Fertilizing potential of struvite recovered from organic fraction of municipal solid waste

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Abstract

Struvite derived from anaerobically digested organic fraction of municipal solid waste could be an alternative phosphorus fertilizer reducing the Europe dependency on phosphorus imports for supply food needs. The main objectives of this work was to assess the agronomic value of the recovered struvite for rye (*Secale cereale* L.) cultivating. A 45-day pot trial was performed to compare recovered struvite with single superphosphate on crop biomass production and phosphorus uptake.

The pot experiment clearly showed that the biomass production of rye was almost two times higher in fertilized soils with struvite and SSP than in unfertilized soils. The phosphorus uptake of the fertilized pots with struvite (2.5 times) was significantly higher than with single superphosphate (1.6 times). Regarding the levels of heavy metals on dry plants, it was found that Pb and Cd were not detected in rye from both unfertilized and fertilized pots. The concentrations of Cu and Ni in unfertilized pots were significantly higher than in fertilized pots. The levels of Cr and Zn were similar in both unfertilized and fertilized pots. Based on these findings, it was concluded that struvite recovered from anaerobically digested organic fraction of municipal solid waste could be used as a phosphorus nutrient fertilizer.

Keywords

Agronomic effectiveness; Municipal solid waste; Phosphorus; Struvite.

1. Introduction

Phosphorus (P) is one of 17 essential nutrients for plant development and growth representing about 0.2 % of a plant's dry weight (Liu et al. 2015). The limitation of P in soils leads to shifts in metabolism and physiology and also induced morphological changes in plants affecting mainly the shoots and roots and contribute to reduce the growth and yields plants (Pandey et al. 2015). However, P is a non-renewable resource predominantly obtained from phosphate rock deposits that currently are in decline due to the massive increased demand of agricultural products such as food, biofuels and animal feed (Cordell et al. 2009). In addition, about 80 % of P from phosphate rock deposits is used to manufacture fertilisers that will be applied on agricultural land. Then, this P ends up in food waste, wastewaters and their sludges. Thus recycling of P from various waste streams aiming to reduce the dependence on phosphate rocks and also ensure a supply of P for the future (Shu et al. 2006).

The present work assessed the fertilizing potential of struvite recovered from the anaerobically digested organic fraction of municipal solid waste. The fertilizing value of struvite was compared with that of commercial fertilizer (single superphosphate, SSP). Struvite is a slow release fertilizer with lower impurity that can be directly used in agriculture (Xu et al. 2012; Rahman et al. 2014; Karunanithi et al. 2015) being an effective source of P, nitrogen and magnesium for plants. The application of P fertilizers is the most direct and efficient approach to increase the crop production.

2. Materials and methods

2.1 Evaluation of the agronomic value of struvite

Pot trial was carried out using soils fertilised with struvite and was performed in a growth climate chamber with temperature of 24 °C daytime and 15 °C night-time, 75 % of relative humidity and 16 h of daylight (90 µmol photons m^{-2} s^{-1}). A total of 12 plastic pots were prepared with 150.0 g of soil and 50.0 g of purified sand: four pots with struvite fertilisation; four pots with a commercial fertilizer (SSP); four used as control (no fertilisation). Three seeds of rye (*Secale cereale* L.) were placed on top of each pot. The pots were irrigated, when necessary, with distilled water to maintain a 75 % of relative humidity. After 5 d of sprouting one plant was left in every pots. A half-strength Hoagland solution (without P) was applied three times a week in every pot in order to prevent nutrient deficiencies. The P nutrient only was provided by the fertilizers. After 6 weeks, the plants were harvested and shoots were separated from roots. Then, shoots and roots were air dried at 65 °C for 48 h and weighed, and the plant dry matter was determined. The dried plants were ground in a ball mill and then were placed in a muffle furnace at a temperature of 480 °C for 16 h. Total P, copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), niquel (Ni) and lead (Pb) were measured in the ashes. The fertilizing potential of struvite and SSP were evaluated through: (i) biomass production (g of dry matter per kg of soil) and (ii) P uptake (mg of P per kg of soil).

2.2 Analytical methods

Dry matter of shoots and roots was grounded in a ball mill, sieved at a 0.5 mm-mesh and then placed in a muffle furnace at a temperature of 480 ºC for 16 h to obtain the ashes. Total P, Cu, Zn, Cd, Cr, Ni and Pb were measured in shoots and roots using atomic absorption spectrometry, after digestion of the ashes with hydrochloric acid solution (HCl 20 %, v/v). All concentrations are given on dry weight basis and represent mean values.

2.3 Statistical analysis

One-way ANOVA analysis was performed to identify differences between treatments (control, struvite and SSP) on plant biomass production, P uptake by rye and heavy metals concentration in the plant. Tukey's test was used to compare means at 0.05 probability level. All statistics were performed with IBM SPSS Statistics software (version 23).

