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Comparative characterization of digestate versus pig slurry and cow manure – Chemical composition and effects on soil microbial activity

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ABSTRACT

The growing number of biogas plants in Europe has resulted in increased production of nutrient-rich digestate with great potential as fertilizer for arable land. The nutrient composition of digestate varies with the substrate treated in the biogas plant and may contain compounds that stimulate or inhibit soil microbial activity. This study compared 20 digestates (D) with 10 pig slurries (PS) and 10 cow manures (CM) regarding their chemical content and their effect on soil microbial activities, i.e. potential ammonia oxidation rate (PAO) and soil respiration. The results showed no significant differences within the D group when divided based on substrate type. i.e. manure dominated vs. other organic waste materials in any of the tests. In general D contained significantly higher concentrations of ammonium while the concentrations of total carbon and volatile fatty acids were higher in PS and CM than in D. The D showed both stimulating and inhibiting effects on PAO, while all CM and all PS except one showed inhibiting effects on PAO. However, PAO activity was negatively correlated with the content of volatile fatty acids in the residues indicating that these compounds may be the cause of the inhibition. The maximum respiration activity ($h_{peakmax}$) was lower and the time point for the maximum respiration activity ($t_{peakmax}$) occurred earlier for D compared with CM and PS. This earlier peak time could be indicative of a high proportion of easily degradable carbon in D compared with PS and CM. However, the utilization rate of carbon, i.e. the proportion of added organic C converted to CO_2-C during 12 days, did not differ significantly between D, PS and CM, indicating that overall carbon quality in the different fertilizers was still roughly comparable. In short, our results suggest that digestates were different compared with PS and CM but without posing a higher risk with respect to their impact on soil microbial activity.

1. Introduction

Anaerobic digestion (AD) is a widely used technology whereby organic material is converted into energy-rich biogas and a plant nutrient-rich residue (digestate). The flexibility of AD means that many different types of organic material are suitable as feedstock for the process, such as organic municipal waste, sludge from wastewater treatment, waste from food processing industries, energy crops and agricultural wastes such as manure and plant residues (Appels et al., 2011). The biogas can be used for producing heat, electric power and vehicle fuel, and therefore AD is an important technology when it comes to meeting the European Commission's goal that 20% of all energy consumed should have its origin in renewable resources by the year 2020 (EREC, 2008). Moreover, the digestate can be used as a fertilizer on arable land, enabling recirculation of plant nutrients and thus reducing the need for fossil fuel-dependent mineral fertilizers (Holm-Nielsen et al., 2009).

The multi-functionality of the AD process has attracted interest in recent years and has resulted in an increasing number of biogas plants and, consequently, increasing production of renewable energy in Europe (Weiland, 2010). In 2013, 52.3 TW h of biogas electricity were produced in the European Union (EurObservER, 2014), a 13% increase from 2012. In Sweden, total biogas production in 2013 corresponded to 1.5 TW h, with 3, 31, 54 and 13% used for electricity, heat, vehicle fuel and other purposes, respectively (Swedish Energy Agency, 2014). In total, 264 biogas plants were in operation in Sweden in 2013, an increase of 9% from 2012. In line with the trend of increasing biogas production, the amounts of digestate have also increased. For example, in 2013 roughly 1,360,000 tons of digestates were produced in Sweden (not including digestate from biogas processes at wastewater treatment plants, WWTP). Of these, 990,000 tons were produced at large-scale co-digestion plants (i.e. plants that simultaneously digest different types of organic material, except that from WWTP) and

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370,000 tons at farm-scale plants, and close to 100% of all digestate were returned to arable land (Swedish Energy Agency, 2014). In comparison, 27,410,000 tons of animal manure (cow: 24,190,000 tons, pig: 2,750,000 tons) were spread annually on agricultural land in Sweden in 2012/13 (SCB, 2014).

Anaerobic digestion of animal manure before use as a fertilizer is generally considered positive, since the digestate obtained has higher proportions of mineralized plant-available nutrients than the untreated manure and since digestion results in a significant odour reduction as reviewed by Insam et al. (2015) and Arthurson (2009).

The content of plant macronutrients, micronutrients and organic components in the digestate depends on the origin of the ingoing substrate and the management of the digestion process (Möller and Müller, 2012; Zirkler et al., 2014). The nutrient composition of different manures also varies greatly, due to factors such as type of animal (omnivore, ruminant, etc.), sex, species, age and the diet fed to the animal, as well as geographical and climate conditions (Lukehurst et al., 2010). The proportion of ammonium (NH_4^+) is generally higher in digestate than in the organic substrate going into the AD process (Arthurson, 2009). Higher NH_4^+ content is of great importance in a fertilizer, as it is immediately available to the plant. Spreading organic fertilizers on arable land generally has positive effects on soil chemical properties (Doran, 2002; Joshua et al., 1998; Jakobsen, 1995) and may increase the soil organic matter content, which is very important for maintaining or improving soil quality (Nkoa, 2013). However, digestate and animal manure may also contain heavy metals (Kupper et al., 2014; Govasmark et al., 2011; Odlare et al., 2008; Kirchmann and Witter, 1992), different organic pollutants (Limam et al., 2013; Govasmark et al., 2011; Hellström et al., 2011; Engwall and Schnürer, 2002; Levén et al., 2006; Angelidaki et al., 2000) and antibiotic residues (Spielmeyer et al., 2014; Martínez-Carballo et al., 2007; Hamscher et al., 2005). This could explain why different organic fertilizers have been found to induce both positive and negative effects on the soil microbial community (Sänger et al., 2014; Abubaker et al., 2013; Odlare et al., 2011; Levén et al., 2006; Nyberg et al., 2004; Svensson et al., 2004; Kirchmann and Lundvall, 1993). In Sweden, the SPCR 120 certification system was launched in 2010 to create confidence in digestate as a fertilizing agent. The system is based on European Union health rules regarding animal by-products and derived products not intended for consumption (EC No. 1069/2009; http://eur-lex.europa.eu/; 25/11/14). It includes e.g. checks on raw materials, treatment process, and declaration of content regarding plant nutrient composition, levels of heavy metals, human pathogens and visual contaminants (SPCR120, 2010). However, the content of organic pollutants is currently not taken into account.

