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Biomass ash reutilisation as an additive in the composting process of organic fraction of municipal solid waste

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ABSTRACT

In this work the effects of selected types of biomass ash on the composting process and final product quality were studied by conducting a 96-day long experiment where the source separated organic fraction of municipal waste, mixed with wood prunings that served as bulking agent, was added with 0%, 2%, 4% and 8% wt/wt of biomass ash. The evolution over time of the main process parameters was observed, and the final composts were characterised. On the basis of the results, both the composting process and the quality of the final product were improved by ash addition. Enhanced volatile solids reduction and biological stability (up to 32% and 52%, respectively, as compared to the unamended product) were attained when ash was added, since ash favored the aerobic degradation by acting as a physical conditioner. In the final products, higher humification of organic matter (expressed in terms of the humification index, that was 2.25 times higher in the most-enriched compost than in the unamended one) and total Ca, K, Mg and P content were observed when ash was used. The latter aspect may influence the composts marketability positively, particularly with regards to potassium and phosphorus. The heavy metals content, that is regarded as the main environmental disadvantage when using ash as a composting additive, did not negatively affect the final composts quality. However, some other controversial effects of ash, related to the moisture and temperature values attained during the process, pH (8.8–9.2 as compared to 8.2 of the unamended compost) and electrical conductivity levels (up to 53% higher as compared to the unamended compost) in the final composts, were also observed.

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1. Introduction

In the recent years, a new strategy for achieving a more sustainable economic growth, based on the circular economy approach, has been adopted by the European Commission (European Commission, 2015). The aim of circular economy is to contrast the depletion of natural resources, protect the biosphere, and increase the valorisation of residues in the production cycles (European Commission, 2014b). In the wake of this new approach, efforts to look for renewable energy sources and proposing efficient reuse options for any valuable waste stream originated by the production cycles are intensified. In the last decade a partial transition from fossil fuels to renewable energy sources has been carried forward (Fernández-Delgado Juárez et al., 2015), and new waste streams emerged, consisting of the residues generated by the renewable energy plants. As of now, a significant part of the

energy supply in Europe is covered by biomass and, according to the National Renewable Energy Action Plans, its consumption in 2020 will be 22% higher than it was in 2012 (European Commission, 2014a). In particular, combustion is the most common technology for generation of heat and power from forestry biomass, and its residues consist of slag and ash (James et al., 2012), the production of which is destined to grow dramatically. Vassilev et al. (2010) estimated that the amount of ash produced worldwide annually from biomass combustion was approximately 480 million tonnes. James et al. (2012) reported that the biomass ash amount produced in 2005 in Europe ranged from 1.6×10^7 to 3×10^7 tonnes, and suggested that the future trend in the use of biomass for energy production could potentially lead to a production of 15.5×10^7 tonnes of ash in the EU-27 by 2020.

One possible reuse option for biomass ash could be the addition to organic waste undergoing the composting process so to recycle nutrient-rich materials into soil improvers, that is one of the actions promoted by the European Commission for the implementation of the circular economy approach (European Commission,

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2015). Composting is a biochemical conversion process aimed at degrading and stabilising organic substrates. Optimal conditions of moisture, aeration and heat-insulation are essential for the composting process (Bernal et al., 1998; Haug, 1993); in particular, moisture, temperature and pH unfavourable conditions, the scarcity of free airspace, and the shortage of nutrients can negatively affect the composting process and the final product quality. Some unfavourable conditions could be contrasted by using mineral additives to the composting mixtures (Himanen and Hänninen, 2009). The possibility of using residues of combustion processes has already been suggested for coal ash to which forest wood combustion residues are sometimes related (Belyaeva and Haynes, 2009; Fang and Wong, 2000; Wong et al., 1997, 2009). However, biomass ash differs significantly from coal combustion residues, and has peculiarities, such as wide variability in dependence to the more heterogeneous feed, combustion technology and operating conditions, and also higher macro-nutrients and lower sulfur total content (Cuenca et al., 2013; Fuller et al., 2013; Singh et al., 2011; Teixeira et al., 2013; Vamvuka and Kakaras, 2011; Vassilev et al., 2010; Xing et al., 2016). The recycling of biomass ash as an additive in the composting process has already been proposed by some authors (Fernández-Delgado Juárez et al., 2015; Koivula et al., 2004; Kuba et al., 2008; Kurola et al., 2011). Kurola et al. (2011) suggested that biomass ash may enhance the composting process and improve the final compost quality. The favourable effects exerted by ash included higher organic fraction degradation rates and the increase in Ca, K, Mg and P levels in the final composts (Fernández-Delgado Juárez et al., 2015; Koivula et al., 2004; Kuba et al., 2008; Kurola et al., 2011). In addition, Bougnom et al. (2010) who conducted field experiments using the ash-amended composts produced in the experiment described by Kuba et al. (2008), observed that the composts enriched with ash had an ameliorating effect on acidic soil due to its liming effect. On the other hand, some possible disadvantages were observed in the final compost produced by using ash, such as the increase in heavy metals content and salinity, and the dilution of nitrogen, that this kind of residues contains in small amounts or are lacking of (Fernández-Delgado Juárez et al., 2015; Kurola et al., 2011). However, these studies have only partially explored the subject; in fact, different types of ash are generated in a power plant (bottom, boiler and fly ash), whose properties vary significantly with the discharging point. The type of ash represents an essential information, since the chemical and physical characteristics of the residues drive the potential impacts on the process and the final compost quality. It is worth to underline that the studies conducted so far do not specify the type of biomass ash involved in the experiments, or use bottom ash only. This is aligned to the regulation existing in the few European countries (Austria, Belgium, Denmark, Finland, Hungary, and Poland) which allow the use of bottom and boiler ash as an additive in composting (European Commission, 2008). Indeed, in these countries only bottom and boiler ash are admitted, but it is fly ash that, together with boiler ash, typically displays the highest pH levels, thus acting as a liming agent, and content of macro- (such as Ca, K, Mg and P) and microelements (including Cu, Fe, Mn and Zn). Therefore, the nutrient intake resulting from the use of fly and boiler ash could confer compost with a higher added value and marketability (James et al., 2012). In particular, phosphorus is an essential nutrient that often constitutes the limiting factor for plant growth, and potassium is usually low in the composts derived from organic waste (Tittarelli et al., 2007). Fly ash also has physical characteristics, such as low bulk density and moisture, that could have a positive impact on the composting process (Asquer et al., 2015).

