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Nitrification of leachates from manure composting under field conditions and their use in horticulture

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ABSTRACT

This work aimed to demonstrate the feasibility of nitrification applied to the treatment of leachates formed during composting of cattle and pig manure in order to promote their further use as liquid fertilizer in horticulture. Nitrification trials were successfully conducted in summer and winter seasons under Mediterranean climate conditions. Subsequently, effect of using the nitrified effluents as nutritive solution in the fertigation of lettuce (*Lactuca sativa* L.) was assessed in terms of productivity and nutrient uptake. Similar productivities were obtained when using the nitrified effluents and a standard nutritive solution. However, results also evidenced high nutrient uptake, which indicates that dosage should be adjusted to culture requirements.

1. Introduction

The intensive livestock production substantially contributes to the economics of most developed countries (FAOSTAT, 2015). This productive sector is responsible for several issues which can affect the environment, including the generation of solid and liquid organic waste. Thus, appropriate waste management is needed to ensure the feasibility of this industry, and research can help in optimizing the agricultural use of such by-products. Concerning horticulture, potential targets to be studied are the organic amendment, fertilization, biostimulation against plant stress, correction of crop deficiencies, and production of growing media (Cáceres and Marfà, 2013; Marfà et al., 2009; Polo et al., 2006).

Particularly, manure processing through composting has extensively been investigated as a method for producing a value-added product (compost) for the recycling of organic matter and nutrients (Bernal et al., 2009). However, this treatment may involve formation of leachate because of several reasons: (i) the high moisture content of manure and the compression caused by the overlying material column (Mason et al., 2004); (ii) the application of water to maintain the moisture content of the material that is being composted within an appropriate range (Cáceres et al., 2015; Tejada et al., 2008); and (iii) rainfall events – in uncovered composting systems – (Parkinson et al., 2004).

Composting leachate is a complex type of wastewater with high organic and mineral load (Gagnaire et al., 2011; Trujillo et al., 2006; Vázquez et al., 2013; Zhou et al., 2010). In composting facilities, leachate should be properly collected, stored, and managed in order to avoid negative environmental impacts such as aquatic eutrophication. Different alternatives have already been proposed for treating composting leachate targeting reduction of potentially polluting compounds (nutrients included), which are encompassed in two different sets of technologies; i.e., physicochemical technologies (Gagnaire et al., 2012; Liu and Lo, 2001; Trujillo et al., 2006), and biological technologies (Savage and Tyrrel, 2005; Tyrrel et al., 2008; Vázquez et al., 2013; Zhou et al., 2010). However, nutrient-rich wastewaters are broadly available for potential reuse as liquid fertilizer in crop production systems. Such reuse can reduce water consumption, the cost of the fertilizer, and the cost of leachate treatment/disposal, while resulting in environmental benefits (Chong et al., 2008). Several works have already described the agricultural use of this kind of effluents for crop production as foliar fertilizer for vegetables (Singh et al., 2010; Tejada et al., 2008), as well as fertilizer for cereals (Gutiérrez-Miceli et al., 2008), ornamental plants (Gils et al.,

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2005; Zhou et al., 2010), and trees (Justin et al., 2010). It was also reported that certain pre-conditioning treatment of the leachate (dilution, addition of microorganisms, storage, etc.) can favor such reuse (Gutiérrez-Miceli et al., 2008; Zhou et al., 2010). On the other hand, the main deterrents against using composting leachate in plant cultivation are nutrient imbalances, high salinity, and variability in the physiological response depending on the particular crop (Chong et al., 2008; Gils et al., 2005). Concerning the edible horticulture, the study of heavy metals and nutrient uptake as well as the translocation of undesirable substances to the plant is mandatory in order to assure not transferring these elements into the food chain (Al-Lahham et al., 2007).

Nitrogen (N) content in composting leachates is relatively high, and mainly in form of ammonium (NH_4^+). This is quite similar to the case of livestock slurries produced in cattle and swine farming (Flotats et al., 2009). High NH_4^+ concentrations may become phytotoxic in crop fertigation (Britto and Kronzucker, 2002; Bugarín et al., 1998). However, if NH_4^+ is previously transformed into nitrate (NO_3^-), the resulting effluent will be potentially usable for fertigation without toxicity risk for plants. In other words, such conversion will imply the production of a nitrogenous form easily assimilable by plants (Bugarín et al., 1998) while maintaining the fertilizing value of the leachate in terms of N units. In addition, by converting NH_4^+ into NO_3^- it is possible to prevent N loss due to volatilization during storage. This is because the NH_4^+ ion and ammonia (NH_3) are in chemical equilibrium depending on the pH and temperature (T) of the medium, and NH_3 is a volatile form of N (Ndegwa et al., 2008).

