



Research article

Agronomic characteristics of five different urban waste digestates

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ABSTRACT

The use of digestate in agriculture is an efficient way to recycle materials and to decrease the use of mineral fertilizers. The agronomic characteristics of the digestates can promote plant growth and soil properties after digestate fertilization but also harmful effects can arise due to digestate quality, e.g. pH, organic matter and heavy metal content. The objective of this study was to evaluate the differences and similarities in agronomic characteristics and the value of five urban waste digestates from different biogas plants treating either food waste, organic fraction of organic solid waste or a mixture of waste-activated sludge and vegetable waste. The digestate agronomic characteristics were studied with chemical analyses and the availability of nutrients was also assessed with growth experiments and soil mineralization tests. All studied urban digestates produced 5–30% higher ryegrass yields compared to a control mineral fertilizer with a similar inorganic nitrogen concentration, while the feedstock source affected the agronomic value. Food waste and organic fraction of municipal solid waste digestates were characterized by high agronomic value due to the availability of nutrients and low heavy metal load. Waste-activated sludge as part of the feedstock mixture, however, increased the heavy metal content and reduced nitrogen availability to the plant, thus reducing the fertilizer value of the digestate.

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1. Introduction

Anaerobic digestion is a widely used technique for the treatment of various organic waste materials to produce energy in the form of biogas and nutrient-rich residue, digestate. In Europe the total digestate production in 2010 was 56 Mtonnes per year of which 80–97% was used in agriculture (Saveyn and Eder, 2014). The use of digestate in agriculture has been acknowledged as an efficient way to mitigate greenhouse gas emissions through material recycling, avoidance of mineral fertilizers and improvement of soil properties as reported in several life cycle analyses (Bernstad and la Cour Jansen, 2011; Boldrin et al., 2011; Evangelisti et al., 2014). However, proper digestate management, processing and spreading techniques are needed to avoid potential acidification and eutrophication impacts due to increased nutrient leaching (Abdullahi et al., 2008; Alburquerque et al., 2012a; Bernstad and la Cour Jansen, 2011; Boldrin et al., 2011; Haraldsen et al., 2011) which is dependent on the local soil quality and meteorological conditions

as well as digestate characteristics (Evangelisti et al., 2014).

The digestate agronomic characteristics, including organic matter content and quality and plant-available nutrients as well as possibly harmful properties, e.g. heavy metals and pathogens, define the effect on soils and plants (Abubaker et al., 2012; Nkoa, 2014; Teglia et al., 2011), i.e. the agronomic value of the digestate. Anaerobic digestion typically converts most of the feedstock's organic material into biogas while the nutrients of the feedstock are conserved in the digestate (Odlare et al., 2011) in more inorganic and soluble forms (Tambone et al., 2010). The soluble ammonium nitrogen increases the short-term effect of nitrogen in soils enhancing plant growth shortly after fertilization (Abubaker et al., 2012; Gutser et al., 2005). The organic matter in the digestate increases the soil carbon balance (Odlare et al., 2008, 2011) that leads to enhanced microbial processes (Abubaker et al., 2012; Odlare et al., 2008) and enzymatic activity (Galvez et al., 2012), which further increases the long-term nutrient release in soils (Abubaker et al., 2012; Odlare et al., 2008). In addition, digestate has also been reported to increase germination and plant root growth (Maunuksela et al., 2012) and soil quality by increasing water balance and soil structure (Abubaker et al., 2012). As a result, the application of the same amount of plant-available nutrients in

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digestates compared to mineral fertilizers has been found to produce similar and even increased crop yields compared to mineral fertilizers (Abubaker et al., 2012; Haraldsen et al., 2011; Svensson et al., 2004; Walsh et al., 2012). The amount of digestate applied to land in the EU is defined according to the national legislation which outlines the limits for nitrogen and phosphorus use per hectare. For example, in Finland the limits in cereal and grass fertilization are 170 kg/ha for organic nitrogen, 130–250 kg/ha for soluble nitrogen and 4–52 kg/ha for phosphorus depending on the plant type, yield, geographical location, soil type and phosphorus content of the soil (Government Decree No 1250/2014 on the restriction of certain discharges from agriculture or horticulture, MAVI, 2014).

Excess application of digestate can lead to harmful effects on plants and soils due to, e.g., the quantity and quality of organic matter or the impurities, including heavy metals, organic contaminants or pathogens (Alburquerque et al., 2012b; Govasmark et al., 2011). High organic matter content, depending on its composition, can lead to excess microbial activity and immobilization of nitrogen (Alburquerque et al., 2012a; Gutser et al., 2005) as well as phytotoxicity (Abdullahi et al., 2008). Feedstocks of urban biogas plants, e.g. sewage sludge and biowastes, may contain heavy metals (Kupper et al., 2014; Odlare et al., 2008), which are concentrated in the digestate due to the mass reduction during anaerobic digestion (Govasmark et al., 2011), and possibly accumulated in the soils or in the food chain after digestate use (Ottobong et al., 1997; Zhu et al., 2014). Altogether, the characterization of the digestate organic matter, nutrient and heavy metal contents and their effects on plants and soils, i.e. the agronomic characteristics, are essential in order to plan digestate management and to control the positive and negative environmental effects of digestate fertilization.

