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Research article

The use of biological waste as a source of low-temperature heat for hotbeds in spring in north-eastern Poland

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ABSTRACT

This article proposes a method for using biological waste, including kitchen waste and garden waste, as a substrate for hotbeds. Hotbeds have been long used in home gardens, but most of them are supplied with animal manure, usually horse manure. In this study, the temperature of ambient air, soil temperature and temperature distribution in a hotbed and a cold frame were measured with a thermographic camera. The measurements were performed in three experimental treatments – one hotbed, one cold frame and in the garden. Each treatment was sown with radishes (*Raphanus sativus*). The experiment began on 7 April, and temperature was measured until the temperature of garden soil reached the temperature inside the hotbed and the cold frame. After the experiment, the hotbed was left in place until the end of August to complete the composting process and grow other plants. The amount of heat generated inside the hotbed during the experiment was calculated, and the thermal efficiency of the hotbed was compared with the maximum heat capacity of composting. During the experiment, the hotbed generated 98.7 MJ of heat, and its thermal efficiency reached 12% of maximum capacity. Radishes grown in the hotbed were harvested 5 days earlier than those grown in the cold frame and 12 days earlier than those grown in the garden treatment. The compost produced in the hotbed fully meets Polish Standards for organic fertilizers. The proposed solution minimizes the quantity of biological waste collected from households.

1. Introduction

In the modern world, growing levels of consumption and higher living standards generate unprecedented problems (Lehmann and Crocker, 2012) An increase in global energy consumption contributes to carbon dioxide emissions and air pollution. In developed countries, higher waste generation per capita leads to environmental degradation and climate change (Angel et al., 1990; Bölük and Mert, 2014). These problems had been fully identified in the second half of the 20th century in the industrialized world, but they have not been completely resolved in less developed countries (Baker, 1997; El-Hinnawi and Hashmi, 1987).

Growing levels of solid municipal waste pose a significant problem around the world (Karak et al., 2012; Mukhtar et al., 2016). In many developing countries, solid waste is deposited in landfills or, worse yet, is incinerated (Wiedinmyer et al., 2014; Tue et al., 2017; Pongpiachan et al., 2017). Waste segregation and recycling are environmentally-friendly solutions to waste management, but the zero waste strategy exerts the smallest impact on the natural environment. Waste recycling programs have been implemented in many countries, but recycling rates are still very low in some countries, including Poland (Bernstad, 2014; Edjabou et al., 2015; Kierzkowska, 2017). The main reasons for the low effectiveness of waste recycling are low levels of public awareness regarding the correct sorting procedure (Suthar and Singh, 2015) and the residents' reluctance to keep several waste sorting containers in households (Khan et al., 2016; Sahimaa et al., 2015). The collection, processing and diversion of sorted waste require large amounts of energy and contribute to CO_2 emissions (Bernstad, 2014; Dong et al., 2014). In addition, various types of sorted waste have to be collected at different time intervals (Di Maria et al., 2016; Ravindra et al., 2015). Glass waste can be collected once a month. In contrast, wet waste, including biological kitchen waste and mixed waste spoils easily. Therefore, it has to be collected at least once a week in Central Europe and more often in countries with a warmer climate, regardless of the generated volume of waste (Kinobe et al., 2015). The above decreases the effectiveness of waste transport and increases fuel consumption per kilogram of collected waste (Gallardo et al., 2015; Guerrero et al., 2013). A strategy for minimizing the quantity of biological waste generated in households was proposed as part of a hierarchical approach to integrated waste management (Tatàno et al.,

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2015). The zero waste concept was developed in the next stage of the process. The zero waste concept minimizes the amount of waste collected from households. The main aim of this waste management strategy is not to eliminate the generation of waste, but to process and reuse waste close to the source and to reduce waste transports (Zaman and Lehmann, 2013; Zaman, 2015). The zero waste concept is particularly useful for managing wet biological waste (Song et al., 2015). If biological waste were managed in its entirety at the source, the remaining types of waste could be collected and transported less frequently. For this reason, special emphasis should be placed on solutions that effectively reduce the amount of biological waste that is landfilled (Hottle et al., 2015).

There are various methods for processing biological waste, including biofuel production (Zhang et al., 2014). Two solutions are most popular in practice (Kiran et al., 2014). The first is anaerobic digestion with the production of biogas which can be used in energy generation (Fisgativa et al., 2016), for example in cogeneration plants. However, this solution is relatively complex, and it requires large waste streams and dedicated infrastructure. For this reason, it is used only to process large amounts of biological waste, and it does not eliminate waste transport (Snider et al., 2014). The second solution is composting (Gunders, 2015; Herbert, 2010). Composting is a natural process that takes place in the presence of oxygen. An important advantage of this solution is that even small amounts of biological waste can be effectively managed (Van der Wurff et al., 2016). Biological waste can be composted collectively, e.g. in municipal composting plants where the adverse effects of composting, such as odor and greenhouse gas emissions, can be minimized with the use of special additives (Cerda et al., 2018; Waqas et al., 2017). However, it is also possible to composting biological waste in smaller quantities - up to the amount produced in single households (Faverial and Sierra, 2014; Mihai and Ingrao, 2016) Kitchen waste and garden waste can also be effectively composted in households (Tatàno et al., 2015). The zero waste strategy recommends composting as the most effective method for managing biological waste at the source. This solution decreases energy consumption associated with waste transport. Fast-spoiling waste is composted, therefore, the remaining types of waste can be collected less frequently, which increases energy efficiency per kg of waste (Vázquez and Soto, 2017).

