Impact of biogas digestate typology on nutrient recovery for plant growth: accessibility indicators for fertilization prediction

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Introduction

In an environmental biorefinery concept, organic wastes are becoming resources not only for energy but also for soil quality improvement after land spreading (Alburquerque *et al.*, 2012; Gissén *et al*., 2014), such as the anaerobic digestion process. However, agricultural reuse of these treated organic residues (i.e. digestates) is submitted to standards in terms of environmental constraints, quality of organic matter, nutrients availability and safety issues. To fulfil these standards, one way is to make reverse engineering and optimization of the treatment processes. In this light, the first step is the characterization of the organic fertilizers targeted according to both soil and plant demands in terms of organic matter and nutrients (e.g. in this study: nitrogen (N) and phosphorus (P)) availability for plant growth. In this study, a focus has been made on digestates obtained from anaerobic digestion of several types of organic residues. Indeed, digestate management is now a real challenge. Due to their high variability, regulations and treatment disposal costs, the use of digestates as organic fertilizer has to be evaluated. Ten digestates from different classes as described by Guilayn *et al.* (2019) have been chosen for this work. Until now, there are no literature data on the indicator development of both N and P availability contained in digestates for plant growth. This is why the study aims at proposing indicators based on chemical extractions and characterization. Soil incubation tests and plant pot trials were also performed in order to test the validity of these indicators. These data could be used for rapid diagnostic of the fertilization potential of a digestate and can be included in models latter.

Material and Methods

The typology from Guilayn *et al.* (2019) was used to select a large panel of various digestates. Eight raw digestates were used coming from the anaerobic digestion of: sewage sludge, municipal wastes, cow manure, pig manure, centralised (co-digestion) and crop residues. A compost of sludge digestate and a compost of municipal wastes digestate were added to the samples.

Based on Jimenez *et al*. (2017), the sequential extractions of the different accessibility state of organic matter and N was done on the freeze-dried and grounded samples. Based on Grigatti et al (2015), the sequential extractions of the different forms of phosphorus were done.

Soil incubation was conducted in 500 ml plastic vessels as described in Grigatti *et al.* (2015), at the rate of 170 kg N ha^{-1} in three replicates. Soil samples were collected at day: 0, 14, 28, 56, 84, (2g TS for P characterization by 0.5M $NaHCO_3$ extraction and 1g TS for N characterization by 1M KCl extraction). Plant pot trials were performed as described in Grigatti *et al*. (2015) in three replicates with 0.8 g of seeds of Italian ryegrass (*Lolium multiflorum subsp. Italicum*), cv. Sprint. At each harvest, N and P characterization were performed (days 28, 56 and 84). On plant tissue (shoots and roots), plant nitrogen and phosphorus utilization efficiency was calculated on the basis of the Apparent Recovery Fraction (ARF) approach (Gunnarsonn *et al*., 2010).

Results and Conclusions

The OM, N and P extractions showed a great variability according to the 10 digestates: that means that experimental soil and plant pot tests would be representative enough of the high variability of the digestates quality. Indeed, accessibility and digestates characteristics played an important role on P and N mineralization and consequently on N and P recovery by plants, above all considering the first water extractable inorganic and organic fraction. Plant growth was affected by all the treatments (ANOVA, $p < 0.001$), harvest time and interaction on plant nitrogen and phosphorus recovery.

Concerning P evolution, different results were observed in terms of ARF depending on the digestate. Total ARF_P is negatively correlated with Water P and Water inorganic P (r=-0.557* and -0.597) and represents the main part of P recovery (Total ARF and shoots: r = 0.942, p<0.0001) because of its depletion during the soil incubation. Hierarchical clustering analysis (HCA) revealed 5 clusters, depending on the substrates nature of the digestates as presented in Figure 1. Partial Least Square regression models were obtained to predict available P concentration on total shoots ($r^2 = 0.70$) and roots ($r^2 = 0.96$) depending on soluble P, labile P ($NaHCO_3$) and Ca-P bounded. Concerning N evolution and mineralization on soil, different levels of N mineralization and nitrification occur, depending on the digestate. The mineralization state affected the ARF_N for plant growth as shown by statistical analysis performed and PCA scores and loadings (Figure 1). Digestate characteristics affect negatively the mineralized N such as the C/N ratio (i.e. high for fibrous samples) or the least accessible fraction (PEOM_N) whereas soluble nitrogen fractions had a positive impact. As for P, HCA revealed in the scores plot 4 clusters, depending on the substrates nature of the digestates. Thanks to this clustering and the statistical analysis, some guidelines and trends can be drawn for each typology of digestate. Partial Least Square regression models were obtained to predict available N content on total shoots ($r^2 = 0.80$) and roots ($r^2 = 0.61$) depending on C/N ratio, soluble organic N and ammonium, and nitrate content. From all the results obtained in this study, some guidelines and trends can be drawn: the typology of digestate impacts the nutrient fertilization potential (N or P or both). The next step would be to propose some mechanistic models based on the fractionations proposed. P evolution seems to be independent from C and N mineralization.

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