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Effect of drying, composting and subsequent impurity removal by sieving on the properties of digestates from municipal organic waste

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ABSTRACT

The application of organic soil amendments is a common measure to prevent structural degradation of agricultural soils and to maintain and improve long-term soil fertility. Solid residues from anaerobic digestion of municipal organic waste (MOW) are rich in nutrients and organic matter and have a promising potential to be used as soil amendment. However, no study has related amendment properties of MOW digestate of one origin to different treatment procedures. We therefore investigated the impact of drying, composting and sieving on final digestate properties and specifically nutrient availability and heavy metal and carbon elution.

Samples were provided by a semi-industrial two-stage biogas plant with dry fermentation of MOW. Results confirm that in comparison to drying, composting of MOW digestates leads to a significant increase of K, P, Mg, Ca, Cd and Cr in the digestates. Sieving of composted digestates showed that heavy metals are not evenly distributed and that heavy metal concentration in the digestate increases with decreasing mesh sizes (highest concentrations in the fractions <1 mm). Although the element concentration is higher in composted batches, the water-extractability of nutrients, heavy metals and carbon is significantly lower from composted over dried digestates. A significant correlation was found between the dissolution of Zn, Ni, Ca and Mg and pH of eluate as well as dissolved organic carbon (DOC) release ($R > 0.7$, $p < 0.05$). Results confirm that the extent of carbon elution depends on the degradation rate of digestates. DOC may therefore be a good measure to evaluate digestate stability and to decide on treatment measures.

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1. Introduction

One of the requirements of the EU Waste Framework Directive is that member states take measures to establish a separate collection of biowaste and to encourage the utilisation of materials produced from biowaste (Directive 2008/98/EC, Article 22). In Germany, every household has been obliged to collect organic waste in a separate bin since 2015 (Kreislaufwirtschaftsgesetz, KrWG, § 11). This facilitates a nationwide recovery of municipal organic waste (MOW), which refers to all kitchen and garden waste from private households. One possibility to recover the energetic potential of MOW is anaerobic digestion. In 2014, the total digestion capacity for organic waste was 1.9 million tons in more than 100 plants operating (Kern and Raussen, 2014). Along with the recent subsidies policy development under the German Renewable Energies Law (Erneuerbare-Energien-Gesetz, EEG) and the search

for alternative, cost-efficient and sustainable biogas substrates an increase of MOW utilisation in biogas plants can be expected (Kern and Raussen, 2014; Schüch et al., 2016).

Anaerobic digestates have been investigated by a few studies (Al Seadi et al., 2013; Maynaud et al., 2017; Pognani et al., 2012; Risberg et al., 2017; Zirkler et al., 2014), which show that they provide a broad range of nutrients and residual organic compounds. Final digestate properties depend on feedstock composition, process conditions during digestion and post-treatment. Altogether, anaerobic digestates are considered as valuable fertilizer and humus source and shall therefore be redistributed to arable land as soil amendment (Alburquerque et al., 2012; Insam et al., 2015; Nkoa, 2014). Digestate treatment aims to reduce the digestate mass, to guarantee hygienic and ecological harmlessness and to provide a storable, transportable, tradable and applicable fertilizer product of high quality. Legal requirements (nitrogen-limits, contamination thresholds) and economical aspects (limited storage capacity, high transportation costs) as well as limited application options (oversupply of fields, blocking periods) increase pressure

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on plant operators to adapt digestate management. Digestate treatment is becoming a substantial part of the successful operation of biogas plants (Dahlin et al., 2015).

There is a variety of treatment options for digestates (Al Seadi et al., 2013; Drosig et al., 2015). However, the treatment of solid digestates from MOW is challenging as they are subject to more strict legal requirements than digestates originating from agricultural crops. According to the German Fertilizer Ordinance (Düngemittelverordnung, DüMV) and the German Biowaste Ordinance (Bioabfallverordnung, BioAbfV) impurity and heavy metal content of digestates as well as hygiene are crucial quality criteria. Impurities such as plastics, metals or glass mainly result from miss-sorting during on-site collection. Total impurity content of the amendment must not exceed 0.5% of dry matter (§ 4, BioAbfV). 40% of German biogas plants utilising MOW operate with thermophilic temperature conditions (Fricke et al., 2014). Hence, the predominant proportion of solid digestates does not fulfill hygiene criteria. Consequently, the removal of impurities and hygienisation are the main treatment objectives to obtain a high-quality amendment product. Hygienisation can be realised by composting or drying of digestates. Impurity removal is usually done by sieving. The effect of these treatment steps on digestate properties will therefore be investigated in this study.

