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# Assessment of compost maturity by using an electronic nose

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ABSTRACT

The composting process produces and emits hundreds of different gases. Volatile organic compounds (VOCs) can provide information about progress of composting process. This paper is focused on the qualitative and quantitative relationships between compost age, as sign of compost maturity, electronic-nose (e-nose) patterns and composition of compost and composting gas at an industrial scale plant. Gas and compost samples were taken at different depths from composting windows of different ages. Temperature, classical chemical parameters, $O_2$, CO, combustible gases, VOCs and e-nose profiles were determined and related using principal component analysis (PCA). Factor analysis carried out to a data set including compost physical–chemical properties, pile pore gas composition and composting time led to few factors, each one grouping together standard composting parameters in an easy to understand way. PCA obtained from e-nose profiles allowed the classifying of piles, their aerobic–anaerobic condition, and a rough estimation of the composting time. That would allow for immediate and in-situ assessment of compost quality and maturity by using an on-line e-nose. The e-nose patterns required only 3–4 sensor signals to account for a great percentage (97–98%) of data variance. The achieved patterns both from compost (chemical analysis) and gas (e-nose analysis) samples are robust despite the high variability in feedstock characteristics (3 different materials), composting conditions and long composting time. GC–MS chromatograms supported the patterns.



## 1. Introduction

In accordance with the waste hierarchy, and for the purpose of reducing greenhouse gas emissions originating from waste disposal on landfills, the European directives about waste (European Union, 2008, 2009) point out the need to facilitate the separate collection and proper treatment of bio-waste in order to produce environmentally safe compost and other bio-waste based materials. Such waste, which includes biodegradable garden and park waste, when decomposing in landfills accounted for some 3% of total greenhouse gas emissions in the EU-15 in 1995. The Landfill Directive (European Union, 2009) obliges European countries to reduce the amount of biodegradable municipal waste that they landfill to 35% by 2016 (of 1995 levels) which will significantly reduce this problem. Composting has proven to be one of the most efficient and effective ways to manage these wastes, from both an economic and an environmental point of view. The composting process reduces toxicity, for example decreasing the concentrations of most pesticides (Büyüksönmez et al., 2000) and other organic pollutants present in feedstocks. Composting also reduces volume and moisture content of residues and transforms them into useful sources of organic matter for agricultural use contributing to enhanced soil quality and resource efficiency (Haug, 1993).

The composting process itself emits some gases into the atmosphere. Compost emissions have been studied in some length with widely varying results. They include non-greenhouse gases such as $NH_3$ (Nakasaki et al., 2001) and CO (Hellebrand and Schade, 2008). Though CO is not a direct greenhouse gas, CO emissions have indirect effects on climate through enhanced levels of tropospheric $O_3$ and $CH_4$ and it might affect local air quality in and near composting facilities (Hellebrand and Schade, 2008). Greenhouse gases such as nitrous oxide ($N_2O$), methane ($CH_4$) (Amlinger et al., 2008), and $CO_2$ and volatile organic compounds (VOCs) (Büyüksönmez, 2012; Büyüksönmez and Evans, 2007; Delgado-Rodríguez et al., 2012a; Komilis et al., 2004; Kumar et al., 2011) were also

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considered. The amount and type of emissions depends on a number of variables; the type and mix of feedstocks determine the molecules available for biochemical reactions, and their proportions. Feedstocks are considered the most important factor in determining what particular intermediate and potentially compounds develop (Büyüksönmez et al., 2007, 2012). Additional managing factors such as temperature, $O_2$ levels, humidity, pH and duration of composting are also of significance (Akdeniz et al., 2010; Blazy et al., 2014; Büyüksönmez and Evans, 2007; Delgado-Rodríguez et al., 2012b; Romain et al., 2005).

Odours coming from wastes are caused by substances such as some inorganic gases (ammonia and hydrogen sulphide) and VOCs released during the biodegradation of organic residues (Shareefdeen et al., 2005). Electronic noses (e-noses) have proven useful to monitor the odour emissions in composting (Littarru, 2007; Sironi et al., 2007), and the aeration conditions (Rajamäki et al., 2005). A significant relationship between the biological activity (measured by the dynamic respiration index), and the odour molecule production (measured by an e-nose), has been found during high-rate food-waste composting processes (D'Imporzano et al., 2008). Gutiérrez et al. (2014) studied the evolution of total VOC concentration with maturity time, although they concluded the e-nose was unable to accurately predict the odour concentration and maturity time.

The weight of evidence indicates that it could be feasible to determine compost age, as sign of compost maturity, from e-nose patterns, in the same way that an experienced operator can tell the condition of compost by its odour among other characteristics. However, to date, few efforts (Romain et al., 2005) have been made to do this.

The objective of this research was to find qualitative and quantitative relationships between compost maturity, expressed as composting time, and e-nose patterns obtained from pore gas of different industrial scale compost piles. A set of compost chemical parameters and composition of pile gases have been also compared.

