Journal of Cleaner Production 47 (2013) 61–69

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Recycling of anaerobic digestates by composting: effect of the bulking agent used

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ARTICLE INFO

Article history:
Received 8 February 2012
Received in revised form
30 May 2012
Accepted 9 July 2012
Available online 1 August 2012

Keywords:
Compost
Anaerobic digestion
Pig slurry
Physical properties
Maturity
Multivariate analysis

ABSTRACT

Digestate, the by-product of the anaerobic digestion, can present characteristics which would limit its recycling by direct use in agricultural soils. Composting can be a feasible treatment to stabilise digestate and thus, to improve its properties for using as a soil conditioner or substrate. The aim of this work was to study the viability of composting for the recycling of digestates after solid–liquid separation and the effect of the bulking agent used in the characteristics of the end-products obtained. For this, five piles were elaborated by mixing the solid fraction of a pig slurry digestate (SD) with different bulking agents (wheat straw (WS), vine shoot prunings (VP), exhausted grape marc (EGM) and pepper plant prunings (PP)). Also, one of these piles was watered with the liquid fraction of the pig slurry digestate (LD). Throughout the composting process, the temperature of the mixtures was monitored and physico-chemical, chemical, physical properties and maturity degree were determined. Also, factorial analysis (FA) was used for interpreting the data set of compost characteristics. The composts obtained showed a suitable degree of stability and maturity and suitable physical properties for their potential use as growing media. Also, the type of bulking agent strongly influenced the development of composting and the final properties of the composts, showing the mixtures with WS and VP the most suitable characteristics.

1. Introduction

The intensification of the livestock production systems has resulted in a high density of animals in relatively small areas that produces large quantities of wastes (Ko et al., 2008), which in EU-27 is mainly collected in housing systems and mostly come from cattle and pig production (Holm-Nielsen et al., 2009). More than half of this, is in the form of slurry (a liquid mixture of urine, feces, water, and bedding material), while the rest is solid and often includes bedding material (from deep litter stables, littered ground-based systems, and tie-stalls with separate collection of liquids and solids) (Oenema et al., 2007).

This intensive livestock production implies a potential pollution risk, if the large amount of livestock wastes produced is not properly managed. To prevent the associated detrimental effects on the environment, such as the discharges to soils and surface waters (e.g., nitrogen, phosphorus, and heavy metals), the spread of pathogens and the emissions of greenhouse gases (GHG), it is necessary to develop methods to improve the management of animal manures.

Anaerobic digestion is a method of producing energy from renewable resources, while achieving multiple environmental benefits (Rehl and Müller, 2011; Poeschl et al., 2012). In developed countries, the biogas technology is used on a large scale for power and heat production, while in developing countries it can potentially contribute to solve current problems with animal manure management (Thu et al., 2012). This process implies the reduction of the greenhouse emissions, in particularly ammonia and methane (Holm-Nielsen et al., 2009; Poeschl et al., 2012). Also, it has the additional benefits of energy recovery producing biogas, a renewable fuel mainly composed by methane (50–80% vol.) and carbon dioxide (Tambone et al., 2010), and the digested substrate (digestate), with a potential fertilising value (Alburquerque et al., 2012). However, some undesirable characteristics of the digestate, such as odour, viscosity, high humidity and high content in volatile fatty acids, which can be phytotoxic (Walker et al., 2009), may restrict its application to agricultural soils without treatment (Abdullahi et al.,

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http://dx.doi.org/10.1016/j.jclepro.2012.07.018

2008). Also, digestates can represent a source of pathogens, if the digestion is not developed under thermophilic conditions (Walker et al., 2009). Therefore, anaerobic digestates require final 'polishing' to enhance their fertiliser value and applicability as a soil conditioner (Abdullahi et al., 2008). One option is to separate the digestate into a liquid and a solid fraction, the latter being composted in order to obtain valuable and marketable end-products for agriculture (Holm-Nielsen et al., 2009).

Several authors have studied aerobic post-treatments of digestate, such as Abdullahi et al. (2008), Bortone (2009) and Drennan and DiStefano (2010). The composting of the solid fraction of the digestate could constitute a viable method not only to manage these materials, but also to improve the quality of the end-product, reducing the odour emission by decreasing the concentration of volatile compounds (Smet et al., 1999), the moisture content, the potential phytotoxicity and also contributes to the elimination of pathogens (Tchobanoglous et al., 2002). However, not enough information is currently available on the composting of anaerobic digestates and on the assessment of the characteristics of the composts obtained.