There have been a few investigations on fermentation residues application (Insam et al., 2015; Nkoa, 2014). However, most research focuses on characteristics and impact of untreated digestates (water content 95–98%) from wet fermentation of energy crops and manure on soil and plant development (Abubaker et al., 2013; Albuquerque et al., 2012; Voelkner et al., 2015). There has also been research on the effect of application of solid residues from MOW digestion (Odlare et al., 2015; Odlare et al., 2011). However, no study related amendment properties of one digestate to different treatment procedures yet. We suppose that the application of MOW digestates affects nutrient, heavy metal and carbon availability in soil and that the way of digestate treatment influences soil performance of final amendment products. This study therefore aims to investigate and compare the properties of MOW digestates of one origin after drying or composting and sieving under laboratory and semi-industrial scale conditions and to evaluate the potential impact of treated MOW digestates on available nutrients, heavy metals and carbon in the soil solution. The results obtained shall deliver new insights into the impact of MOW digestates on soil and contribute to a better understanding of how digestate treatment influences the quality of soil amendments.

2. Materials and methods

2.1. Origin of digestates, post-treatment and sampling

Three batches of digestates (D1, D2, D3) were obtained from a semi-industrial scale two-stage biogas plant using MOW as feedstock (see Table 1 for sample acronyms). MOW was separately

collected and provided by a local composting facility from a small town near Dresden (Saxonia, Germany). MOW collection and subsequent test series took place from May to July 2016. An overview of MOW and digestate treatment is presented in Fig. 1. Prior to digestion, MOW was mixed with organic bulk material. Feedstock was treated in a semi-industrial scale two-stage biogas plant consisting of two anaerobic hydrolysis box fermenters (40 m³), an anaerobic fixed-bed digester (14 m³) and two percolate storage tanks. Hydrolysis digesters were operated in batch under continuous percolation with process liquid. Percolate was subsequently fed to the fixed-bed digester (carrier media: RVT-Bioflow 401) for methanation. Process temperature in the digesters was 37–40 °C. Retention time of MOW in the hydrolysis box fermenters was 14 days. At the end of the digestion process percolation was stopped and digestate was drained. Process liquid remained in the storage tanks of the biogas plant.

Solid digestate was removed from the hydrolysis fermenters and a composite sample of 50 kg was taken for drying. The remaining digestate was delivered to a composting plant near Dresden (Saxonia, Germany), where it was treated in open heaps for 6 weeks (D1_{comp}, D2_{comp}, D3_{comp}). Drying was carried out within our laboratory facilities. 25 kg of each batch were dried at 70 °C in a laboratory oven (D1_{oven}, D2_{oven}, D3_{oven}). Another 25 kg were air-dried at 20–30 °C (D1_{air}, D2_{air}, D3_{air}). The drying process was finished when the weight of digestate remained constant.

All digestates were manually sieved at a mesh size of 20 mm to remove bulk material and impurities. A composite sample of 2 kg of fresh matter (FM) was taken from all dried and composted samples of every batch. ½ of the sample was stored in the freezer. The rest was dried at 105 °C, impurities >2 mm were removed and the leftover sample was shredded in a laboratory cutting mill and subsequently ground in a mortar mill until a particle size of 0.25 mm was reached.

2.2. Determination of digestate characteristics

Fresh samples were used to determine pH, plant available nitrogen (N_{pa}), plant available phosphorus (P_{pa}), plant available potassium (K_{pa}) and salt content according to the analysis handbook of German Federal Compost Association (BGK, 2006). pH and N_{pa} were measured after 1 hour extraction of a 20 g sample (DM) with 200 ml CaCl₂ solution using a WTW pH meter (inoLab Multi 9620) and a Shimadzu TN/TOC-Vcph-Analyzer (N_{pa}). P_{pa} and K_{pa} were quantified after 1 hour extraction of a 20 g sample (DM) with 200 ml calcium-lactate-acetate solution with ICP-OES. Salt content was determined after 1 hour extraction of a 20 g sample (DM) in 200 ml deionized water with WTW meter (inoLab Multi 9620). All extractions were examined on a shaker at 100 rpm and extracts were filtered before measurement (Whatman cellulose filter N°1). Water content or dry matter (DM) content of fresh samples was quantified after 24 hours drying at 105 °C (DIN EN 13040).

The dry and ground sample was used for the quantification of volatile solids (VS), total carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn) and cation exchange capacity (CEC). VS was determined after 3 hours ignition of a 3 g sample (DM) at 550 °C in a muffle furnace (DIN EN 12879). C and N were measured after combustion of a 2 mg sample (DM) in an automatic CNS-Analyser (Vario EL III, DIN ISO 10694). P, K, Ca, Mg, Cd, Cr, Cu, Ni, Zn and Pb were determined after pressure digestion of a 0.3 mg sample (DM) in aqua regia (DIN EN 13567) with ICP-OES (DIN EN ISO 11885). CEC was quantified by shaking a 5 g sample (DM) with 30 ml BaCl₂ solution (3 times, 100 rpm) and applying MgSO₄ solution (once, 100 rpm) to fill free exchange places (DIN 19684-8). After the experiment, Mg in the solution was determined with ICP-OES.

Table 1
Overview of most important acronyms used for sample description.

Acronym	Meaning
MOW	Municipal organic waste
D	Digestate
D _{fresh}	Fresh digestate
D _{air}	Air-dried digestate
D _{oven}	Oven-dried digestate
D _{comp}	Composted digestate
DM	Dry matter
FM	Fresh matter
HM	Heavy metals
pa	Plant available

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