Management of the wastes derived from anaerobic digestion: development of an industrial composting strategy

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Abstract
This work studies the feasibility of co-composting as post-treatment for the management of the solid fraction of anaerobically digested pig slurry (SFP), and the effect of the use of different co-composting agents on the process and on the final compost characteristics. For this, two different experiments were carried out in an industrial composting plant. In the first experiment, six mixtures were prepared with SFP and different organic wastes available in the facility and in the second one, an optimised composting pile was elaborated at an industrial scale considering the results previously obtained. Temperature evolution was monitored and the final properties of the composts were evaluated. In general, all the composts showed suitable properties and a good degree of maturity, but the use of certain raw materials (paper mill sludge and sewage sludge) produced composts with several limiting aspects for their agricultural use, such as high salinity and/or notable concentrations of Cu and Zn, which can also come from SFP.

Introduction

The intensification of the livestock production systems has resulted in a great generation of animal wastes that can imply a potential environmental risk if these wastes are not managed properly. Anaerobic digestion is an efficient biological method for renewable energy production from livestock and agroindustrial wastes, which transforms organic wastes into biogas and a digested material (digestate). However, digestates usually present some undesirable characteristics for its direct soil application, requiring post-treatments prior to its agricultural use [1]. These post-treatments can consist on a solid-liquid separation of the digestate and composting of the obtained solid fraction. Composting, a treatment based on the aerobic biological decomposition and stabilisation of organic substrates, can constitute a suitable method to improve the properties of the solid fraction of digestate and thus, enhancing its fertilising value [1]. In this sense, the demonstration project "Demonstration of the production of organic fertilisers from the anaerobic co-digestion of livestock and agroindustrial wastes" (ref. PROBIOGAS PSE-120000-2009-22 Project), deals with the optimisation of the management of the anaerobic digestates by composting at an industrial scale. So, this paper describes the principal objectives of this project, showing the main results achieved.

Material and Methods

Description of the project and composting procedure

The aim of the demonstration project was to validate and optimise the management of anaerobic digestates derived from livestock wastes by composting at the industrial scale. The specific objectives were: i) to study the viability of the composting process as post-treatment to manage the solid fraction of anaerobically digested pig slurry (SFP) produced in a centralized treatment plant, together with other industrial organic wastes; ii) to evaluate the effect of the type and proportion of the co-composting and bulking agents used in the mixtures on the final characteristics of the composts obtained and iii) to scale the best results obtained in the first stage at the industrial level.

Previous to the composting experiment, a complete characterisation of the potential raw materials for the co-composting, available at the industrial composting site, was carried out. The composting study was divided into two stages:

a) Experiment 1: Six mixtures were prepared using the solid fraction of anaerobically digested pig slurry (SFP), produced in an industrial waste treatment plant (Gestcompost S.L., Zaragoza, Spain) with other wastes processed at the same facility: sewage sludge (SS), paper mill sludge (PS) and pig hair waste (PW), and two bulking agents (maize straw (MS) and wheat straw (WS)). The mixtures elaborated were (on a fresh weight basis): P1 (100% SFP), P2 (80% SFP + 20% MS), P3 (60% SFP +

40% MS), P4 (35% SFP + 35% SS + 30% mixture of MS and WS), P5 (35% SFP + 35% PS + 30% mixture of MS and WS) and P6 (35% SFP + 35% PW + 30% mixture of MS and WS). These mixtures were prepared in trapezoidal piles (approximately 1500 kg each pile) and composted by the turning composting system in the composting plant. The piles were turned five times, when the temperature started to decrease to improve both the homogeneity of the materials and the composting process.
b) Experiment 2: Taking into account the results obtained in the Experiment 1, an optimised composting pile was elaborated at an industrial scale, using the SFP mixed with the most suitable co-composting agents (P7: 58.7% SFP + 39.8% PS + 1.5% MS (fresh weight basis)). The mixture was also elaborated in a trapezoidal pile (approximately 136 tonne) and composted by the turning composting system in the same industrial facility. This pile was turned 11 times due to the industrial size of the pile to favour both the homogeneity of the materials and the composting process.
In both experiments, the moisture of the piles was controlled weekly by adding the necessary amount of water to keep the moisture at > 40 %, and the evolution of the temperature was monitored. The bio-oxidative phase of composting was considered finished when the temperature was close to the ambient and re-heating did not occur after turning. Then, the composts were left to mature over a period of one month. The samples were taken by mixing seven subsamples from seven representative sites of the pile, from the whole profile (from the top to bottom of the pile). Each sample was divided into two parts, one of which was air-dried and ground to 0.5 mm for chemical analysis and the other was immediately frozen for microbiological determinations.

