Assessing phosphorus recovery potential from ashes: incubation studies of different secondary raw materials after multiple combustion processes

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Introduction

Phosphorus (P) is a key component in agricultural fertilizers since it is a vital macronutrient required for optimum plant development. The recent surge in market prices and concerns about the future scarcity of rock phosphate mines have rekindled interest in exploring alternative sources for this crucial element. One approach to address this challenge is to recover P from waste streams, such as agro-industrial residues and domestic sewage sludge, after a combustion process and convert the obtained ashes into inputs for bio-based fertilizer (BBFs) formulations intended to support crop production. The bioavailability of P in ashes is an increasing topic discussion because biomass ashes are nearly free of nitrogen but contain P and other nutrients that could be available for plant growth. In addition, some studies showed that they can also be used as liming agents stimulating microbial activities in the soil (Sciemenz and Eichler-Löbermann, 2010). However, recent reports show that P bioavailability in ashes may vary widely since the ashes` characteristics are affected by different factors such as the origin, type and the amount of feedstock, the combustion process itself and the properties of the resulting ash (Deportes et al., 2018). Particularly, the temperature and duration of combustion are crucial operational parameters that could affect the P release bioavailability of the ashes.

The objective of this research is to investigate the bioavailability of P using biomass combustion ashes from different raw materials and combustion conditions. Specifically, we focus on the release of P using an aerobic long-term incubation assay. Also, we intend to provide a wide screening showing the extent to which ashes can serve as a sustainable and efficient source of P for agriculture and to identify the raw materials sources and factors influencing their P content and release.

Materials and Methods

Four secondary P fertilizers were examined. On one hand, three labelled “EBPR sludges” were produced by the enhanced biological phosphorus removal process in different scales and facilities. “EBPR 1” was produced in lab scale (5 L) bioreactors using dairy wastewater as feedstock. “EBPR 2” sludge is derived from a side-stream full scale domestic wastewater treatment facility while “EBPR 3” sludge came from a mainstream full scale domestic wastewater treatment facility. Total P (TP) content of each of these ashes was 15.1; 17.4; and 12.3 % respectively. The EBPR sludge samples were burned in a muffle at 550ºC except for the “EBPR 2” sludge which was burnt at 850 ºC. On the other hand, combustion manure ash “CMA” was obtained through the pelletized solid fraction pig manure from an on-farm Spanish experimental pilot within the H2020 project FERTIMANURE. The temperature combustion achieved in the biomass boiler was 600 ºC. Livestock manure ash contains soluble salts which could have a negative influence on plant growth and shall be preferably removed. Some studies such as Oshita et al. (2016) demonstrate that the application of a water pre-treatment highly eliminated water-soluble salts and resulted in a P richer material. Consequently, the labelled “CMAW” derives from “CMA” after a pre-treatment with water for 24 hours at a liquid:solid ratio of 10 $mL \cdot g^{-1}$ ash with the aim to remove these salts. The TP content of these ashes was 7.1%., in both, “CMA” and “CMAW”.

The five stated ashes were used to estimate the phosphorus release dynamics using an aerobic soil incubation of 160 days. The soil was incubated at 22 °C and the moisture was kept at 50% water holding capacity (WHC) during the incubation. To determine the mineralization rate, the ashes were applied at 48 $kg\ TP \cdot ha^{-1}$ in all treatments. In addition, a negative control (without applying any additional P) and a positive mineral control (applying triple super phosphate, “TSP”) were included. To capture phosphorus dynamics, ten destructive samplings with four replicates for each day were performed. At each sampling day, the Calcium Acetate Lactate (CAL) method was used to extract the labile P, which is considered available for plants during their growth cycle. Statistical analysis was performed using RStudio (V2022.12.0). Data was analyzed with a one-way ANOVA, and post-hoc Tukey’s test at $\alpha = 0.05$. Here, we present partial results (day 0 to 80) of the ongoing 160 days incubation experiment.

Results & Discussion

The amount of P available after the incubation period of 5, 10, 20 and 80 days is presented in Figure 1. Throughout the incubation, the average P release was 101 ± 15% for “TSP”, 98 ± 15% for “EBPR 2”, 68 ± 12% for “EBPR 3”, 58 ± 9% for “EPBR 1”, 49 ± 8% for “CMA” and 46 ± 8% for “CMAW” at the end of day 80. During early stage of the incubation (day 5-10), an increasing P release was observed in all the treatments. However, there were no significant differences until day 10. Although some data still needs to be analyzed as the experiment is ongoing, it can be observed that from day 10 to 80, the rate of P release decreased in all treatments except for the positive mineral control.

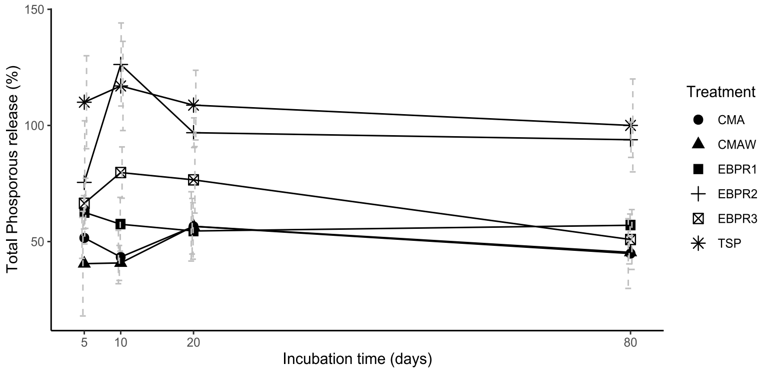

Figure 1: P release (in percentage of the TP applied) during the incubation time for each treatment.

Overall, results showed that despite being originated from different feedstocks, all EBPR sludges displayed rapid mineralization, with over 45% of the total applied phosphorus becoming available within the first 10 days. On the other hand, pig manure ashes (either with or without the stated water pre-treatment) exhibited a release pattern considerably lower.

By simultaneously using various raw materials and combustion temperatures, in this study it was not possible to determine which parameter had a greater impact on the P release. However, recent research has suggested that ashes produced from combustion processes at 850ºC exhibit improved P bioavailability (Li et al., 2017) which could have influenced the EBPR 2 results. At the same time, the different origin of the raw material might have also determined the potential P release found in this research (Zhou et al., 2020).

Conclusion

This study suggests that ashes from different waste streams could be developed into alternative and sustainable P sources with relatively high expected agronomic efficiencies. Nevertheless, more research efforts are still required, including field-studies of the recovered ashes comparing them with inorganic fertilizers to understand which feedstock and combustion parameters positively affect the P bioavailability of secondary raw materials which would definitively enhance the agro-industrial sustainability and bio circularity.

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