Therefore, the aim of this work was twofold: (1) to study the feasibility of the treatment of the solid fraction of a pig slurry digestate by co-composting with different bulking agents and (2) to evaluate the final characteristics of the composts obtained related to agricultural quality.

2. Materials and methods

2.1. Compost elaboration

The solid fraction of the digestate (SD) was obtained after the continuous, anaerobic thermophilic digestion of pig slurry in an industrial digester (3000 m^3), placed in a centralised treatment plant of pig slurries in Catalonia, and its subsequent mechanical separation by centrifugation without any additive addition.

Then, five piles (P1, P2, P3, P4 and P5) were prepared by mixing SD with different bulking agents: wheat straw (WS) for P1 and P2, exhausted grape marc (EGM) for P3, vine shoot prunings (VP) for P4 and pepper plant prunings (PP) for P5. Prior to be used in the composting piles, the bulking agents were homogenised and crushed to 1 cm particle size (except EGM that was only homogenised). WS came from an agricultural plantation of cereal placed in Albacete (Spain); EGM was collected from an alcohol distillery placed in Villarrobledo (Albacete, Spain), VP was obtained from a vineyard of Petit Verdot 3 years Rootstock SO4 (*Vitis vinifera* L.), planted in 2007 and situated in Fuente Alamo (Albacete, Spain) and PP came from a commercial greenhouse of bell pepper (*Capsicum annuum* L.) placed in Almeria (Spain).

Then, SD was thoroughly mixed with the corresponding bulking agent using a mixer and the mixtures obtained (about 150 kg) were placed in the respective 350 L thermo-composters. The thermo-composters, 70 cm × 70 cm × 85 cm, were made of high-density polyethylene (HDPE) and have a lateral system of natural ventilation to guarantee aerobic conditions. In piles P1, P2 and P5 almond shell powder was included as an additive to increase the C/N ratio of the mixture. Additionally, P2 was watered with the liquid phase of the anaerobic digestate of pig slurry (LD); 0.22 L LD per kg was added on the first day and the remaining volume, up to 0.45 L kg^{-1} was added weekly up to 27 days of composting, while the rest of piles were watered with water, maintaining a moisture content within the range 40–70%, especially during the bio-oxidative phase when the water loss due to evaporation was high. To adjust this, the moisture content of the piles was previously determined in the samples collected. The main characteristics of the raw materials are shown in Table 1. The mixtures were prepared in the following proportions, on a dry weight basis:

P1: 74% SD + 24% WS + 2% almond shell powder
P2: 74% SD + 24% WS + 2% almond shell powder (plus 0.45 L kg^{-1} of LD)
P3: 75% SD + 25% EGM
P4: 75% SD + 25% VP
P5: 70% SD + 23% PP + 7% almond shell powder

The mixtures were composted in the thermo-composters by the turning composting system. In windrow composting, turning is considered as the primary mechanism of aeration and temperature control (Tiquia et al., 1997). The piles were turned when the temperature in the mixtures decreased, to provide aeration and to improve the homogeneity of the materials, enhancing the composting process. Each pile was turned 1–2

Table 1
Main physico-chemical and chemical characteristics of the raw materials used in the composting piles (dry matter basis, except for LD).