Analytical methods
In the raw materials and in the composting samples, electrical conductivity (EC) and pH were analysed in a 1:10 (w/v) water-soluble extract. Organic matter (OM) was assessed by determining the loss-on ignition at 500 °C for 24 h. Total organic C (C_{OT}) and total N (N_T) were determined by automatic microanalysis. Cation exchange capacity (CEC) was determined with $BaCl_2$-triethanolamine. After HNO_3/$HClO_4$ digestion, P was analysed colorimetrically, K was determined by flame photometry and Fe, Cu, Mn and Zn were measured by ICP-OES. The germination index (GI) was calculated using seeds of *Lepidium sativum* L. The presence of *Salmonella* and faecal coliforms (*Escherichia coli*) was investigated in the mature composts. All the analyses were made in triplicate and according to the methods described by Bustamante et al. [1].

Results and discussion
Characteristics of the raw materials for the co-composting process
All the wastes showed pH values close to neutrality, within the optimum range (pH = 6-8) for the suitable development of the composting process [2], except for SS and PW, with acidic values (Table 1).

Table 1. Mean values of the main physico-chemical and chemical characteristics of the raw materials available in the facility.

	SFP	SS	PS	PW	MS	WS
pH	6.8	5.9	7.8	5.3	6.3	7.5
EC (dS/m)	3.76	2.92	0.72	1.90	4.81	3.98
OM (%)	69.9	78.2	37.2	99.4	91.7	93.1
C_{OT}/N_T ratio	14.5	13.4	40.5	3.65	62.4	60.4
K (g/kg)	5.25	2.18	0.59	0.17	50.2	53.6
Fe (mg/kg)	3071	10596	836	431	3427	2255
Cu (mg/kg)	271	230	61.8	31.2	13.4	19.3
Mn (mg/kg)	668	122	70.8	48.4	132	110
Zn (mg/kg)	3549	587	69.1	22.2	361	137

EC: electrical conductivity; OM: organic matter.

The EC values were, in general, lower than 4 dS/m, except for MS, being especially notable the low values found in PS. In general, all the wastes showed high OM contents, except for PS due to its inorganic character. N_T contents were very variable in these materials, observing the highest concentrations in SFP and SS. The C_{OT}/N_T ratio ranged from very low values, as in PW, to high values, as in the bulking agents (MS and WS) due to its lignocellulosic nature. These wastes also showed an important variability regarding to the concentrations of K, microelements and heavy metals, observing the highest contents of Fe in SS, due to the treatments of wastewater, and the greatest concentrations of Mn, Cu and Zn in SFP, due to the origin of the digestate (pig slurry). High concentrations of Cu and Zn were also observed by Bustamante et al. [1] in anaerobic digestates derived from pig slurries. This fact is of great importance for the co-composting process, since high contents of Cu and, especially, of Zn in SFP can imply a potential limiting aspect in relation to the quality of the final composts.

Evolution of the temperature of the composting piles

In general, all the composting piles of the Experiments 1 (Fig. 1 a) reached thermophilic temperature values (> 40ºC) during the first two weeks of composting, except for P1, elaborated only using the solid fraction of anaerobically digested pig slurry (SFP).

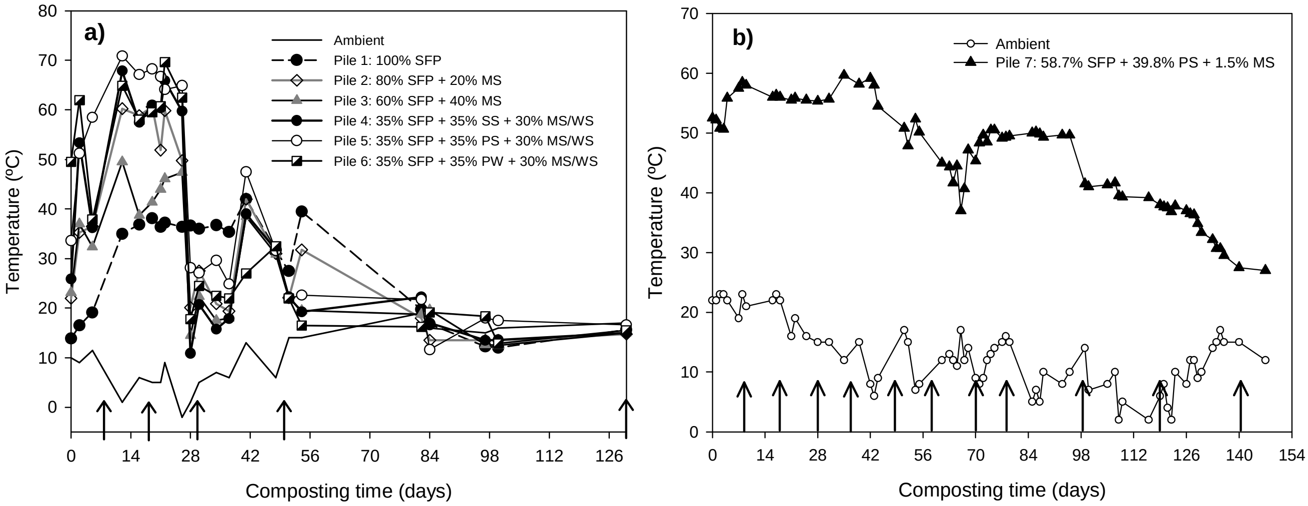

Figure 1. Temperature profile of the composting piles studied a) Experiment 1 and b) Experiment 2. Arrows indicate turnings.