Composting produces compost, highly nutritious fertilizer that can be used in home gardens (Van der Wurff et al., 2016). Compost is a product of biological waste (food waste, green waste), and it is generally free of toxic compounds such as heavy metals (Neugebauer and Sołowiej, 2017; Pandey et al., 2016b). Before composting, waste has to be adequately sorted to guarantee the biological safety of compost. The composting process involves a thermophilic phase during which the temperature of the substrate increases substantially (sometimes in excess of 60 °C), which eliminates bacterial pathogens and sanitizes the obtained compost (Neugebauer et al., 2014; Sudharsan Varma and Kalamdhad, 2015). Compost sanitation standards, including minimum composting temperature and duration of the composting process, in various countries are presented in Table 1 (HMJ Consulting Limited, 2008).

In rare cases, compost is heated to accelerate and stabilize the composting process (Pandey et al., 2016a). In general, compost piles containing biological waste do not require additional heating. On the contrary, heat generated during composting can be harnessed to increase the energy efficiency of the entire process (Neugebauer et al., 2014). There are various methods for recovering heat from the compost pile and using it for energy generation (Chambers, 2009; Smith et al., 2016), including with the use of coiled pipes (Roman, 2015). In this study, biological waste was a source of heat for hotbeds. In a typical hotbed, manure characterized by a desirable C:N ratio and high density is placed under a layer of soil (Vincene and Garver, 1935; Warnock, 2013). Heat generated by the composted substrate increases the temperature inside the hotbed and accelerates plant growth. Hotbeds are generally supplied with manure, and the use of food wastes has not been documented in the literature to date.

Table 1
Compost sanitation standards in selected countries (Brinton, 2000).

Country	Composting method	Temperature/Pathogens
Australia	All methods	> 55 °C for at least 3 days, with a margin for variations and lower temperatures
Germany	Open windrow	> 55 °C for 2 weeks, or > 65 °C for 1 week
	Closed/In vessel	> 60 °C for 1 week
	In all new facilities, absence of the following in 25 g:	Human/Veterinary Hygiene: *S. senftenberg* W775
	Elimination of added:	Phyto-hygiene: Tobacco-mosaic Virus (TMV) & *Plasmodiophora brassicae*
Austria	All composts	> 60 °C for 6 days, or > 65 °C for 3 days
Switzerland		> 55 °C for 3 weeks, or > 60 °C for 1 week, or proven time-temperature relationship
Denmark	All composts	> 55 °C for 2 weeks

A cold frame supports plant cultivation in spring and autumn in the moderate climate. It is composed of a box (made of wood or other materials) which is set partially in the ground and covered with glass or, increasingly often, plexiglas panels. The only source of heat inside the cold frame is solar radiation which is retained for longer than outdoors.

The aim of this study was to determine whether biological waste (food waste and green waste such as dried leaves) collected in fall and winter can be used effectively as a source of heat in hotbeds in north-eastern Poland.

2. Materials and methods

The following research hypothesis was formulated based on an analysis of the literature: organic food waste combined with garden waste (leaves) can be effectively used as a source of heat in hotbeds in north-eastern Poland.

The above hypothesis was verified experimentally in the following stages:

1. A hotbed and a cold frame were built.
2. Temperature was measured on the surface of soil with a thermographic camera.
3. Soil temperature was measured at a depth of 2 cm.
4. Radishes were sown in a hotbed, a cold frame and in the garden, to compare their yields.
5. The growth and yield of radishes in each experimental treatment were evaluated.
6. Plants inside each treatment were watered according to need. In the hotbed, soil was separated from compost by a layer of perforated film, and excess soil moisture reached the compost layer during watering. The compost layer was not watered separately.
7. Compost quality was evaluated at the end of the growing season in September 2017. The chemical composition of compost was determined.

Two chambers with internal dimensions of 97 × 97 cm each were built (Fig. 1) to verify the research hypothesis. The structure of each chamber is presented in Fig. 1: a – hotbed; b – cold frame; c – transparent cover; d – soil; e − compost; f – permeable mesh on the sides of the chamber for compost aeration. The chambers were built in 2 h (without purchasing additional components). The first chamber was filled with 6 kg of composted humus (to inoculate the substrate), topped with a 25 cm layer of mixed biological waste (Table 2). The sides of the first chamber were left open (secured with mesh to prevent waste from