Applied Soil Ecology 113 (2017) 107–116

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

The chemical convergence and decomposer control hypotheses explain solid cattle manure decomposition in production grasslands

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ARTICLE INFO

Article history:
Received 24 August 2016
Received in revised form 1 February 2017
Accepted 6 February 2017
Available online 14 February 2017

Keywords:
C:N ratio
Fertilisation
Litterbags
Macrofauna
Management history
Mesofauna
Microbiota
Nitrogen mineralisation

ABSTRACT

Recently, we reported for the first time that home field advantage (HFA) of litter decomposition also exists in agricultural production systems, in addition to earlier reports from natural ecosystems. Here, we provide evidence that adaptation of the soil decomposer community to differences in the chemical composition of solid cattle manure (SCM) explains the HFA. Two dairy farms were selected which differed in type of home-produced SCM (high-quality stacked or low-quality composted SCM) and soil type (sand or peat). Manure was exchanged between these two farms. Also, manure was incubated in fields of two neighbouring non-SCM farms. Using litterbags with three different mesh-sizes (125 μm, 1.5 mm, and 4 mm), we investigated the contribution of microbiota, mesofauna and macrofauna, to SCM dry matter (DM) and nitrogen (N) disappearance after 60, 120 and 240 days of litterbag placement. Home field advantage was estimated after accounting for effects related to structural differences in manure quality (quality index) and grassland soil biota communities (ability index). We found HFA in meso- (14–34%) and macro-mesh (19–31%) size litterbags. In micro-mesh litterbags, the HFA for dry matter and nitrogen disappearance was significant only after 120 days (18 and 26%, respectively). With time, trends of initial increase and then decrease in HFA of both aforementioned parameters were observed, but these were not significant. The quality index indicated that the composted manure had a lower dry matter and nitrogen disappearance rate compared to the stacked manure, irrespective of the location of incubation. The difference between the two manure types for N disappearance had vanished at day 240. Also, the chemical composition of the manure that remained in the litterbags changed over time. After 120 days, the C:N ratio of SCM at home was significantly higher compared to the translocated SCM ($P < 0.01$), an indication of a higher N-use efficiency of the home soil biota communities. After 240 days, no such differences in C:N ratio were observed, thus suggesting chemical convergence of SCM quality with time. Given the soil biota size-class dependent effects and location-specific changes of substrate quality with time, our findings support both the decomposer-control and chemical-convergence hypotheses. However, chemical convergence did not result in a significant reduction of the HFA. Furthermore, the location-specific temporal changes in the chemical composition of SCM indicated that the fertilisation management, which drives soil biota communities and their functions, regulates N-use efficiency in production grasslands.

1. Introduction

Climate and organic matter quality are major drivers controlling organic matter decomposition at the global scale (Gholz et al., 2000; Strickland et al., 2015; Veen et al., 2015). However, several recent studies suggested that the composition of the local decomposer communities could also play an important role in this regard (Austin et al., 2014; Handa et al., 2014; Makkonen et al., 2012; Vos et al., 2011, 2013; Wall et al., 2008). Soil decomposer communities are assumed to be adapted to degrade the type of organic matter they encounter most often, i.e. the locally produced plant litter (Ayres et al., 2009a; Strickland et al., 2009a,b). This phenomenon of adaptation is well documented in recent literature

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http://dx.doi.org/10.1016/j.apsoil.2017.02.009
0929-1393/

and is known as home field advantage (HFA), which typically indicates that organic matter decomposes faster in the habitat where it was produced as compared to its decomposition elsewhere, after translocation (Austin et al., 2014; Ayres et al., 2009a,b; Milcu and Manning, 2011; Rashid et al., 2013; Wang et al., 2012). The magnitude of HFA established thus far for dry matter (DM) disappearance was on average 8% in forest ecosystems (Ayres et al., 2009b; Veen et al., 2014) and 20% in agricultural grassland (Rashid et al., 2013). However, there was a large variation in the size of the observed HFA (-9 to 35%) (Ayres et al., 2009a,b; Rashid et al., 2013; Veen et al., 2014). The near zero or even negative HFAs challenge the generality of HFA in leaf litter decomposition studies (Freschet et al., 2012; Gießelmann et al., 2011; Jewell et al., 2015; Perez et al., 2013; Veen et al., 2014). A better understanding of the mechanisms behind the HFA is necessary to explain such contrasting findings.

Recently, several hypotheses have been proposed to explain HFA (Ayres et al., 2009a; Wickings et al., 2012; Wallenstein et al., 2013). The 'chemical convergence hypothesis' of Ayres et al. (2009a) and Wallenstein et al. (2013) assumes that initial differences in chemical composition of litter will decrease when decomposition proceeds and so will the HFA. Wickings et al. (2012) proposed the 'decomposer control hypothesis', which states that decomposer communities impose constraints on organic matter decomposition regardless of time (i.e. the stage of decomposition) and/or differences in the initial litter quality. Thus, in addition to initial differences in organic matter quality, soil biota communities might play an essential role in determining the size of the HFA during decomposition (Wallenstein et al., 2013). Soil decomposer communities are assumed to develop traits specialised in degrading certain types of organic material leading to some degree of adaptation (Austin et al., 2014; Ayres et al., 2009a; Milcu and Manning, 2011; Strickland et al., 2009a; Wallenstein et al., 2013). Especially the microbial part of decomposer communities might rapidly respond to changes in the local quality of organic matter by increase in abundances of adapted relative to less-well adapted species (Gießelmann et al., 2011; Perez et al., 2013). Such rapid species turnover is less likely for detritivorous soil fauna like Collembola and Acarina (Milcu and Manning, 2011) and earthworms (Bohlen et al., 1997).

