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Respiration, available N and microbial biomass N in soil amended with mixes of organic materials differing in C/N ratio and decomposition stage

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ABSTRACT

The effect of C/N ratio on decomposition after amendment with individual litters and their mixes has been studied extensively. But less is known about the effect of highly decomposed organic materials such as manures on interactions in mixes. In this study, a sandy clay loam was amended with finely ground young faba bean shoots (FB, C/N 9), sheep manure (SM, C/N 6) and mature wheat straw (W, C/N 82) either individually (referred to as 100FB, 100SM, 100SM) or as mixes (e.g. 75FB-25SM, 50FB-50SM, 25FB-75SM, where the value represents the weight percentage of the organic materials). Soil was sampled on days 16, 32 and 48. Cumulative respiration after 48 days was similar with 100FB and 100 W, where it was about seven-fold higher than in 100SM. It decreased with percentage SM in the mixes and was about two-fold higher in 25SM-75 W than in 75SM-25 W. Available N was low with 100 W and microbial biomass N (MBN) was low with 100SM (five-fold lower than with FB). In mixes of W with FB or SM, available N was between two and 40-fold lower than expected with greater differences between measured and expected values FB-W than with SM-W. In FB-W and SM-W mixes, MBN was between 50% and two-fold higher than expected. In mixes of FB and SM, MBN on day 16 was 50% higher than expected in 75FB-25SM, but 30–50% lower than expected in mixes with ≥50% SM. We conclude that mixing of W with FB can provide plants with N, but also reduce N loss via leaching or denitrification.

1. Introduction

It is well-known that composition of organic amendments determines decomposition rate and nutrient availability (Bending and Turner, 1999; Tian et al., 1992). For example, N availability after amendment depends on C/N ratio with low C/N organic materials (C/N < 20) resulting in net N mineralisation (Hadas et al., 2004) whereas high C/N amendments inducing net N immobilisation (Moritsuka et al., 2004). Decomposition of mixes of organic materials has been studied extensively (Cobo et al., 2008; Gartner and Cardon, 2004; Xiang and Bauhus, 2007). In such mixes, expected nutrient availability can be calculated based on nutrient availability with each organic material individually and the ratio of each organic material in the mixes. In an additive response, measured and expected values such as mass loss and nutrients in the mix are similar, whereas in a non-additive response, measured decomposition in the mix is either greater or lower than expected (Gartner and Cardon, 2004). Similar measured and expected values could be due to spatial separation of the decomposer communities of organic materials in the mix (Shi et al., 2013). Greater than expected decomposition has been attributed to transfer of nutrients from rapidly decomposing organic materials to recalcitrant materials (Blair et al., 1990; Seastedt, 1984), changed decomposer community composition (Blair et al., 1990), niche complementarity or specialisation within the decomposer community (Chapman and Koch, 2007; Hector et al., 1999) and priming effects in which decomposition of low-nutrient materials is stimulated by high-nutrient materials (Chapman et al., 1988; Chapman and Koch, 2007; Wardle et al., 1997). Lower than expected decomposition in a mix can be due to diffusion of inhibitory compounds such as phenolics and tannins from slow decomposing materials to fast decomposing litter (Dix, 1979; Hättenschwiler and Vitousek, 2000).

A number of studies investigated mass loss or N content in mixes of leaf litters differing in decomposability. In most of these studies, the N concentration of the fast decomposing litter was higher than slow decomposing litter. For example, measured decomposition of 1:1 mixtures of fast (soybean) and slow decomposing (poplar) leaves was greater than expected (Mao and Zeng, 2012). In a study with leaf litter from a number of species, fast decomposing litters had a C/N ratio of about 20, slow decomposing litters a C/N ratio of 50–80 (Cuchietti et al., 2014). In that study, intact litter was added individually or mixed into litter

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bags which were placed in soil for two or nine months. At harvest, they were able to separate and individually weigh the different litter types in mixes. Cuchietti et al. (2014) found that in 1:1 mixes of fast and slowly decomposing litter, measured decomposition was usually greater than expected due to enhanced decomposition of the fast decomposing litter. Harguindeguy et al. (2008) buried litter bags with mixtures of two to five litter types and placed them in soil for 80 days. They reported that in mixtures of fast (high N) and slow (low N) decomposing litter, measured decomposition was greater than expected irrespective of the proportion of the fast decomposing litter in the mix. De Marco et al. (2011) mixed leaf litters with C/N about 100 which differed in decomposition rate due to differences in lignin content and lignin/N ratio (high in Quercus leaves, low in Cistus leaves). They reported lower than expected decomposition in the initial stages (days 0–90) of decomposition, but greater than expected decomposition later (day 90–400). De Marco et al. (2011) suggested that initially, inhibitory compounds from Quercus leaves reduced decomposition, but later, decomposition of lignin in Quercus leaves was enhanced as a result of greater microbial activity induced by the fast decomposing litter.

