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Biochar improves agro-environmental aspects of pig slurry compost as a substrate for crops with energy and remediation uses

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ABSTRACT

Composting is considered an appropriate approach for stabilising and sanitising pig slurry, incorporating its nutrients into the soil-plant system. However, pig slurry compost (PSC) can be highly saline with high concentrations of Cu and Zn, and can emit greenhouse gases (GHGs) and volatile organic compounds (VOCs), when not properly stabilised. In order to produce substrates with adequate characteristics for containerised soilless plant production, PSC must be mixed with other materials. In this study two materials were chosen: coir (coconut fibre; CF), as the most popular material after peat for this purpose, and biochar (BCH), a novel material in this scenario. Substrates were prepared by mixing PSC:CF and PSC:BCH at 60:40, 40:60, 20:80 and 0:100 (% v:v) ratios and their physical and chemical characteristics, their emission of GHG and VOC and seed germination and growth of two species grown for non-food purposes (milk thistle (*Sylibum marianum* L.) and sunflower (*Helianthus annuus* L.)) were studied. The results showed that BCH was more adequate than CF for the preparation of substrates with PSC, enabling seed germination and plant growth by decreasing the EC and available Cu and Zn contents, hence limiting phytotoxic effects, whilst also reducing CO_2, NO and VOC emissions. Toxic effects appeared in plants grown in substrates prepared with PSC at proportions greater than 20%; whilst at low rate (up to 20%) the beneficial effects might have been caused by the nutrients (N, P and K) supplied by PSC to the crops.

1. Introduction

In horticulture, plants are often grown in soilless organic or inorganic media. Of the organic media, peat has been the most popular in the last fifty years (Schmilevski, 2009). However, its price and environmental concerns related to peatland degradation are forcing growers to look for alternative materials such as compost, bark and, particularly, coir, which is the favoured substrate in most areas. The use of compost produced from plant or animal organic wastes has the additional advantage of recycling these wastes by means of environmentally-friendly management processes such as composting (Lim et al., 2016; Wu et al., 2014). Pig slurry is one of the wastes produced in animal farms which present most difficulties with regard to their management and recycling, due to its low dry matter content and high proportion of NH_4^+-N and its production in concentrated areas as a consequence of intensive production systems. Spain is the second-greatest pig producer in Europe (Eurostat, 2015), and hence faces a big challenge for the reuse of pig slurry. Composting is an appropriate approach for stabilising and sanitising pig slurry, allowing the recovery of its nutrients and their reclaim in agriculture (Santos et al., 2016). Organic fertiliser produced by composting or vermicomposting is becoming increasingly important in the agricultural sector especially because the global demand for fertiliser has carried on increasing in the last few years (Lim et al., 2015).

When considering the use of new materials as substrate or substrate constituents for containerised, soilless plant production, adequate physical (mainly air and water relations), physico-chemical (pH and electrical conductivity [EC]) and chemical (absence of toxic levels of organic compounds and heavy metals) characteristics are of chief importance (Abad et al., 2001; Bunt, 1988). The original raw material for composting is one of the most-significant factors affecting the quality of composts (Masaguer and Benito, 2007). Some composts show physical and chemical characteristics which are similar to peat, making them suitable as peat substitutes (Abad et al., 2001; Farrell and Jones, 2010). However,

Abbreviations: AR, adequate range; BCF, bioconcentration factor for total metal; BCF', bioconcentration factor for water soluble metal; BCH, biochar; CF, coir; CI, coarseness index; EAW, easily available water; EC, electrical conductivity; GHG, greenhouse gas; PSC, pig slurry compost; TAW, total available water; VOC, volatile organic compound.

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there are composts, such as those obtained from crop residues or from the agro-food industry, which are moderately to highly saline (Fornes et al., 2010), and some others, such as those from sewage sludge or pig slurry manure, are also too high in heavy metals (Hua et al., 2009; Santos et al., 2016), which hinders their use in high proportions as growing media constituents.

Composts prepared from the solid phase of pig slurry usually have a chemical composition that confers on them inadequate characteristics with regard to their use as the sole constituent of growth media: they can be highly saline, with a high content of Cu and Zn, yet rich in nutrients (Santos et al., 2016). Such high metal contents restrict the use of pig slurry compost in food crops, but an alternative use, for growing plant species for non-food purposes, might be worth considering. In this context, sunflower (*Helianthus annuus* L.), which is one of the main oil crops, may also be cultivated as a biofuel crop (Flagella and Monteleone, 2010) or considered in programmes for the remediation of heavy-metal-polluted soils (Kötschau et al., 2014; Yeh et al., 2015). Also, wild species have been screened for their potential for remediation of contaminated soils (Del Rio-Celestino et al., 2006; Zehra et al., 2009); in particular, milk thistle (*Sylibum marianum* L.) showed high heavy metal tolerance (Martínez-Fernández et al., 2014) and its use together with the application of compost has been suggested as a good combination for the remediation by phytostabilisation of trace-element contaminated soils under semiarid conditions (Martínez-Fernández et al., 2014). Another concern arising from the use of compost as a component of substrate is associated to the emission of a large amount of greenhouse gases and stinking volatile organic compounds, especially if composts are not fully stabilised, although emissions are meagre in highly mature compost (Jo et al., 2015; Santos et al., 2016).

