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Phosphates recycled from semi-liquid manure and digestate are suitable alternative fertilizers for ornamentals

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ABSTRACT

In several regions in Europe, the amounts of both manure produced by pig husbandry and biogas digestates from anaerobic digestion are too high to be sustainably applied to the surrounding fields. In these regions, nutrient surpluses are therefore often a problem. The research projects GOBi and BioEcoSIM succeeded in developing innovative recycling technologies for the recovery of phosphorus (P) from biogas digestates and manure, converting them into valuable fertilizers. This study tested the suitability of recovered phosphate salts ("P-Salts") and dried solids as P fertilizers for sunflower, marigold and Chinese cabbage in a greenhouse experiment. Treatments included two recovered P-Salts (from manure and digestate), two dried solids (air-dried and steam-dried), a combination of salt and solid, and triple superphosphate (TSP) as reference, each at two fertilization levels. Measurements included biomass production (ornamentals separated into shoots and flowers), P concentration in the biomass and plant-available P in the growing medium. Both P-Salts had more or less the same effect as TSP on biomass production. The combination of P-Salt and air-dried solids resulted in a synergistic effect on sunflower in terms of biomass yield, P concentration and number of flowers. The P concentration was mostly higher in plants treated at the higher P fertilizer level.

A fast P uptake into plants and thus high plant availability is particularly important in the horticultural sector due to the short production periods of potted plants. In general, all the tested recycled products except the air-dried solids could be adapted to the requirements of different ornamentals, met their P demand as efficiently as TSP and thus have high potential as P fertilizers. The P-Salts are more suitable for short-term and the steam-dried solids more for long-term P supply. The combination of both may ensure optimal P supply and guarantee long-term product quality.

1. Introduction

Phosphorus (P) is required for good flowering quality and quantity of ornamental plants. Nowadays, it is mainly applied in the form of fertilizer manufactured from phosphate-rich rocks. It is well-known that fossil P resources are limited. Assuming future consumption continues to increase at a constant rate, the economically exploitable reserves will be exhausted in about 350 years (USGS, 2016). Total resources are estimated to last up to 1300 years (USGS, 2016). However, there is a high degree of uncertainty in this prediction as it includes all naturally occurring material for which an economic extraction is currently or potentially feasible. Today, the entire P requirements for chemical fertilizers and feed are derived from phosphate-rich rocks. About 75% of the identified global reserves are located in Morocco (Western Sahara), which is also the main exporter of phosphate ore (Schoumans et al., 2015). Koppelaar and Weikard (2013) reported that 17.6 Mt of P were utilized in fertilizer production in 2009, representing more than 80% of the total mined P. The manufacturing process of chemical P fertilizers produces waste that contaminates soil and water resources and the use of these fertilizers contributes to heavy metal contamination of soils, resulting in increased expenses for soil remediation (Moura Filhio and Dantas Alencar, 2008).

The high demand for phosphate fertilizers in food and flower production makes finding affordable alternative products crucial. Such alternatives should be available in relatively high quantities, have consistent quality and equivalent fertilization effects and plant nutrient availability to conventional fertilizers.

One possibility is the recycling of P from manure and biogas digestates produced in agriculture. The accumulation of large amounts of

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semi-liquid manure is a particular problem in regions with intensive livestock production. Moreover, livestock husbandry is often found in combination with anaerobic digestion as an efficient method of converting animal manures into biogas and heat by co-fermentation with energy crops (Nkoa, 2014), resulting in biogas digestates. In Germany, the amount of biogas digestates is estimated to be around 65.5 million m^3 per year (Möller and Müller, 2012). The quantities of manure and digestate produced are likely to increase in future due to ongoing intensification in livestock breeding, worldwide trends in energy consumption and the predicted need for a 30% increase in energy production in the next 25 years, especially from renewable energy (IEA, 2015).

Both manure and digestates are particularly nutrient-rich and their positive effect on crop growth has frequently been demonstrated. These positive effects are mainly attributed to the supply of nitrogen and phosphate (Alburquerque et al., 2012), and the return of organic matter (Möller and Müller, 2012).

However, farmers are often reluctant to use organic fertilizers as the release of nutrients is slower and more weather-dependent compared to soluble chemical fertilizers (Figueiredo et al., 2008). In addition, the high water content (around 90%) of manure and digestates (Risberg et al., 2017) makes the application of large quantities per hectare necessary and renders the handling and transport in horticulture challenging. Moreover, untreated anaerobic digestate may not always be a perfect organic fertilizer due to its unbalanced nutrient ratio (Westerman and Bicudo, 2005) and specific requirements for soil application techniques as a consequence of the increasing necessity to avoid ammonia losses (Kreith and Tchobanoglous, 2002; BMEL, 2017).

