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Composting municipal biosolids in polyethylene sleeves with forced aeration: Process control, air emissions, sanitary and agronomic aspects

R. Avidov [a,b], I. Saadi [a], A. Krassnovsky [a], A. Hanan [a], Sh. Medina [a], M. Raviv [c], Y. Chen [b], Y. Laor [a,*]

[a] Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, Newe Ya'ar Research Center, Israel
[b] Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Israel
[c] Institute of Plant Sciences, Agricultural Research Organization, Newe Ya'ar Research Center, Israel

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ABSTRACT

Composting in polyethylene sleeves with forced aeration may minimize odor emissions, vectors attraction and leachates associated with open windrows. A disadvantage of this technology is the lack of mixing during composting, potentially leading to non-uniform products. In two pilot experiments using biosolids and green waste (1:1; v:v), thermophilic conditions (>45 °C) were maintained for two months, with successful control of oxygen levels and sufficient moisture. Emitted odors declined from $1.5–3.8 \times 10^5$ to $5.9 \times 10^3–2.3 \times 10^4$ odor units m^{-3}-air in the first 3 weeks of the process, emphasizing the need of odor control primarily during this period. Therefore, composting might be managed in two phases: (i) a closed sleeve for 6–8 weeks during which the odor is treated; (ii) an open pile (odor control is not necessary). Reduction of salmonella, *E. coli* and coliforms was effective initially, meeting the standards of "Class A" biosolids; however, total and fecal coliforms density increased after opening the second sleeve and exceeded the standard of 1000 most probable number (MPN) per g dry matter. Compost maturity was achieved in the open piles following the two sleeves and the final compost was non-phytotoxic and beneficial as a soil additive.

1. Introduction

Compost in general is highly desired for sustainable agriculture, yet its manufacturing industry involves multiple environmental concerns. Most composting operations worldwide are based on open windrows technology of which odor control has long been recognized as a critical issue. Nuisance odors associated with composting processes representing a complex mixture of gases and volatile organic compounds (VOCs). Anaerobic byproducts (e.g. sulfur containing compounds, short-chain aliphatic acids) together with aerobic type byproducts (e.g. alcohols, ketones, esters and organic acids) (Eitzer, 1995; Homans and Fischer, 1989) and inorganic gases such as hydrogen sulfide (H_2S) and ammonia (NH_3) will finally determine the character, hedonic tone and the concentration of emitted odors (Laor et al., 2008; Schiffman et al., 2001). Recognizing the reality that the formation of odorous compounds is an unavoidable outcome of biodegradation processes, the solution is either to maintain sufficient distance between such operations and potential receptors (Forgie et al., 2004) or to move into enclosed facilities with forced-aeration that are equipped with odor treatment. Maintaining sufficient distance is not always practical, especially in densely populated regions. On the other hand, moving into enclosed facilities is not always economical as considerably more capital investment is required than for open windrows technologies (Renkow and Rubin, 1998).

In Israel, odor regulations become a bottleneck, preventing the potential expansion of organic matter recycling. As in other regions of the world, increase in environmental awareness and transition of urban population to areas that were previously rural, led to increased number of odor complaints (Gostelow et al., 2001; Sweeten and Miner, 1993). Thus, although more expensive, enclosed composting facilities are in many cases recommended or enforced by environmental authorities. Such facilities include covered static piles with forced aeration (e.g. GORE® covers) or indoor piles and different kinds of composting drums with biofiltration as the most common odor treatment technology (McNEVIN and Barford, 2000; Rappert and Müller, 2005). Alternatively, the EURO Bagging or Ag-Bag commercial technology is a relatively cheap enclosed system. Using this technology, the desired material is pushed into a plastic (polyethylene) sleeve while a perforated aeration pipe is laid on the bottom of the bag. Advantages of the system

* Corresponding author at: Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, Newe Ya'ar Research Center, P.O.B. 1021, Ramat-Yishay 30095, Israel.

E-mail address: laor@agri.gov.il (Y. Laor).

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include simplicity in construction and operation. Moreover, because of the minimal infrastructure needs, this technology may not require building permits. However, the main disadvantage is the lack of mixing during composting, which in turn may affect the stability and quality of the end-product. There are only a few studies that explored this technology: Roberts et al. (2007) reported effective composting of green waste, biosolids and paper processing waste. They revealed significant spatial gradients in temperature but no significant spatial differences in nutrients within the composting sleeve. McMahon et al. (2008) used three different composting mixtures based on timber products, poultry manure and green waste and reported a relatively short thermophilic phase (>45 °C) of about two weeks; yet, based on toxicity bioassays and plant growth trials, they suggested that their end products were suitable for agricultural use. Successful composting of biosolids and green wastes (Farrell, 2002) or catering waste with green waste and shredded paper (Farrell and Jones, 2010) were also reported. On the other hand, other studies raised questions regarding moisture heterogeneity and especially dryer conditions near the aeration pipe (U.S. Army Corps of Engineers, 2010) or regrowth of pathogens (Williamson et al., 2006).