Solid cattle manure (SCM) is a valuable source of nitrogen (N) when applied to production grasslands (Schröder et al., 2007). Its contribution to net ecosystem productivity largely depends on the biological decomposition and mineralisation of complex organic compounds into plant-available nutrients. The balance between N mineralisation and immobilisation will affect the net N availability of applied organic N for plant uptake, which can be highly variable (range between 20 and 50%) in case of, e.g., SCM when broadcast-applied to temperate production grasslands (Rashid et al., 2014b; Schröder et al., 2007; Shah et al., 2012; Sonneveld and Lantinga, 2011). The chemical composition of SCM can vary greatly due to differences in animal species or breeds, feed ration, bedding materials and SCM handling and processing (composted or stacked) (Rotz, 2004; Tunney and Molloy, 1975). Hence, it can be expected that, like in forest litter of different quality, differences in SCM quality may result in adaptations in the local soil biota communities leading to a HFA for N-use efficiency of SCM. Recently, Rashid et al. (2013) reported that the disappearance rate of SCM dry matter and N was larger on farms with a SCM application history as compared to cattle slurry manure farms. Furthermore, when comparing SCM farms, relatively large HFAs of 20 and 14% were found for SCM dry matter and N disappearance, respectively. Apparently, farm-specific fertiliser management shapes the interaction between organic matter input and decomposer community composition, and a better understanding thereof can contribute to the development of more sustainable agricultural management systems (Rashid et al., 2013).

The aim of our study is to better understand the mechanisms underlying HFA in SCM decomposition in production grasslands. We investigated the effects of differences in substrate quality in terms of lignin:N ratio, and the contribution of various groups of soil biota, i.e. macro- and mesofauna and microbiota, to the disappearance rate of SCM. Our research aims to test the 'chemical convergence' versus the 'decomposer control' hypothesis. First, we hypothesize that HFA will be larger in high than in low lignin:N ratio SCM. Secondly, the initial differences in substrate quality will diminish over time as decomposition proceeds, resulting in a decrease of the HFA for dry matter and N disappearance of SCM. Thirdly, for dry matter and N disappearance of SCM, the HFA will be more dependent on meso- and macrofauna than on microbes. After application to the field, SCM will preferentially be colonized by local meso- and macrofauna (Sandor and Schrader, 2012), whereas for microbes the 'home' manure populations are expected to remain of importance because of synergistic interactions with the soil microbial community (Molina-Herrera and Romanyà, 2015).

2. Materials and methods

Soil biota-specific effects and time-dependent effects of SCM dry matter and N disappearance were studied at four dairy farms in The Netherlands. Initial differences in SCM quality were realised by making use of different manure production methods (composting *vs.* stacking during storage). The SCM's were incubated in litterbags with three different mesh-sizes (125 μm, 1.5 mm, and 4 mm) which allow access to different body-size groups of soil organisms. The litterbags were incubated for a period of 60, 120 and 240 days in fields used for production grassland. Effects of manure application history were studied by incubating the litterbags in production grasslands that were fertilised for >5 years with both SCM and cattle slurry, and in production grasslands fertilised with cattle slurry only, or supplemented with artificial fertiliser.

2.1. Selection and description of experimental sites

We made the selection of dairy farms (A and B) based on their production and application of solid cattle manure and organic-N rich cattle slurry (SCM farms). Two neighbouring farms (C and D) were selected where the manure-handling system was designed for producing slurry manure, which was richer in mineral-N content. The differences in N composition between the slurries was obtained by specific adjustments in the composition of the diet of the cattle (Reijs et al., 2007). The grasslands on farms A and C were located on peat soil (province Utrecht), whereas soils of farms B and D were sandy and located in the Gelderland province, The Netherlands. Farms A and C were located close to each other (1 km) and the distance between farms B and D, was 15 km.

On farm A, the farmer produced compost from SCM (AM) whereas the SCM remained stacked on farm B (BM) during the storage period. Therefore, the lignin:N ratio in AM was higher than in BM (Table 1). Grasslands of both farms A and B received SCM plus organic-N rich slurry. In contrast, mineral-N rich slurry and artificial fertiliser were applied on farm C, whereas in case of farm D, only mineral-N rich slurry was used. Farms C and D did not receive SCM for decades and are henceforth indicated as non-SCM farms. Details of the grassland fertilisation management on all farms, and manure handling and processing on farms A and B are given in Rashid et al. (2013, 2014a).