Previous studies on mixing organic materials have focused on CO_2 release, mass loss and nutrient contents of mixes using fresh or dried litter, usually with only one or two sampling times. There is limited understanding about the influence of mixing plant residues and manures, which may occur in agricultural ecosystems where manures are added after harvest of a crop or termination of a cover crop. Manures can have low C/N ratio, but are strongly decomposed during passage through the digestive system of animals and may be further decomposed during storage (Hungate, 1966). Therefore, they are at a late stage of decomposition and thus may decompose more slowly when added to soil and release less N than plant residues with similar C/N ratio. Further, little is known about changes in nutrient availability and microbial biomass during decomposition of mixes (Blair et al., 1990; Schwendener et al., 2005). The aim of this study was to determine the effect of low C/N organic amendments differing in decomposability and high C/N residue added to soil separately or as mixes on soil cumulative respiration, microbial biomass N and P and available N and P. Young faba bean shoot, sheep manure and mature wheat straw were added into soil singly or mixed. The selection of these organic materials was based on a preliminary experiment which showed that although young faba bean shoot and sheep manure had a similar low C/N ratio, sheep manure decomposed much more slowly than faba bean. Mature wheat straw was chosen as high C/N amendment.

The first hypothesis was that in mixes of high C/N wheat straw with low C/N faba bean or sheep manure, N availability and microbial biomass N will decrease with proportion of wheat straw. Based on the differences in decomposability of faba bean and sheep manure, the second hypothesis was that in mixes with mature wheat straw, the effect of faba bean on N availability and microbial biomass N is greater than with sheep manure. The third hypothesis was that in mixes of faba bean and sheep manure, N availability and microbial biomass N increase with proportion of faba bean in the mix. The fourth hypothesis was that interactions in mixes depend on ratio of organic materials and that they change over time.

2. Materials and methods

2.1. Soil and organic materials

The sandy clay loam used in this study was collected from 0 to 10 cm at Waite Campus, The University of Adelaide (Longitude 138°38′3.2″ E, Latitude 34°58′0.2″ S). The area is in a semi-arid region and has a Mediterranean climate with cool, wet winters, and hot and dry summers. The soil is a Red-brown Earth in Australian soil classification and a Rhodoxeralf according to US Soil Taxonomy. The soil has been managed as permanent pasture for over 80 years and has the following properties (for methods see below): sand 54%, silt 20% and clay 25%, pH (1:5 soil:water) 6.3, electrical conductivity (EC 1:5 soil:water) 143 $\mu S\,cm^{-1}$, total N 1.5 $g\,kg^{-1}$ and total P 371 $mg\,kg^{-1}$, total organic carbon (TOC) 17 $g\,kg^{-1}$, available N 15 $mg\,kg^{-1}$, available P 10 $mg\,kg^{-1}$, maximum water holding capacity (WHC) 378 $g\,kg^{-1}$ and bulk density 1.3 $g\,cm^{-3}$. The soil was collected from several randomly selected sites on the plot. In each sampling site, plants and surface litter were removed and five samples (0–10 cm) were collected. The soil was then air dried at 40 °C in a fan-forced oven. The drying is not unusual for soils in this area because during summer, top soil often reaches temperatures of 40–50 °C on hot sunny days. After air-drying, visible plant debris was removed and the soil sieved to < 2 mm. Soil from all sampling sites was pooled and thoroughly mixed before taking soil for the experiment.

Three types of organic materials were used: young faba bean (*Vicia faba* L., referred to as FB) as fast decomposing low C/N material, sheep manure (referred to as SM) as slow decomposing low C/N material and mature wheat straw (*Triticum aestivum* L., referred to as W) as high C/N material. The plant residues were chosen because they are common crops in southern Australia and often follow each other in crop rotations. Sheep manure was used because a preliminary experiment showed that sheep manure was slowly decomposing as compared to other low C/N organic materials such as young faba bean, composts and poultry manure. The organic materials were dried at 40 °C in a fan-forced oven, finely ground and sieved to 0.25–2 mm particle size. The organic materials were finely ground to maximise contact of organic materials in mixes and with the soil. In the field, applied organic materials are usually much coarser. Larger particles will decompose more slowly than fine particles because of physical protection and smaller surface area to volume ratio (Ambus and Jensen, 1997; Angers and Recous, 1997). Therefore mineralisation rates and nutrient transfer between organic materials in this study are likely to be higher than in the field.

2.2. Experimental design

Before the start of the experiment, the air-dried soil was incubated for 10 days at 50% of maximum WHC at 20–25 °C in the dark to activate the soil microbes and stabilise soil respiration after rewetting of air-dry soil. This water content was chosen because in previous studies with this soil, microbial activity was maximal at 50% (Marschner et al., 2015). Soil was amended with organic materials on day 0 at the rate of 20 $g\,kg^{-1}$ soil. This rate was high compared to average amounts used in the field, but it could occur in some situations, e.g. in windrows left by harvesting machines, uneven spreading of manure or in nurseries. There were twelve treatments in which organic materials were added to the soil singly or in mixes (Table 1). In treatments with single

Table 1
Experimental design with treatment names and corresponding details about organic amendments: young faba bean shoot (FB), sheep manure (SM) and mature wheat straw (W) and their mixing proportions.

Treatment name	Faba bean	Sheep manure	Wheat
	% in mix		
100FB	100		
100SM		100	
100 W			100
75FB-2.5SM	75	25	
50FB-50SM	50	50	
25FB-75SM	25	75	
75FB-25 W	75		25
50FB-50 W	50		50
25FB-75 W	25		75
75SM-25 W		75	25
50SM-50 W		50	50
25SM-75 W		25	75