In order to produce fertilizers with reduced volume that can be easily stored, transported and applied, efficient solutions are required to increase the nutrient content and decrease the water content of residues such as digestates and manure. The plant availability of P in recovered products is often low, or at least unpredictable (Kahiluoto et al., 2015). Bilbao et al. (2017) have developed a recovering process for manure and digestates in which 95% of the insoluble P is first converted into a dissolved form. The pretreated manure or digestate is then subjected to a solid-liquid separation. Phosphate salts (P-Salts) are obtained from the liquid fraction by precipitation. The resulting P-Salts are in the form of a powder that can be dried and granulated and, as such, are easy to dose and mix with horticultural growing media. The separated solid fractions of digestate and manure are also dried and used as organic P fertilizer with a texture comparable to wood shavings.

All of these recycled P-fertilizers are expected to have a high potential as alternative P-fertilizers (Bilbao et al., 2017); the manure-based P-Salt has already been found suitable for barley and faba bean (Ehmann et al., 2017). As horticulture is a business which is fairly location-independent, particularly the protected production in greenhouses, a dry and transportable form of recovered P fertilizers would be of considerable interest. The P-Salts and dried solids can be applied separately or in combination. The combined application of mineral and organic fertilizers in the form of TSP and compost was shown to result in increased plant P availability in a greenhouse study with maize (Muhammad et al., 2007). For this reason, we included a combination of P-Salt and dried solids in order to evaluate a potential synergy effect of these two components. This combined treatment may also provide a nutrient ratio more suited to the crops' requirements.

The recycled P fertilizers were tested in a greenhouse experiment with, sunflower (*Helianthus annuus* L.) and marigold (*Tagetes erecta* L.), both of which are among the most prominent ornamentals in Germany. Sunflower ranks fifth in sales of cut flowers in Germany, with a volume of 120 Mio. € per year (AMI, 2016). Marigold, a member of the family *Asteracaea* or *Compositae*, is an important commercial flower that is gaining popularity on account of its easy cultivation and wide adaptability (Asif, 2008). Both plants are marketed as cut flowers and potted flowers. Marigolds are often used for flower beds and for making garlands. Single sunflowers grown and sold in pots achieve high profit margins.

Chinese cabbage (*Brassica campestris* L. var. pekinensis Lour (Olson)) was included as a P sensitive indicator test crop. Symptoms of P deficiency are shown immediately through purpling of the leaves. Crops of the *Brassica* genus are among the ten most important vegetables in economic terms on global agricultural markets. Chinese cabbage is a cole crop plant and is an important fresh and processed vegetable, especially in Asian countries. In 2016, approx. 38.000 t were produced on 850 ha in Germany (Destatis, 2017).

The objectives of this study were: 1) to test the suitability as P fertilizers of P-Salts recovered from semi-liquid pig manure and biogas digestates and of dried solid fractions of non-treated digestates in two ornamentals and one vegetable; 2) to assess the competitiveness of these alternative P fertilizers compared to conventional superphosphate; 3) to determine whether the combined application of P-Salt and dried solid digestate improves the fertilizing performance through synergy effects; and 4) to assess the role of P fertilization in the flowering of sunflower and marigold, comparing the effect of the recycled fertilizers and commercial TSP.

Based on these objectives, the following hypotheses were set up:

- The effect of P-Salts recovered from semi-liquid manure and digestates, and the two dried solid fractions on biomass production and P concentration of sunflower, marigold and Chinese cabbage is equivalent to that of the conventional P fertilizer triple superphosphate (TSP).
- The combination of P-Salt and separated solids has a synergistic effect on plant growth.
- Recycled fertilizers enhance flowering in the same way as TSP and the level of P influences the number of flowers

These hypotheses were tested by means of a pot experiment with sunflower, marigold and Chinese cabbage.

2. Material and methods

2.1. Production of P-Salts and solids from pig manure and biogas digestate

The P-Salts were recovered from acidified semi-liquid pig manure (P-Salt_manure) and biogas digestate (P-Salt_digestate) as described by Bilbao et al. (2017). The dried solids were obtained from untreated digestate purely through solid-liquid separation. The solid fraction was dried either in warm air at 40 °C (air-dried solids) or with superheated steam at 120 °C (steam-dried solids).

The P-Salts had P concentrations approximately 5 times higher than the dried solids (Table 1). Soluble plant-available P fractions were determined for all products, Hedley fractionation was only performed for the digestate-based products (Tables 2 and 3). Both P-Salts are mixtures of magnesium ammonium phosphate (struvite) and calcium phosphates. The P-Salt_manure also contained 2.4% N, 1.3% K, 10.0% Ca and 4.8% Mg and the P-Salt_digestate 1.3% N, 1.0% K, 17.0% Ca and 5.0% Mg in the fresh matter.

Table 1
P concentration of the fertilizers.

Fertilizer	Acronym	Dry matter in % FM	P in % FM
P-Salt recovered from semi-liquid pig manure	P-Salt_manure	68.6	10.5
P-Salt recovered from digestate	P-Salt_digestate	69.7	10.7
Steam-dried separated solids from digestate	Steam-dried solids	91.6	2.3
Air-dried separated solids from digestate	Air-dried solids	95.4	2.1
Mineral P fertilizer as reference (Triple superphosphate)	TSP	–	19.0

FM, fresh matter; dry matter determined according to DIN EN 12880; P determined according to DIN EN ISO 11885.