et al., 2015; Venter et al., 2016). Crop rotation involves changes in the amount, quality and timing of root metabolites, above-ground residue deposition, fertilization and pest control (Follett, 2001; Roger-Estrade et al., 2010). Therefore, the final impact of particular rotations on soil biota structure will depend on the net balance among such factors. Empirical evidence is scarce: even though rotations seem to increase microbial diversity compared to monocultures (Lupwayi et al., 1998; González-Chávez et al., 2010; Postma-Blaauw et al., 2010, Venter et al., 2016; but also see Jiang et al., 2016), the effects of different rotation schemes are not known. In schemes promoting sustainability, where monoculture is not conceived as a regular practice, the consequences of alternative rotations should be critically evaluated to identify the best combinations of crops. A complete knowledge would also require disentangling both the underlying mechanisms and the relationships with crop production.

The Rolling Pampa, the corn-belt of Argentina, provides a useful context to study crop rotations because agricultural intensification has been dramatic during the last decades (Baldi et al., 2006). In this region, intensively managed, continuous croplands replaced mixed systems that combined perennial pastures and annual crops. The widespread adoption of new technologies, such as no-tillage, fertilization, and genetically modified crops, as well as the increase of soybean international prices, led to a rapid removal of fencerows to enlarge fields. Rotations of maize, soybean and wheat/soybean double crops are dominant, even though double cropping of field pea/maize, barley/soybean, and rapeseed/soybean are also frequent to increase total biomass production and resource use efficiency (Andrade et al., 2015). In these cropping systems, relationships between crop yields and rotations have been well established (Caviglia et al., 2004; Andrade et al., 2015). Nevertheless, the effects of crop rotations on soil microbial communities remain contentious.

Here, we investigated the impact of diversifying crop rotations on the functional diversity of heterotrophic soil bacterial communities. We hypothesize that increasing the number of different crops, particularly by including double-cropping, increases the total inputs of root exudates and plant residues into soil in terms of both mass and substrate diversity. In turn, crop diversity might alter soil properties relevant to soil microbial structure and function such as soil pH. Therefore, a greater amount and diversity of resources will promote the growth and activity of different groups of the heterotrophic soil bacterial community.

2. Materials and methods

2.1. Study system

The study was carried out from 2010 to 2012 in three locations along a 100-km transect in the Rolling Pampa, northern of Buenos Aires province (Argentina): Junín (34°23′S; 60°48′W), Pergamino (33°55′S; 60°23′W), and San Pedro (33°47′S; 60°00′W). Climate is temperate subhumid, without a marked dry season but with frequent water deficit during summer. Mean annual rainfall is approximately 1000 mm and mean annual temperature is 17 °C (Hall et al., 1992). The frost period extends from mid-April to late-September. Soils are mostly Argiudolls, which are characterised by a topsoil horizon rich in organic matter and a clay accumulation subsurface horizon (Soriano et al., 1991). The original grassland vegetation was extensively ploughed, and nowadays continuous cropping dominates the landscape. Annual crops exceed 90% of the land surface, 8% is for feed cattle, and 2% correspond to uncultivated areas. Soybean occupies 60% of the area as a single crop, and 16% as a second crop right after wheat. Maize occupies 15% of the area and wheat is the main winter crop, with 13% of the sown area. Other winter crops are barley, rapeseed, and peas, with less than 5% of total cropped area (Satorre, 2011).

2.2. Experimental design and analyses

In each of the three locations (Junín, Pergamino and San Pedro), three crop rotations were implemented, based on their relevance in the region: in the first year, crops were (1) fallow/soybean, (2) barley/soybean and (3) field pea/maize, and in the second year there was a common double cropping of wheat/soybean (Fig. 1). In summary, rotations ranged from 2 to 4 different crops. Genotypes were those recommended as most productive in the region. Sowing dates, plant densities and row spacing were adjusted to the selected genotypes and the typical recommendations (Table 1). Each rotation had two replicates per location, each consisting of a 22 × 200 m plot. Because a