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Response of soil fertility indices to long-term application of biogas and raw slurry under organic farming

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ABSTRACT

The long-term effects of biogas slurry application on soil fertility indices were compared with raw slurry in biodynamic organic farming systems. An on-farm soil and slurry sampling was carried out to quantify the effects on stocks of soil organic matter, microbial biomass and microbial residues. Five fields with biogas slurry and five neighbouring fields with raw slurry amendments were selected at 5 different sites in the north-east of Baden-Württemberg, Germany. The application of biogas slurry ranged from 15 to 25 years and did not affect SOC, total N stocks or the soil C/N ratio. Biogas slurry application decreased the soil microbial biomass to SOC ratio, which indicates a reduced availability of the biogas slurry C input to soil microorganisms compared with raw slurry. At some sites, differences in clay content masked any slurry effects on the microbial activity, biomass, and residue indices. There were no general effects of biogas slurry on the ratios of ergosterol to microbial biomass C or amino sugar-based fungal C to bacterial C, whereas an increasing clay content caused a significant shift towards bacteria according to the latter ratio. Since the soils had been farmed organically in diverse crop rotations for at least 40 years, chemical differences in slurry composition were not great enough to result in different biochemical properties. The consistency in the data of all approaches strongly indicates the validity of the current on-farm study by comparing neighbouring fields.

1. Introduction

Biogas is an important component for energy production from renewable resources (Møller et al., 2009) and for this reason biogas slurry, the secondary product of the anaerobic digestion process, is increasingly used as fertilizer in organic farming systems (Möller, 2009; Terhoeven-Urselmans et al., 2009). Biogas plants use a wide variety of substrates, whereas raw slurries are derived from faeces and urine, some water and rarely straw. In the early 1980s, biogas production was introduced to Germany by biodynamic organic farmers in north-east Baden-Württemberg. The basic motivation was to gain independence from nuclear power electricity, which had been strongly expanded in that period. However, heat production, odour reduction, and a higher fertilizer quality were further reasons for using biogas slurry (Friedel et al., 1996; Bachmann et al., 2011; Möller and Müller, 2012).

Biogas slurries have advantages and disadvantages in respect to their effects on soil (Arthurson, 2009; Möller, 2009). The positive effects of biogas slurries on plant yield, soil chemical, physical and particularly soil microbial biomass characteristics have been repeatedly evaluated in highly artificial incubation (Friedel et al., 1996; Odlare et al., 2008; Sänger et al., 2011), greenhouse pot (Andruschkewitsch et al., 2013), and short-term field experiments (Terhoeven-Urselmans et al., 2009; Bachmann et al., 2011; Johansen et al., 2013). Anaerobic digestion increases the concentration of NH_4-N and reduces dry matter, leading to lower C concentrations and C/N ratio as well as to increased slurry pH values (Asmus et al., 1988; El-Shinnawi et al., 1989; Kirchmann and Witter, 1992; Möller and Müller, 2012). Due to the larger inorganic N concentrations, biogas slurries supply more plant-available N than other organic fertilizers, e.g. sewage sludge or farmyard manure (Odlare et al., 2008) or undigested slurry (Bachmann et al., 2011). Biogas slurry also contains large concentrations of soluble inorganic P and thus may represent a valuable P fertilizer (Bachmann et al., 2011).

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Furthermore, in stockless farming systems, biogas slurry provides a good option for producing an organic fertilizer from grass/clover sites, which can be widely used as fertilizer on other parts of the farm (Stinner et al., 2008). However, concerns have also been raised about the use of biogas slurry (Scheller, 2006; Möller, 2009; Terhoeven-Urselmans et al., 2009). The lower C input by the biogas slurries and the higher recalcitrance of their organic matter in comparison with raw slurries may not only reduce microbial activity and biomass, but also earthworm biomass (Ernst et al., 2007) and in the long-term also soil organic C (SOC) sequestration (Friedel et al., 1996). At the same time, the higher recalcitrance of the organic matter remaining in biogas slurries has also been considered as beneficial for SOC sequestration (Asmus et al., 1988; Gutser et al., 2005).

These conflicting results point to the need for long-term field experiments to evaluate the effects of biogas slurry application (Möller and Müller, 2012). In north-east Baden-Württemberg, there is a unique opportunity to compare biodynamic organic farmers who have been applying biogas slurry for up to 25 years with their biodynamic neighbours who have been applying raw slurry. All farms have been under organic farming management for at least 40 years and use similar crop rotations according to best organic management practice. This on-farm approach comparing neighbouring fields with similar soil texture and soil pH has been successfully used in several investigations on the long-term effects of different land-use systems (Ahl et al., 1998; Probst et al., 2008; Bowles et al., 2014).

Microbial biomass and the fungal cell-membrane component ergosterol are sensitive indicators for the effects of organic fertilizer application to soil and thus for soil fertility (Heinze et al., 2010). As highly specific microbial cell-wall components, amino sugars are recalcitrant and, consequently, serve as slow responding indices for the contribution of microbial residues to the sequestration of SOC (Amelung, 2001; Liang et al., 2011). Fungi are the main source of glucosamine (Joergensen and Wichern, 2008), whereas bacteria are the exclusive source of muramic acid (Millar and Casida, 1970; Appuhn and Joergensen, 2006), making it possible to assess the specific contribution of these two main microbial groups to SOC (Joergensen et al., 2010).