Different approaches have recently been employed for evaluating the ecotoxicity of digestates including standardized *in vitro* ecotoxicologial tests using aquatic test organisms (e.g. *V. fischeri*, *D. magna*) and soil-based bioassays using specific test plants and earthworms (Pivato et al., 2016; Tigini et al., 2016). Studying the indigenous soil microbial community response after soil amendment can provide an integrated yet sensitive way to assess the safety of digestates (Stenberg, 1999). Soil microorganisms perform critical soil functions, such as the formation of stable aggregates and cycling of plant nutrients (Sapp et al., 2015; Kennedy and Papendick, 1995) and changes in microbial activity often occur faster than changes in the physical and chemical properties of the soil. Therefore, studying microbial responses after application of organic fertilizers can give an early indication of potential negative effects (Stenberg, 1999). Soil microbial activity can be evaluated by either estimating the metabolic activity of the total community or by focusing on the specific activity of various microbial groups. Soil respiration is a general process performed by most microorganisms and hence provides information on the whole soil microbial community (Stenberg, 1999). Ammonium oxidation, on the other hand, is performed by only a small group of bacteria sensitive to disturbance and therefore their activity is suitable for detecting the presence of e.g. toxic compounds in the fertilizer (Odlare and Pell, 2009; Pell et al., 1998). A minimum dataset (MDS) has been suggested when analysing soil quality and within this MDS, soil respiration and potential ammonium oxidation (PAO) are suggested to be two important descriptors (Stenberg, 1999; Kennedy and Papendick, 1995). So far, a number of studies have examined the effect of digestate on the soil microbial community and compared it with that of other organic fertilizers (Abubaker et al., 2015, 2012; de la Fuente et al., 2013; Odlare et al., 2008; Kirchmann and Lundvall, 1993). However, these studies, which included a total of seven digestates, three pig slurries and two cow manures, produced inconclusive results. With the digestate, a positive response on soil respiration was seen for all samples, but PAO was both positively and negatively affected (Abubaker et al., 2015, 2012; Odlare et al., 2008). Fertilization with pig slurry (PS) and cow manure (CM) complemented with mineral N did not show any clear effect on either respiration or PAO (Odlare et al., 2008). Moreover, Odlare et al. (2008) found that digestate had a better fertilizer value in term of crop yield than PS, CM and NPS, and also more markedly stimulated soil nitrification and soil respiration. In contrast, Abubaker et al. (2012) observed higher biomass yield after fertilization with PS compared with digestate.

The varying and contradictory results reported concerning soil microbial responses after application of digestates and manures are most likely due to the large variations in quality within and between these groups of fertilizers, in combination with the limited number of samples studied. It is clear that further studies are needed for a better understanding of anaerobic digestates as fertilizing agents. The aim of the present study was thus to investigate a large set of organic fertilizers including 20 digestates, 10 cow manures and 10 pig slurries. The hypothesis was that an analysis of a large number of samples would give a more clear result regarding difference and/similarities between manures and digestates and gives a better foundation for the use of digestate as a fertilizer. The organic fertilizers were analysed concerning differences and correlations within and between the groups regarding their chemical composition, plant nutrient content and effect on respiration and PAO rates in soil.

2. Materials and methods

2.1. Soil sample

Soil was collected in autumn 2009 from the topsoil layer (0–20 cm) of an arable field located in central Sweden (N 59°36.985′, E 16°39.674′; WGS84), and classified as an Eutric Cambisol (FAO, 1998). Since 1998, the field has been fertilized annually with 100 kg N ha^{-1}, with no addition of farmyard manure since 1975. The crop rotation consisted of barley and oats grown every second year and at harvest in the autumn crop residues were removed as straw. The soil sample extracted for this study were stored for one day at +2 °C before being sieved (5 mm mesh width), thoroughly mixed, portioned in polyethylene bags and stored at −20 °C until analysis. The physical and chemical characteristics of the soil are presented in Table 1.

2.2. Organic residues

Digestates (D) were collected from 20 AD production plants, six in Denmark and 14 in Sweden (Table 2). All D were collected from the digestate storage tank except one, which was collected from

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