3. Results and discussion

3.1 Assessment of P phytoavailability from struvite

The biomass production and P uptake of rye obtained from soil fertilization with SSP and struvite is shown in Figure 1. The pot test clearly showed that fertilization with SSP and struvite significantly increased the plant biomass production ($p < 0.001$) and P uptake ($p < 0.001$) when compared to an unfertilized soil (control). The use of fertilizers (SSP or struvite) almost doubled the plant biomass production, showing that P nutrition of rye was strongly affected by the P fertilisers. Previous studies also reported that plants grown in soils fertilised with struvite have had much higher production than unfertilised soils. For instance, Ryu and Lee (2016) referred the effectiveness of struvite recovered from swine wastewater as a multi-nutrient fertilizer for lettuce cultivation. A similar result was also found by Ryu et al. (2012), which evaluated the fertilising value of struvite recovered from semiconductor wastewater in cultivating Chinese cabbage. In the current work, it was also noted that the fertilization significantly increased both shoots and roots biomass ($p < 0.001$), regardless of the fertilizer used. The shoot biomass was 0.8 g kg^{-1} of soil in control treatment while a significant increase ($p < 0.001$) was registered in the fertilised treatments (1.7 g kg^{-1} of soil in SSP and struvite).

The P uptake was about 1.6 times higher in SSP treatment and almost 2.5 times higher in struvite treatment compared to the control treatment. The P uptake of the soils fertilised with struvite was significantly higher (5.9 mg kg^{-1} of soil for shoots) than with SSP (4.7 mg kg^{-1}) and control (2.3 mg kg^{-1}) ($p < 0.001$) which means that struvite provided a higher phytoavailable P source than did SSP. The P

uptake in the soils fertilised with struvite was higher than that reported by Horta (2017) for struvite derived from deep frozen French fries wastewater (4.4 mg kg^{-1} of soil).

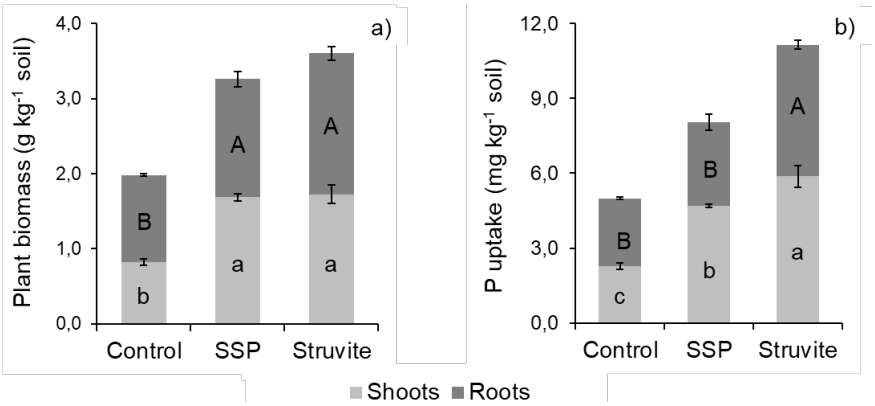

Fig. 1 Biomass production (a) and P uptake (b) of rye obtained from soil fertilization with SSP and struvite. Different capital letters denote significant differences among treatments in roots and different small letters denote significant differences among treatments in shoots, at confidence level of 95 %. Error bars represent standard error

3.2 Heavy metals in dry plant tissue

The levels of heavy metals on dry plants should be analysed when struvite recovered from wastes is applied as fertilizer. The concentrations of Cu, Zn, Cr, Ni, Pb and Cd were measured in the shoots and roots of rye obtained at the end of pot tests (Fig. 2). Levels of Pb and Cd were not detected in rye from unfertilized or fertilized pots. In overall, there were significant differences of the concentrations of Cu, Ni and Cr in the shoots ($p < 0.01$) and roots ($p < 0.001$). The accumulation of heavy metals on rye was significantly higher in roots than in shoots ($p < 0.05$) with exception of Cu and Ni in which the fertilized pots with SSP showed no significant differences ($p \geq 0.05$). In addition, it was also clear that the concentration of heavy metals in fertilized pots was never higher than in unfertilized pots. Indeed, the concentrations of Cu, Cr and Ni in unfertilized pots were significantly higher than in fertilized pots with exception of the concentration of Cr in fertilized pots with struvite where similar concentrations were found. Regarding the accumulation of heavy metals at shoots level, it was observed that the concentrations of Cu, Cr and Ni of fertilized pots with struvite were significantly smallest than fertilized pots with SSP and also than unfertilized pots, for the Cr and Ni concentrations ($p < 0.05$). It was also noted that at roots level, only the concentration of Cr in fertilized pots with struvite was significantly higher than in fertilized pots with SSP being that concentration was similar to those of unfertilized pots. The concentrations of Zn were not significantly different among treatments at shoots and roots levels ($p \geq 0.05$). Rye et al. (2012) reported a similar levels of heavy metals in Chinese cabbage in which struvite recovered from wastewater was tested as fertilizer. Based on these results the use of struvite recovered from anaerobically digested of organic fraction of MSW does not increase the levels of heavy

metals in rye plant, which indicates that struvite could be used as a P nutrient fertilizer despite that waste commonly contains heavy metals that not enable their application as fertilizer.