	SD	WS	EGM	VP	PP		LD
pH	6.54 ± 0.01	5.94 ± 0.05	6.43 ± 0.02	6.01 ± 0.01	10.08 ± 0.01	pH	8.1 ± 0.1
EC (dS m^{-1})	5.64 ± 0.06	3.99 ± 0.01	1.35 ± 0.01	1.60 ± 0.01	6.15 ± 0.02	EC (dS m^{-1})	25.7 ± 0.2
OM (%)	65.7 ± 1.4	94.3 ± 0.1	86.1 ± 0.1	92.8 ± 0.5	43.8 ± 0.2	RP (mV)	−390 ± 7
TOC (%)	35.2 ± 0.1	46.1 ± 0.1	51.2 ± 0.7	46.7 ± 0.8	27.3 ± 0.2	d (g cm^{-3})	1.011 ± 0.001
TN (g kg^{-1})	26.7 ± 1.3	2.70 ± 0.1	23.5 ± 0.7	5.50 ± 0.01	17.6 ± 0.3	COD (mg O_2 l^{-1})	13,667 ± 500
C/N ratio	13.2 ± 0.9	169 ± 2.4	21.8 ± 0.9	84.4 ± 1.0	15.4 ± 0.3	BOD_5 (mg O_2 l^{-1})	2500 ± 100
P (g kg^{-1})	31.0 ± 0.2	0.69 ± 0.07	3.37 ± 0.2	0.83 ± 0.02	4.47 ± 0.01	SS (mg l^{-1})	4.55 ± 0.28
K (g kg^{-1})	11.4 ± 0.5	8.97 ± 0.5	13.0 ± 0.5	7.00 ± 0.00	12.7 ± 0.8	VS (mg l^{-1})	6989 ± 163
Ca (g kg^{-1})	26.8 ± 8.8	5.67 ± 1.1	11.6 ± 0.5	8.10 ± 1.0	27.5 ± 0.7	TS (mg l^{-1})	14,580 ± 179
Mg (g kg^{-1})	7.01 ± 0.3	0.96 ± 0.07	0.48 ± 0.05	1.55 ± 0.21	6.08 ± 0.07	TN (mg l^{-1})	2573 ± 52
Na (g kg^{-1})	4.99 ± 0.4	5.73 ± 0.00	3.87 ± 0.1	3.75 ± 0.00	2.87 ± 0.1	NH_4–N (mg l^{-1})	2170 ± 112
Fe (mg kg^{-1})	3927 ± 130	45.7 ± 19.0	382 ± 81	165 ± 20	5267 ± 378	Fe (mg kg^{-1} f.w.)	15.2 ± 3.4
Mn (mg kg^{-1})	370 ± 125	27.5 ± 2.1	6.42 ± 0.23	8.02 ± 1.44	117 ± 4.0	Cu (mg kg^{-1} f.w.)	2.51 ± 0.53
Cu (mg kg^{-1})	186 ± 63	1.87 ± 0.66	5.78 ± 0.08	1.89 ± 0.54	17.2 ± 0.92	Mn (mg kg^{-1} f.w.)	0.78 ± 0.03
Zn (mg kg^{-1})	1698 ± 354	10.6 ± 1.0	13.1 ± 1.2	16.6 ± 2.0	79.5 ± 0.1	Zn (mg kg^{-1} f.w.)	10.5 ± 2.67
Cr (mg kg^{-1})	17.5 ± 0.7	4.56 ± 0.29	8.27 ± 1.30	7.25 ± 0.72	16.2 ± 2.64	Cd (μg kg^{-1} f.w.)	2.57 ± 0.74
Co (mg kg^{-1})	1.88 ± 0.06	0.14 ± 0.01	0.38 ± 0.05	0.20 ± 0.01	2.93 ± 0.13	Cr (μg kg^{-1} f.w.)	51.1 ± 14.5
Ni (mg kg^{-1})	9.49 ± 0.18	0.98 ± 0.05	3.00 ± 0.36	2.59 ± 0.21	9.42 ± 0.06	Co (μg kg^{-1} f.w.)	15.5 ± 3.27
Cd (mg kg^{-1})	0.25 ± 0.01	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.22 ± 0.01	Ni (μg kg^{-1} f.w.)	42.1 ± 9.01
Pb (mg kg^{-1})	2.30 ± 0.09	0.20 ± 0.02	0.86 ± 0.07	0.39 ± 0.01	12.1 ± 0.41	Pb (μg kg^{-1} f.w.)	10.7 ± 1.0
Hg (mg kg^{-1})	0.10 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.14 ± 0.01	0.11 ± 0.01	Hg (μg kg^{-1} f.w.)	50.9 ± 1.5

EC: electrical conductivity; OM: organic matter; TOC: total organic carbon; TN: total nitrogen; RP: redox potential; d: density; COD: chemical oxygen demand; BOD_5: biological oxygen demand; SS: suspended solids; VS: volatile solids; TS: total solids; f.w.: fresh weight.
SD: solid fraction of pig slurry digestate; WS: wheat straw; EGM: exhausted grape marc; VP: vine shoot pruning; PP: pepper plant pruning; LD: liquid fraction of pig slurry digestate. Values reported as mean ± standard error.