Therefore, the characteristics of pig slurry compost need to be improved for using in growth media formulation by mixing with other suitable constituents. Among the broad spectrum of organic materials available as growth media constituents for soilless plant production, biochar is one of the most recently assayed (Méndez et al., 2015; Steiner and Harttung, 2014; Vaughn et al., 2013), however, its production market is still not fully developed. Biochar is charred organic matter (ideally obtained from organic wastes), usually produced by dry pyrolysis. The chemical characteristics of biochars can show high variability depending on the raw material and manufacturing conditions. Biochars from nutrient-poor feedstock, such as wood, are usually alkaline and non-saline, whilst biochars from nutrient-rich feedstock, such as olive mill waste, sewage sludge and pig manure, are highly saline (Fornes et al., 2015; Xu et al., 2016). Biochar shows interesting properties regarding its use in soilless growth media: it is remarkably recalcitrant, taking hundreds of years to decompose (Kuzyakov et al., 2009); it helps to maintain the structural integrity and the physical properties of the growth media throughout the crop cycle; it is a porous material that properly incorporates air and water and accommodates microbiota; and it presents a large surface area which includes reactive groups, leading to a high cation exchange capacity. It has also been described that biochar decreases the availability of heavy metals and organic toxins (Ahmad et al., 2014; Beesley et al., 2011; Inyang et al., 2016) and reduces emissions of GHG (Nelissen et al., 2014; Xiang et al., 2015) and VOC (Higashikawa et al., 2013). Also, biochar has been successfully assayed as a bulking agent during composting of pig slurry, improving both the process and the final compost quality (Chen et al., 2010; Li et al., 2015). A recent study conducted by Ghosh et al. (2015) showed that the combination of compost and biochar had optimal effects on both soils and the growth of two urban tree species, namely *Samanea saman* and *Suregada multiflora*.

The aim of this study was to determine the advantages of using biochar or coir as mixing agents, to produce acceptable growth media from pig slurry composts. To reach this objective, the effects of the mixing agents on the physical and chemical characteristics of the growth media – focusing on the pollutants Cu and Zn, which were abundant in the pig slurry compost, and on the gaseous emissions – were studied. The beneficial effect of the mixing agents on substrate production was tested on the seedling growth of two plant species, milk thistle and sunflower, which can be used for non-food purposes such as soil remediation and energy production.

2. Material and methods

2.1. Characteristics of the materials

The compost (PSC) used in this study was prepared in a pig breeding farm located in Guazamara (Almeria, Spain). A 19-m^3 composting pile was built by mixing the solid phase of pig slurry with cotton gin waste as bulking material, in the proportion 3:1 (w:w). Composting was carried out by the open windrow (turning) composting system, for 6 months. The biochar (BCH; particle size <6 mm) was purchased from Piroeco Bioenergy S.L. (Malaga, Spain). It was produced from holm oak by slow pyrolysis at 650 °C and atmospheric pressure, the residence time in the reactor chamber being 12–18 h. The coir (coconut fibre; CF) (Horticoco®) was purchased from Valimex (Valencia, Spain).

Two plant species used for non-food purposes were grown in this experiment. Seeds of milk thistle, with a potential for soil remediation, were obtained from Semillas Silvestres S.L. (Córdoba, Spain) and seeds of sunflower, grown as an energy crop, were obtained from RAGT Ibérica (Palencia, Spain).

2.2. Experimental design and plant growing conditions

The treatments consisted of different mixtures of PSC with biochar (PSC:BCH), and similar mixtures of PSC with CF (PSC:CF), in the proportions (% v:v): 60:40, 40:60, 20:80 and 0:100 (controls of BCH and CF). In order to equilibrate the nutrients supplied by the PSC, the mixtures were fertilised with a controlled-release fertiliser (Multicote® extra 6, Haifa Chemicals Ltd., Haifa-Bay, Israel) in an increasing proportion, inversely related to the compost in the mixture: 1 g L^{-1} of substrate for the 60:40 proportion; 2 g L^{-1} for 40:60; 3 g L^{-1} for 20:80; 4 g L^{-1} for 0:100. Celled plastic seed trays (cell volume = 60 mL) were used in the assays. Four replicates of 20 cells were filled with each of the mixes for each of the two plant species and distributed in a random block design. The experiments were conducted in a climatic greenhouse equipped with heating and cooling systems, and a fog system for irrigation.

Seed germination was tested with milk thistle. Three seeds were sown in each cell. Germination was recorded over 40 days and the germination percentage calculated. Only the first seedling which emerged was kept for the experiment (one plant per cell). For sunflower, only one seed was sown in each cell. The seedlings were grown for 46 days in March–April 2015 for milk thistle and for 35 days in April–May for sunflower.

At the end of the growing period, total leaf chlorophyll-related SPAD units and parameters related to growth and development were recorded. The SPAD measurements were carried out with a SPAD-502 Chlorophyll Meter (Konica, Minolta, Tokyo, Japan) in four leaves per plant, and the average calculated. Shoot dry weight was obtained by oven-drying at 65 °C for 72 h. Root size was evaluated by taking the root ball out of the pot and assessing the extension of the root system visually, with a scale ranging from 1 to 4, in which 1 represents roots which do not reach the surface of the substrate and 4 represents a root system forming a compact mesh that is present in the whole substrate (Fornes et al., 2007).

Oven-dried leaf tissue was finely ground for analysis. The leaf N, P, K, Ca, S, Fe, Cu and Zn concentrations were determined as indi-