The specific feature of this work was an on-farm soil sampling approach at six biodynamic farms, where biogas slurry was applied for between 15 and 25 years. The objectives of the current study were to measure the soil fertility indices microbial activity (basal respiration), microbial biomass C and N, fungal ergosterol, microbial residues (amino sugars), and soil organic C, total N, soil pH and clay content at five sites with two neighbouring fields using either biogas or raw slurry under biodynamic farming management. The underlying hypothesis was that long-term biogas slurry application has similar effects on soil organic matter, microbial residue or microbial biomass indices as raw slurry.

2. Material and methods

2.1. Experimental sites and soil sampling

The study area is located in the north-east of Baden-Württemberg (Germany). Here, a pairwise comparison of fields was performed, whereby six biodynamic farms were chosen, three with biogas plants and three using raw cattle slurry. The first criterion for choosing a site was that the farms had the same agricultural land-use management system. The second criterion was that the climatic and geological conditions are nearly the same due to the vicinity of the farms within each site. The third and main criterion was that one farm at each site had a biogas plant and had been using biogas slurry as fertilizer for a prolonged period of up to 25 years. Two experimental sites are located in Kirchberg (KB-I and KB-II), two in Aspach (AS-I and AS-II), and one in Künzelsau (KA) within a radius of about 86 km. Each site consisted of one field treated with biogas slurry and one field treated with raw slurry application. KB I and II as well as AS I and II had 2 fields per farm and KA only one. The mainly clayey loam soils at these sites were classified as Haplic Cambisols (36% of the study area), Stagnic cambisols (27%), Argic cambisols (9%), Stagnic luvisols (18%), and Haplic Luvisols (9%) according to the FAO-WRB (2006) classification system, forming a complex mosaic in some fields. Soil samples were taken about 4 weeks after fertilization and ploughing in November 2010 (KB and KA) and April 2011 (AS) at 0–5, 5–10, 10–20 and 20–30 cm depth from 9 sampling points, resulting in 36 samples per field and 360 samples in total. The field-moist soils were sieved (<2 mm) and stored in polyethylene bags at 4 °C. A sub-sample of each soil sample was dried and finely ground for chemical analyses. Another sub-sample was frozen at −18 °C for further analysis.

At all sites, organic farming has been practised for at least 40 years. On the farms with biogas plants, the application of biogas slurry as fertilizer has been performed for about 25 years (Table 2). Depending on crop rotation and availability, the farmers added some farmyard manure to each site, despite slurry fertilization. In each field, ploughing was carried out to a maximum of 20 cm depth, except at site KA, where reduced tillage was performed to a maximum of 15 cm depth. In general, the crop rotations on all farms consisted of legumes, grain, and root crops (Table 2).

2.2. Slurry sampling and analysis

All raw slurries consisted of cattle faeces, cattle urine and straw. Biogas slurry KB, added to the respective sites, was produced from 95% cattle slurry and 5% whole crop silage, a mixture of rye, wheat, and rapeseed. Biogas slurry AS was produced from 70% cattle slurry and 30% grassland silage or whole crop silage, a mixture of oats, barley, beans, and clover/grass. Biogas slurry KA was composed of 60% cattle slurry and 40% clover/grass silage, followed by mechanical separation into a liquid and a dry fraction after digestion. Only the liquid fraction was collected in this study.

Raw slurries (3 farms) and biogas slurries (3 farms) were directly taken from the storage tanks with 4 replicates each. After homogenization by stirring, all samples were frozen in liquid N_2 directly after removal, kept cool during transport and stored at -18 °C until analysed. A sub-sample was dried at 60 °C and finely ground for chemical analyses using a ball-mill. In the dried slurries, total C was determined using a Vario MAX (Elementar, Hanau, Germany) elemental analyser and total P, S, Na, K, Mg, Ca, Mn, Fe, and Al were analysed after HNO_3-pressure digestion as described by Chander et al. (2008) using ICP-AES (Spectro Analytic Instruments, Kleve, Germany). Total N was analysed in the non-dried slurries, using Kjeldahl digestion (Blume et al., 2011). Ammonium and nitrate were extracted from the slurries using 0.5 M K_2SO_4 (20 ml per gram fresh slurry) and measured on a continuous flow analyser (Evolution II, Alliance Instruments, Salzburg, Austria). The slurry pH was measured in a 0.01 M $CaCl_2$ solution (2.5 ml per gram of fresh slurry).

2.3. Soil chemical analyses

The soil pH was determined using a soil to water ratio of 1–2.5. Soil textural analysis was carried out after pre-treatment with H_2O_2, HCl and suspension in sodium polyphosphate, using a combined sieving and pipette method (Blume et al., 2011). Total C and N were determined using a Vario MAX (Elementar, Hanau, Germany) elemental analyser. Carbonate was gas-volumetrically analysed using a Scheibler apparatus (Blume et al., 2011). Then, SOC was calculated as total C minus carbonate C.