The recent research on the use of digestates in agriculture has focused largely on digestates from agricultural feedstocks such as manure, plant biomass and a mixture of agro-industrial products and manure (e.g. Alburquerque et al., 2012a, 2012b; Fouda et al., 2013; Galvez et al., 2012; Grigatti et al., 2011; Gunnarsson et al., 2010). Furthermore, some studies have reported the effect of digestates originating from urban feedstocks, e.g. of different food and household wastes and sewage sludge, on the crop growth and nitrogen uptake (Abubaker et al., 2012; Haraldsen et al., 2011; Odlare et al., 2011; Rigby and Smith, 2014; Svensson et al., 2004) and on soil quality (Abubaker et al., 2012; Odlare et al., 2008, 2011; Rigby and Smith, 2013). As the focus of these studies is mainly on the growth response of crops, the digestate heavy metal and organic matter content are thoroughly reported only in a limited amount of studies with urban waste digestates (Abubaker et al., 2012; Tambone et al., 2010). Additionally, to the authors' knowledge there are only a few digestate fertilization/quality studies, which take the feedstock composition and origin into consideration when evaluating the fertilizer value (Tambone et al., 2009, 2010) and where the digestion process parameters are considered (Alburquerque et al., 2012b; Tambone et al., 2009). The digestate characteristics are known to be affected by the characteristics of the feedstock (Abubaker et al., 2012; Tambone et al., 2010) as well as the anaerobic digestion process; the reactor type and process parameters (Zirkler et al., 2014). In addition, the feedstock composition can also vary depending on, e.g., waste collection regulations (Saveyn and Eder, 2014) and pretreatment prior to anaerobic digestion, which may significantly affect the digestate composition (Tampio et al., 2014). However, urban feedstocks, especially food waste and household waste, have been found to have rather uniform characteristics despite temporal or geographical differences (Davidsson et al., 2007; Valorgas, 2011).

The objective of this study was to evaluate the differences and similarities in the agronomic characteristics of different urban

waste digestates and to evaluate the agronomic value of these digestates. The agronomic characteristics were studied by (I) analyzing the digestate quality, including pH, organic and heavy metal content of digestates, and reflecting on the results within the context of the European digestate quality criteria and (II) analyzing the fertilizer value with chemical analyses of nutrients, soil nitrogen mineralization test and short-term ryegrass growth experiments. The aim was also to compare the effect of feedstock composition and digestion processes on the digestate agronomic characteristics by taking into consideration the pretreatment of the feedstock. Studied materials originated from anaerobic digesters from different European countries treating food waste (FW), organic fraction of organic solid waste (OFMSW) and a mixture of waste-activated sludge and vegetable waste (VWAS).

2. Materials and methods

2.1. Origin of materials

This study evaluated the agronomic characteristics of five digestates of which three originated from digesters fed with a source-segregated domestic food waste (FW), one from a digester fed with an organic fraction of municipal solid waste (OFMSW) and one from a digester fed with a mixture of waste-activated sludge and vegetable waste (mixture referred as VWAS, Fig. 1, Table 1). The respective feedstocks were characterized as well except VWAS, which was not available.

Two food wastes and digestates originated from laboratory stirred tank reactors. Reactors were fed with FW collected from Ludlow, UK, where the FWs were either macerated with a S52/010 Waste Disposer (IMC Limited, UK) (feedstock and digestate referred as FW1) or autoclaved with a double-auger autoclave (160 °C and 6.2 bars, AeroThermal Group Ltd, UK) and macerated (FW2). Both Ludlow feedstocks were frozen (−20 °C) and sent to Natural Resources Institute Finland, to produce the FW1 and FW2 digestates, which were combined samples from two parallel reactors (a more detailed description of both digestates is provided in Tampio et al., 2014). Digestates were stored frozen (−20 °C), and were thawed before analysis. The third FW feedstock and digestate (FW3) were obtained from a sub-commercial-scale anaerobic digester from Greenfinch, UK. OFMSW feedstock and digestate originated from an anaerobic digestion plant in Lisbon, Portugal, treating source-segregated OFMSW from the Lisbon area. The VWAS mixture, which consisted of vegetable waste and waste-activated sludge, was from a pilot digester treating wastes from Treviso, Italy (Table 1).

The feedstocks and digestates from the UK, Portugal and Italy (excluding FW1 and FW2) were sent in frozen form to a laboratory at Natural Resources Institute Finland, where the samples were thawed and stored approximately one week at 4 °C. Prior to analyses feedstock samples were macerated with a Retch Grindomix GM300 knife mill (Retch GmbH, Germany). From OFMSW feedstock the non-biodegradable material (plastic cups, plastic bags, etc.) was manually removed before analyses of the water soluble nutrients and carbon.

2.2. Nitrogen mineralization

Nitrogen mineralization tests were run to study the effect of digestate applications on soil inorganic nitrogen concentrations. The 48-day mineralization was tested in triplicate at 20 °C according to ISO 14238 (ISO, 2012) with digestates and control soil, where no fertilizer was added. Incubation soil (7% clay, 6% silt and 87% sand; soil organic C 1.8% and pH_w 5.1) was collected from the 0–15 cm top layer of a cultivated agricultural soil in Jokioinen,

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