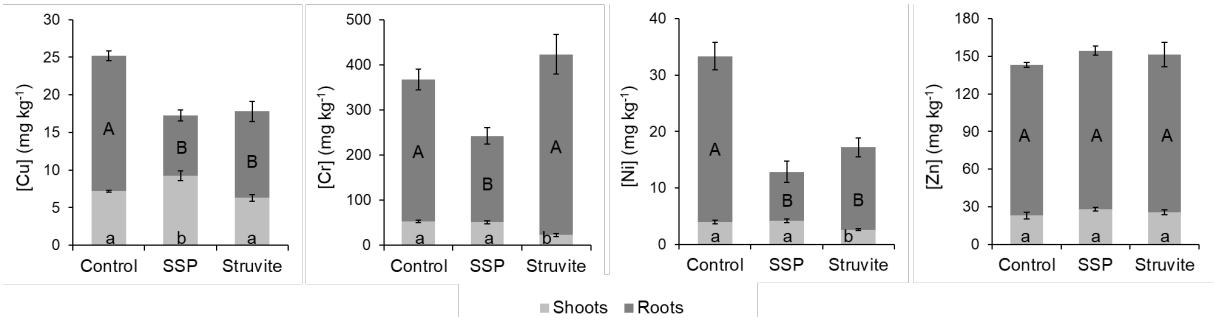

Fig. 2 Concentration of heavy metals (mg kg^{-1}) in dried plant (shoots and roots) at the end of pot experiment. Different capital letters denote significant differences among treatments in roots and different small letters denote significant differences among treatments in shoots, at confidence level of 95 %. The significance level was $p < 0.01$ for shoots and $p < 0.001$ for roots with exception of Zn concentration ($p \geq 0.05$). Error bars represent standard error

4. Conclusions

Struvite derived from the anaerobically digested organic fraction of municipal solid waste was used as P fertilizer in cultivation of rye (*Secale cereale* L.). The agronomic value of the recovered struvite was assessed by comparing it with single superphosphate (commercial fertilizer) by pot experiment. It was concluded that: (i) fertilizing potential of struvite recovered from anaerobically digested organic fraction of municipal solid waste is equal to that of single superphosphate and, (ii) the use of this recovered struvite does not increase the levels of heavy metals in rye plant. This indicates that recovered struvite improves the phytoavailability of P in the same way as a commercial fertiliser produced from phosphate rock, and can be an efficient alternative P source. Although, the effects of application of recovered struvite as P fertiliser have shown to be promising, further research should be focused on conducting experiments with different crops and diverse soil types.

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References

Cordell D, Drangert JO, White S (2009) The story of phosphorus: Global food security and food for thought. Glob Environ Chang 19:292–305 . doi: 10.1016/j.gloenvcha.2008.10.009

Horta, C (2017) Bioavailability of phosphorus from composts and struvite in acid soils. Rev. Bras. Eng. Agrícola e Ambient. 21, 459–464. https://doi.org/10.1590/1807-1929/agriambi.v21n7p459-464

Karunanithi R, Szogi AA, Bolan N, et al (2015) Phosphorus Recovery and Reuse from Waste Streams. Adv Agron 131:173–250 . doi: 10.1016/bs.agron.2014.12.005

Liu C, Wang Y, Pan K, et al (2015) Effects of phosphorus application on photosynthetic carbon and nitrogen metabolism, water use efficiency and growth of dwarf bamboo (Fargesia rufa) subjected to water deficit. Plant Physiol Biochem 96:20–28 . doi: 10.1016/j.plaphy.2015.07.018

Pandey R, Zinta G, AbdElgawad H, et al (2015) Physiological and molecular alterations in plants exposed to high [CO2] under phosphorus stress. Biotechnol Adv 33:303–316. doi: 10.1016/j.biotechadv.2015.03.011

Rahman MM, Salleh MAM, Rashid U, et al (2014) Production of slow release crystal fertilizer from wastewaters through struvite crystallization - A review. Arab J Chem 7:139–155. doi: 10.1016/j.arabjc.2013.10.007

Ryu, HD, Lee, SI (2016) Struvite recovery from swine wastewater and its assessment as a fertilizer. Environ. Eng. Res. 21, 29–35. https://doi.org/10.4491/eer.2015.066

Ryu, HD, Lim, CS, Kang, MK, Lee, SI (2012) Evaluation of struvite obtained from semiconductor wastewater as a fertilizer in cultivating Chinese cabbage. J. Hazard. Mater. 221–222, 248–255. https://doi.org/10.1016/j.jhazmat.2012.04.038

Shu L, Schneider P, Jegatheesan V, Johnson J (2006) An economic evaluation of phosphorus recovery as struvite from digester supernatant. Bioresour Technol 97:2211–2216 . doi: 10.1016/j.biortech.2005.11.005

Xu H, He P, Gu W, et al (2012) Recovery of phosphorus as struvite from sewage sludge ash. J Environ Sci (China) 24:1533–1538 . doi: 10.1016/S1001-0742(11)60969-8