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Phosphorus availability and soil microbial activity in a 3 year field experiment amended with digested dairy slurry

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ABSTRACT

The application of biogas residues to agricultural fields is important for nutrient cycling. A 3 year field experiment was conducted to assess the phosphorus (P) fertilizer value of digestate from biogas production, taking into account soil microbial activity. The input substrate (inputS) and digested substrate (digestS) from a biogas plant using dairy slurry, maize silage and wheat corn, were applied at a rate of 30 m³ ha⁻¹ annually. For control, mineral N and K, but no P, were applied in equal amounts with the biogas substrates. Maize was cultivated every year, and the biomass yield and P and N uptake were determined. Soil samples were collected on different sampling dates, and the P contents, pH, organic matter contents and enzyme activity were analyzed. The CO₂ efflux was measured biweekly using a portable soil respiration chamber (EGM 4). After 3 years, the P and N uptake increased by 25% in the digestS treatment compared with that of the control but did not differ from that of the inputS treatment. The plant-available P contents were also higher in the inputS- and digestS-amended soil. The fertilizer application did not influence the organic matter content but did influence the enzyme activity in soil. Averaging of all the sampling dates in 2010 and 2011, the activities of dehydrogenase and alkaline phosphatase were 50% lower in the soils that were amended with digestS compared with inputS. However, the CO₂ efflux from the soil surface was the same for the inputS and digestS treatments. Our results indicate that the anaerobic digestion of substrates does not affect the plant P uptake but the performance of soil microorganisms.

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1. Introduction

The residues from biogas production are increasingly being used as fertilizers in crop production. It is estimated that approximately 65 hm³ biogas residues (digestate) are produced annually in Germany [1]. Most on-farm biogas

installations use animal slurries with crop and fodder residues or dedicated energy crops as input substrates [2]. The anaerobic digestion process alters the composition of the input substrate, potentially affecting plant nutrition and soil properties when the digestate is applied to the field. The total nutrient contents generally remain constant during anaerobic digestion, but the organic matter contents and the C/N ratio

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decrease, and the mineral N ($\text{NH}_4\text{-N}$) contents and substrate pH increase [1,3]. In contrast, the P solubility might decrease after anaerobic digestion due to the formation of struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) and poorly soluble hydroxylapatite compounds ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$) [4–6].

Many studies have investigated the N fertilizer value of the digestate. In various incubation and pot experiments the digested slurry increased the plant-available N contents in the soil, the crop N uptake and the crop yields compared with the undigested slurry [7–10]. Under field conditions, the positive effect of the digested slurry on the plant N uptake often was less pronounced or occurred only during the early growth stage [11–14]. So far, less is known about the P-fertilizer effect of biogas residues. Recent studies have focused more on the effect of digestate on the soil organic matter pool and soil biology. During anaerobic digestion the easily degradable organic compounds become mineralized [15–17], and it can be expected that less but more stable organic matter is returned to field with the digestate. The mineralization of organic carbon when applied as digestate was often found to be lower than that from undigested materials [7,16,18]. For example, the cumulative CO_2 emissions were 2.5 times lower in the soils that were amended with digested maize straw than in soils that were amended with raw maize straw over a 21 day incubation period [19]. Johansen et al. [20] found that after a 9 day incubation period, the total CO_2 emissions from co-digested cattle slurry were 25% less than when raw cattle slurry was applied. So far, no differences between the undigested and (co-) digested slurry treatments have been found regarding the soil organic carbon content [9,20,21]. However, several laboratory and pot experiments have reported a decrease in the biomass of endogeic earthworm species, microbial biomass and dehydrogenase, β -glucosidase, cellobiohydrolase and xylanase activities in soils that were fertilized with digestate compared with soils that were fertilized with undigested slurry [9,19,22], indicating that the organic matter in the digestate can hardly be used as carbon and energy source by soil (micro-) organisms.