Pile 5, constituted by SFP, PS and the mixture of MS and WS, was the pile that reached faster the thermophilic temperature values and showed the highest temperature values, possibly due to the addition of PS, since the temperature profiles reflected the labile nature of the C forms present in the wastes and its thermal inertia [2]. The temperature behaviour in the industrial pile (P7) (Fig. 1b) was similar to that showed for most of the previous mixtures, with a rapid increase of the temperature at the beginning of the composting process, as well as a longer duration of the thermophilic phase than in the piles of Experiment 1, due to the high mass of the pile.

Characteristics of the final composts obtained

All the composts showed pH values close to neutrality, suitable for their agricultural use. However, EC values were slightly high, especially in C5, probably due to the use of paper mill sludge, co-substrate that presents a high mineral content (Table 1). However, this aspect was not found in the industrial compost (C7), probably due to the different proportions used in this mixture, which shows an improvement of the quality of the final compost obtained. In relation to the maturity parameters, the values of the C/N ratio ranged between 9.54 and 8.38, in all cases being lower than 12, the limit established by the Spanish legislation [3] and by different authors as the limit for mature compost [4]. Also, all composts except C6, showed absence of phytotoxicity (GI > 50%), especially the industrial pile C7, and values of the CEC higher than the minimum value established for mature compost (> 67 meq/100 g OM) [4], aspects that indicate a good degree of maturity. In addition, all the composts showed notable concentrations of C_{OT} and macronutrients, with final contents of N_T higher than 2%, and similar concentrations of P and K to those found in other composts from different origin [1,5]. Heavy metal concentrations were lower than the limits established for compost by the Spanish legislation [3] and the European guidelines [6], except for Cu in C4 and C6, and Zn in all the composts, due to the use of SFP. The absence of *Salmonella* and low concentration of *E. coli* indicated the hygienic conditions of the compost, due to a proper temperature development.

Table 2. Physico-chemical, chemical and biological properties of the composts obtained.

	C1	C2	C3	C4	C5	C6	C7
pH	6.4	6.2	6.8	6.6	6.2	6.9	6.8
EC (dS/m)	7.34	7.41	7.67	7.42	8.67	7.56	5.84
C_{OT} (%)	24.2	24.7	29.3	27.6	24.0	27.6	22.8
N_T (%)	2.63	2.60	3.29	2.95	2.87	3.09	2.51
C_{OT}/N_T ratio	9.21	9.54	8.97	9.34	8.38	8.94	9.10
CEC (meq/100 g OM)	137	172	156	118	122	117	115
P (g/kg)	16.2	19.4	14.7	16.5	12.7	15.5	28.4
K (g/kg)	7.50	7.67	9.34	8.36	7.16	9.43	8.93
Fe (mg/kg)	4969	5394	4779	5208	4059	5894	3280
Cu (mg/kg)	396	389	293	456	392	663	348
Mn (mg/kg)	664	817	634	711	514	618	1041
Zn (mg/kg)	3012	3799	2671	3297	2217	2877	2885
GI (%)	83.5	76.7	60.0	57.9	88.5	42.2	88.3
Salmonella spp.	Absence	Absence	Absence	Absence	Absence	Absence	Absence
E. coli (CFU/g)	<10	<10	<10	<10	<10	43	<10

EC: electrical conductivity; C_{OT}: total organic carbon; N_T: total nitrogen; CEC: cation exchange capacity; OM: organic matter; GI: germination index. C1: 100% SFP; C2: 80% SFP + 20% MS; C3: 60% SFP + 40% MS; C4: 35% SFP + 35% SS + 30% MS/WS; C5: 35% SFP + 35% PS + 30% MS/WS and C6: 35% SFP + 35% PW + 30% MS/WS.

Conclusion and perspectives

Composting of the solid fraction of digestates from pig slurry with different co-composting and bulking agents constitutes an efficient method to recycle these wastes, and demonstrates the viability of the combination of anaerobic digestion with composting for pig slurry management. In general, all the composts showed a good degree of maturity and absence of phytotoxicity, but the use of determined raw materials (PS) can produce composts with several limiting aspects such as high salinity. The main limiting factor for the compost agricultural use was the concentration of Cu and Zn from the digestate of pig slurry origin.

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