Nitrification is a two-step biological reaction catalyzed by autotrophic microorganisms. It consists in the oxidation of NH_4^+ into nitrite (NO_2^-) by ammonium-oxidizing bacteria (AOB), and subsequently, the oxidation of NO_2^- into NO_3^- by nitrite-oxidizing bacteria (NOB). The process basically requires appropriate T and pH, dissolved oxygen (DO) supply, and good substrate-to-biomass contact ratio. Since nitrifying microorganisms use inorganic carbon as carbon source, availability of organic matter, i.e., chemical oxygen demand (COD), is not necessary. According to the US EPA (1993), the complete nitrification reaction can be expressed as:

$$NH_4^+ + 1.89\,O_2 + 1.98\,HCO_3^- \rightarrow 0.0161\,C_5H_7O_2N + 0.984\,NO_3^- + 1.032\,H_2O + 1.899\,H_2CO_3 \qquad (1)$$

where $C_5H_7O_2N$ is the molecular expression for the nitrifying microorganisms. In accordance with this stoichiometry, bicarbonate (HCO_3^-) requirement during nitrification is equivalent to 1.98 mol HCO_3^- per mol of NH_4^+ oxidized (7.07 g $CaCO_3$ g^{-1} NH_4^+–N). Such alkalinity consumption usually results in a decreased pH of the treated effluent. Technical feasibility of the nitrification process coupled to a denitrification strategy was already demonstrated in many studies targeting N removal from wastewaters derived from livestock activities (Deng et al., 2007; Magrí and Flotats, 2008; Magrí et al., 2012; Vázquez et al., 2013). However, nitrification alone can also become a chance for the valorization of these liquid effluents as nitrogenous fertilizer.

The objectives of this work are: (i) to assess the feasibility of nitrification applied to the treatment of leachates from cattle and swine manure composting, under Mediterranean climate conditions, in order to promote their subsequent use as liquid fertilizer, and (ii) to study the effect of this use in a horticultural culture of lettuce focusing on the evaluation of productivity and nutrient uptake.

2. Materials and methods

2.1. Composting leachates

Raw leachates were collected in a collective composting plant located in the Osona county (Catalonia, Spain), which processes manure coming from nearby cattle (C) and pig (P) farms. Cattle and pig manures were composted separately; therefore, two different kinds of leachate were obtained. The composting process was carried out in an open facility using windrows. Physicochemical characterization of the leachates (Table 1) evidenced basic pH and high electrical conductivity (EC) -particularly in the case of leachate P-. High NH_4^+–N concentrations (600–900 mg N L^{-1}) make unfeasible direct leachate use in horticultural fertigation since it would lead to phytotoxicity issues. The carbon-to-nitrogen (C/N) ratio was estimated within the range of 3.2–4.6, which suggests potential coexistence of organic degradation and nitrification during aerobic treatment. Owing to the high level of total suspended solids (TSS) in leachate C (3.2 g L^{-1}), both leachates were subjected to gravity settling during 2 days and subsequent decanting prior to aerobic treatment.

2.2. Setup for leachates nitrification

Nitrification of the composting leachates as well as subsequent tests concerning use of the nitrified effluents in horticulture were both conducted in a glass greenhouse located in the experimental facilities of IRTA Cabrils (Catalonia, Spain; latitude 41°25′N, longitude 2°23′E, and height above sea level of 85 m) (Fig. 1).

The nitrification assays were carried out in three different time periods. The first trial "nitrification preliminary test" (Section 2.2.1) was performed using two reaction tanks. On the other hand, the second and third trials (concerning summer and winter seasons; Sections 2.2.2 and 2.2.3, respectively) were both performed using four reaction tanks. Thus, two different dilutions were considered at most for each type of leachate. All the tanks used were identical; i.e., tanks were made of polyethylene plastic, with cylindrical shape (56 cm diameter and 105 cm high) and total volume of 260 L. Tanks were empty at the beginning of a new

Table 1
Composition of the raw leachates coming from cattle manure composting (leachate C) and pig manure composting (leachate P). Results are referred to fresh sample except when otherwise indicated.

Parameter	Units	Leachate C	Leachate P
pH (1/5)[a]	–	8.4	8.4
EC (1/5)[b]	dS m^{-1}	2.80	4.05
TS	%	1.8	2.0
VS	%, dry weight	48.9	45.2
TSS	mg L^{-1}	3176	105
Org-N	mg L^{-1}	486	720
NH_4^+–N	mg L^{-1}	614	894
NO_3^-–N	mg L^{-1}	1.7	14.7
C/N ratio	g g^{-1}	4.6	3.2
P	mg L^{-1}	113	32
K	mg L^{-1}	3429	4734
Cl^-	mg L^{-1}	918	2133
Na	mg L^{-1}	630	1044
Ca	mg L^{-1}	614	102
Fe	mg L^{-1}	131	40
Mg	mg L^{-1}	153	58
S	mg L^{-1}	135	164
Cu	mg L^{-1}	2.14	0.38
Zn	mg L^{-1}	3.24	1.72

[a] pH and EC were measured after dilution 1/5 (w/w; proportions referred to fresh leachate and distilled water, respectively).

[b] EC: electrical conductivity, TS: total solids, VS: volatile solids, TSS: total suspended solids, Org-N: organic nitrogen.