The P availability in the soil is controlled by the activity of the soil microorganisms. Digestate application may thus affect the P availability in the soil and plant P nutrition directly by adding inorganic and organic P compounds but also indirectly by affecting soil microorganisms due to the supply of nutrients organic matter. Soil microorganisms produce and excrete protons, organic anions and enzymes, thereby mobilizing P from organic and inorganic compounds and increasing the plant-available P pool in the soil [23]. In addition, the bioavailable P pool in the soil could be depleted due to the incorporation of P into the microbial biomass. Because the turnover of microbial biomass in the soil is rapid, the microbial-bound P can still be regarded as labile, readily available and is protected against fixation and leaching [23,24].

Studying the P-fertilizer effect of biogas residues is of particular importance because natural P resources will be exhausted in the short to medium term [25,26] and the recycling of biogas residues in agriculture is an important factor to realize nutrient cycling and to save mineral fertilizers. Therefore, this study investigated the effect of anaerobic digestion on the P fertilizer value of slurries under field conditions, taking into account the impacts on soil microbial

activity. We hypothesized that changes in the composition of organic fertilizers due to the biogas process affect the P and C turnover in the soil when supplied with digestate, which, in turn, affects the plant yield and plant P nutrition.

2. Material and methods

2.1. Study site

An on-farm experiment was established in September 2008 in close cooperation with a local dairy farm. The experimental area is located in Mecklenburg-West Pomerania at $53^\circ 42'$ northern latitude and $12^\circ 53'$ western longitude. The climate of the region is characterized by an average annual precipitation of 550 mm and an average annual air temperature of 8.1°C (German National Meteorological Service, DWD [27]). The experimental area has not received any organic fertilizer since 1995. The soil type was classified as Haplic Luvisol, and the soil texture was a sandy loam. The initial plant-available P contents (Pdl) were 43.6 mg kg^{-1} , indicating a medium P status according to the German fertilizer recommendations, and P fertilization according to the crop demand is required (Table 1).

The experiment ran for 3 years. The monthly rainfall and average air temperature during the maize cropping period (April–September) during the 3 experimental years are presented in Table 2.

2.2. Treatments and experimental design

The input substrate (inputS) and the digested substrate (digestS) of the farm-owned biogas plant were used as fertilizers in the field experiment. The inputS for the biogas process was a mixture of 15 m^3 dairy slurry, 1.0 t maize silage and 0.2 t wheat grain per day. DigestS denotes the mixture after 28 days of anaerobic digestion under mesophilic conditions. Both substrates were applied at rates of $30\text{ m}^3\text{ ha}^{-1}\text{ a}^{-1}$. The rates were split into $20\text{ m}^3\text{ ha}^{-1}$ in the spring before sowing and $10\text{ m}^3\text{ ha}^{-1}$ in the autumn after harvest. With both of the organic fertilizers, the treatments received similar amounts of total N ($140\text{ kg ha}^{-1}\text{ a}^{-1}$) and P ($20\text{ kg ha}^{-1}\text{ a}^{-1}$), but 20 % more $\text{NH}_4\text{-N}$ and 40% less organic matter were applied under the digestS treatment. A control treatment with mineral N in the form of calcium ammonium nitrate (CAN) and mineral K in the form of potash (KCl, 60er Kali) but without P was established. The N and K supplies in the control were adjusted to the average amount of N and K that were supplied with the biogas substrates (Table 3).

Additionally, the entire experimental area received a mineral N supply (CAN) of $70\text{ kg ha}^{-1}\text{ a}^{-1}$, as well as a mineral Mg and S as supply with Kieserite (MgSO_4), and liming was

Table 1 – Soil characteristics before the beginning of the field experiment in September 2008.

Pdl (mg kg^{-1})	Pwater (mg kg^{-1})	pH	SOM (%)	Sand (%)	Silt (%)	Clay (%)
43.6	10.2	4.39	2.45	73.4	20.2	6.40

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