In the case of biosolids composting, it may be possible to set up the sleeves within the area of the wastewater treatment plant, thus eliminating the cost and nuisance odors associated with sewage sludge transportation. Notably, only Class A biosolids have been allowed in Israel since 2004 for all types of land use (the definition of Class A was adopted from the USEPA, meaning that the geometric mean of the density of fecal coliforms determined from at least seven samples should contain less than 1000 most probable number (MPN) per g of dry material or the arithmetic mean of *Salmonella spp.* determined from at least seven samples should be less than 3 MPN per four g of dry material (U.S. EPA, 1993)). In order to achieve successful composting of biosolids, it is necessary to mix it with green wastes for reducing water content, increasing carbon/nitrogen ratio (C/N) and improving the texture in order to allow adequate aeration of the raw mixture. Considering the limited literature regarding the sleeves technology, there are several aspects that deserve in-depth investigation, mainly related to the sanitary safety (elimination of human pathogens) as well as the dynamics of air emissions during the process. Other practical and process control aspects need more investigation as well, including aeration efficiency, dynamics and spatial variability of compost properties, indicators for the appropriate time for sleeve opening and the need for additional maturation in an open pile.

Thus, the aim of the present study was to investigate the suitability of polyethylene sleeves with forced aeration for composting of stabilized municipal sewage sludge while obtaining a final product (compost) that can be defined as "Class A" biosolid and be appropriate for agronomic use. For that we (i) measured physical-chemical characteristics of the composting process; (ii) analyzed odor and gases emissions at the exit port of the sleeve; and (iii) evaluated the phytotoxicity during composting and the agronomic value of the final product.

2. Materials and methods

2.1. Composting in polyethylene sleeves with forced aeration

Two pilot scale experiments were conducted in Newe Ya'ar Research Center during July 6, 2014–January 20, 2015 (first experiment) and May 15, 2015–December 21, 2015 (second experiment); each experimental setup consisting of a polyethylene sleeve of 1.5-m diameter and 20-m long. The raw mixture in both experiments was 1:1 (v:v) of anaerobically digested sewage sludge and shredded municipal green waste (≤30 mm) with initial C/N ratio of 15.9 and 15.0 for the first and the second experiment, respectively. This C/N ratio range is relatively low but it was not corrected before experiments as it represents a common practice in the Israeli sewage sludge composting industry. For the first experiment we used anaerobically digested primary and secondary sewage sludge from the wastewater treatment plant of Herzliya city (located in the central coastal plain of Israel) and for the second experiment we used a stabilized secondary sewage sludge form Nir Etzion wastewater treatment plant (located in a rural area on the northern coastal plain of Israel). A Euro Bagging composting machine (CM 1.5 CCS) (Fig. 1a) was used to pack the sleeves while at the same time a perforated pipe (63.5 mm diameter) was laid at the bottom of the sleeve. The perforated pipe was connected at one end to a piece of solid (non-perforated) pipe that was connected to a blower. Another piece of a solid pipe was installed at the other end of the sleeve for monitoring odor and gases emissions. On a real application of this technology, this end might be connected to an odor treatment unit (Fig. 1b).

The packed sleeves were controlled by a programmable logic controller (PLC); (Vision 570, Unitronics, Israel) that was connected to a blower (U/HC 201, Induvac, Zoetermeer, Netherlands), nine temperature sensors (PT-100; Madid Ltd, Haifa, Israel) and six oxygen sensors (SO-110, Apogee Instruments, Inc., Logan, UT, USA). The PT-100 were constructed in three 1.2-m long stainless steel rods, each containing three sensors at 35, 75, and 115 cm from the top. The blower operation (on/off) was controlled by temperature and oxygen thresholds, based on the average reading of all 9 temperature and 6 oxygen sensors. The PT-100 rods were placed along the sleeve, one rod at each third of the sleeve length. Notably, heat conduction along the rod could result in underestimation of temperature vertical gradients. In a preliminary test we placed the rod horizontally in a tube packed with water-saturated sand to which boiled water was added at one end and iced water to the other end and compared sensors readings with those obtained by a manual thermometer. The results showed that a gradient of ca. 12 °C across the rod (measured by the manual thermometer) could be reduced to ca. 9 °C (recorded by the sensors) because of this effect. The blower was turned on when temperatures exceeded 55 °C or when oxygen concentrations decreased below 12%. Actual flow rates were not controlled but affected by the changing bulk density of the compost (see results). Controller outputs included sensors readings every 10 min or at the times when the blower was turned on. Flow velocities at the exit of the sleeve were measured using an anemometer (Kestrel 4000 weather meter; Nielsen-kellerman LTD; Birmingham, MI, USA).

The full composting cycle in both experiments included two phases: one phase at the closed sleeve and a second one in an open pile. The sleeve of the first experiment (sleeve #1) was opened after 118 days and the sleeve of the second experiment (sleeve #2) was opened earlier, after 62 days only (temperatures dropped below 45 °C) to explore the possibility of shortening the phase in the closed sleeve. Temperature was monitored in the open piles using the same PT-100 rods (two rods in the first experiment and three rods in the second one). The open pile of sleeve #1 was turned once again 157 days since composting started. Composting was terminated 201 days after starting the experiment, when the temperature cooled down and stabilized around 30 °C (average daily ambient temperature during the past week was 10.3 °C). The open pile of sleeve #2 was turned three more times after pile setting, 88, 119, and 187 days since composting started; two turnings were scheduled at month intervals and the last turning was done when pile temperature dropped to ca. 30 °C. Composting was terminated 220 days since the start of the experiment, when the temperature cooled down and stabilized around 30 °C (average daily ambient temperature during the past week was 13.5 °C).

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