## 2. Materials and methods

### 2.1. Composting facility

Compost and gas samples were taken from several composting windrows in a commercial composting facility located in Los Palacios, Seville province, SW Spain. Details about the selected composting piles (composting time, number of turnings) are shown in Table 1. Main feedstock at this facility were trimmings and cut branches from garden trees (windrows P4, P5, P14 and finished compost P17), being palm, pine and orange trees particularly abundant in yards and public gardens in the area. The maximum particle size after grinding was 15 cm. Finished compost (P17) was sieved in a 10 mm trommel. Some piles (PF2 and PF4) consisted of fine particles screened out from biomass used for energy in a different location (Huelva, SW Spain). In this case eucalyptus was the most common tree used in the energy plant. A pile composed of mature horse manure (M) was also included. Wheat straw was the main component in the horse bedding. This pile was installed at the facility 500 days ago. Then, after one year of composting compost batches form this pile were used when needed. Compost obtained at the facility was used to make potting soil and growing substrates by mixing with peat, coconut fibre and pine bark. The composting process was carried out in trapezoidal windrows whose dimensions were 5 m wide in their base, 2.5–3 m high, and 40–50 m long. In the case of piles PF2 and PF4 the pile height was 1 m. The composting process in the facility could be described as: not intensive, adapted to low water availability, moistening of windrows at start-up only, pile turning every 2 months to avoid excessive drying, residence time greater than 1 year keeping the windrows in the facility during the rainy seasons to take advantage of rain water. Composting under minimal technology level is a usual low-cost approach for green waste composting if a large, well isolated area is available (Haug, 1993).

**Table 1**
Composting piles.

| Pile name | Feedstocks | Composting time (day) | Pile turnings | Sampling date |
|---|---|---|---|---|
| P4 | Garden pruning | 106 | 1 | 06/11/2013 |
| P5 | Garden pruning, fines from biomas, 2:1 | 145 | 2 | 06/11/2013 |
| P14 | Garden pruning, rice husk, 2:1 | 423 | 5 | 18/11/2013 |
| P17 | Garden pruning | 510 | 8 | 18/11/2013 |
| PF2 | Fine particulate material from biomass | 58 | 1 | 29/09/2014 |
| PF4 | Fine particulate material from biomass | 111 | 2 | 29/09/2014 |
| M | Horse manure | 500 | 7 | 06/10/2014 |

### 2.2. Gas sampling and analysis

Pore gas samples were taken by drilling a gas probe (Compost Probe SON2IN, RAE Systems Inc., San José, CA, USA) into the windrow and pumping gas samples to a multi-gas analyser, to e-nose and to sampling bags for GC–MS determinations. Compost temperature was measured simultaneously by inserting a probe at the same depths. Determinations with multi-gas analyser and e-nose were done in triplicate and single samples were used for GC–MS. The probe was inserted to a depth of 0.2, 0.4, 0.6, 0.8 and 1 m for analyses with the multi-gas monitor (MultiRAE IR PGM-54, RAE Systems, San José, CA, USA) by using its integrated sampling pump with a flow rate of 0.2 L min$^{-1}$. This instrument incorporated sensors to determine the concentrations of $O_2$, $CO_2$, CO, total-VOCs and combustible (LEL sensor) gas. The VOCs sensor incorporated a 10.6 eV lamp for photoionization. Enough time (approximately 120 s) was left to purge the probe and sampling line and to obtain stabilized readings. The instrument does not detect water but its condensation on UV lamp could cause a loss of VOCs signal (Ojala et al., 2006). To avoid this effect, sampling lines were kept to a minimum and a Teflon filter (0.45 μm pore size) (RAE Systems, San José, CA, USA) was used as aerosol and particulate material trap. The instrument was calibrated by user by using standard gases contained in gas cylinders: 100 ppb$_v$ isobutene for VOCs, 0.88% CH4 for the combustible gases (LEL) sensor and 50 ppm$_v$ CO. Although $CO_2$ measurements were registered, these data were not used because $CO_2$ sensor was calibrated to 5000 ppm$_v$ and most of the readings overranged.

After using the gas monitor, e-nose measurements were performed at two depths in which aerobic (20 or 40 cm) or anaerobic (usually 40–60 cm) conditions were prevailing. In this work, PEN3 e-nose (Portable Electronic Nose, Airsense Analytics GmbH, Hagenover, Schwerin, Germany) was used. This e-nose has an array of 10 different metal oxide sensors (MOS) positioned inside a small chamber (1.8 mL). Orzi et al. (2010) described a similar e-nose with the same sensor configuration and a more general description on the basis and use of e-nose can be found in Romain et al. (2005). The analytical system has a special integrated sampling system, which by an automatic control (auto-ranging) prevents overloading of the sensors and also leads to better and faster qualitative and quantitative analysis. A time of 50 s was selected as stabilization time, after which sensor readings were taken during 10 s.

Gas samples were collected in 2 L Tedlar bags (Supelco, Bellefonte, PA, USA) with a vacuum pump from the aerobic and

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