In order to provide a wider understanding on the use of biomass ash as an additive in the composting of organic waste, in the present work fly and boiler ash were used with the objective of

verifying the impact of their addition on the composting process and quality of the final composts. An experiment was conducted where the source separated organic fraction of municipal waste, mixed with wood prunings that served as bulking agent, was added with increasing amounts of a blend of fly and boiler ash. The evolution over time of the main process parameters was observed, the final composts were characterised, and the effects of the ash addition were discussed.

2. Materials and methods

2.1. Materials and experimental set-up

The boiler ash (BOA) and fly ash (FA) were sampled, respectively, from the super-heater placed after the boiler and the electrostatic filters of a full scale biomass combustion plant. A mixture of BOA and FA (named BASH in the manuscript) according to 71:29% wt/wt (50:50% vol/vol ratio), which corresponds to the shares that are actually produced in the thermal power plant, was used as additive during the composting tests. A 96-day long composting experiment was conducted using four static aerobic reactors filled with approximately 133 kg of organic fraction of municipal solid waste (OFMSW) and wood prunings (WP, used as bulking agent), mixed together according to the 70:30% wt/wt ratio, and amended with BASH. The biomass ash blend was added to the OFMSW+WP mixture in the amounts of 2%, 4% and 8% wt/wt in reactors that were called C2, C4 and C8, respectively. A fourth reactor did not contain ash and served as the control (C0). The choice of the amounts of ash to be added was decided on the basis of current European regulations which set limits to levels lower than 10–15% wt/wt, even with some more restrictive case, such as the Austrian Compost Ordinance, that sets a limit of 2% wt/wt to the total ash amount that could be used as an additive (Kuba et al., 2008). The chemical-physical characterisation of the OFMSW+WP mixture and the BASH blend used in this experiment

Table 1

Characteristics of the OFMSW-WP mixture and BASH (ash blend) used; standard deviation is indicated in brackets (<d.l.: below the detection limit; n.d.: not determined).

	OFMSW + WP	BASH
Moisture [%]	58.30 (0.01)	1.21 (0.02)
VS [%]	66.88 (0.03)	2.26 (0.15)
pH	5.09 (0.03)	12.77 (0.01)
EC [mS·cm ⁻¹]	4.22 (0.10)	26.38 (4.50)
TOC [%]	34.77 (1.97)	4.56 (0.02)
N _{total} [%]	2.05 (0.20)	<d.l.
C _{total} /N _{total}	16.96	n.d.
CaO [%]	2.37 (0.07)	29.01 (0.12)
MgO [%]	0.25 (0.02)	5.18 (0.07)
K ₂ O [%]	0.61 (0.01)	9.43 (0.14)
P ₂ O ₅ [%]	0.44 (0.01)	2.77 (0.05)
Na ₂ O [%]	0.35 (0.00)	1.18 (0.01)
Fe ₂ O ₃ [%]	0.34 (0.00)	2.61 (0.08)
Al ₂ O ₃ [%]	0.29 (0.02)	6.00 (0.14)
MnO ₂ [mg·kg ⁻¹]	116.93 (3.08)	2319.87 (0.01)
Be [mg·kg ⁻¹]	0.83 (0.00)	0.06 (0.00)
Cd [mg·kg ⁻¹]	<d.l.	2.80 (0.09)
Co [mg·kg ⁻¹]	1.66 (0.00)	9.83 (0.36)
Cr [mg·kg ⁻¹]	87.38 (1.07)	39.11 (0.72)
Cu [mg·kg ⁻¹]	17.76 (0.95)	191.47 (0.35)
Hg [mg·kg ⁻¹]	0.02 (0.00)	0.28 (0.02)
Ni [mg·kg ⁻¹]	43.69 (0.54)	27.45 (0.96)
Pb [mg·kg ⁻¹]	<d.l.	44.67 (0.73)
Sb [mg·kg ⁻¹]	1.25 (0.59)	1.04 (0.15)
Se [mg·kg ⁻¹]	0.83 (0.00)	1.31 (2.20)
V [mg·kg ⁻¹]	3.61 (0.48)	42.74 (0.44)
Zn [mg·kg ⁻¹]	56.64 (2.36)	371.06 (3.32)

Note. All values except for moisture, pH and EC are expressed on a dry weight basis.

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