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Ending composting during the thermophilic phase improves cultivation substrate properties and increasing winter cucumber yield

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ABSTRACT

In the world, 10 billion tons of solid wastes were produced each year. Composting is a better method for solid waste management. Vegetable production now tends to be soilless cultivation. However, completed compost is not suitable for vegetable cultivation. So we studied bagasse (BS), corncobs (CC) and sawdust (SD) as composting materials and investigated stopping in the thermophilic phase for different durations (35, 45, and 65 days). Subsequently, cucumbers were transplanted into nine composted samples mixed with vermiculite at a ratio of 1:1 (v/v). The results obtained during the composting of the three composts (BS, CC and SD) showed that composting for 35 and 45 days increased the root temperature by 1.0–2.2 °C during January and February compared to the effects of composting for 65 days. In addition, microbial community numbers were significantly increased ($P < 0.05$) by composting for 35 and 45 days compared to those observed when composting for 65 days. Additionally, composting for 35 and 45 days resulted in the highest net leaf photosynthesis rate, total dry matter and cucumber yield among all treatments. Bacterial community numbers, net photosynthesis rate and physico-chemical parameters (bulk density, water-holding porosity, pH, total K (TK) and TOC) had a positive correlation with yield. Therefore, composting for 35 days creates a suitable substrate for cucumber production and facilitates the use of agricultural waste to achieve significant ecological and economic benefits.

1. Introduction

The inadequate treatment of solid waste has become a major issue in the fields of public health, economic development and living environment. In the world, 10 billion tons of solid wastes were produced each year, and 3 billion people lack effective solid waste disposal methods. Direct backfill and centralized incineration are typically performed to process solid waste, but these methods have negative impacts on the environment. Generally, these waste products are burned, but incineration causes great harm to the environment. Incineration of waste generates could induced large amounts of carbon dioxide then resulting in greenhouse effect (Han, 2015). According to previous studies, solid waste composting treatment is better than burn-and-bury treatment because this approach reduces environmental pollution, and composted agricultural waste products have a certain economic value (Su et al., 2016). Composting of organic wastes is a biooxidative process involving the mineralisation and partial humification of the organic matter, leading to a stabilised final product, free of phytotoxicity, pathogens and weed seeds, and with certain humic properties (Onwosi et al., 2017).

Nowadays, the cultivation of vegetables in protected fields is more and more inclined to soilless cultivation. Composted solid waste can also be used in soilless culture substrates. As shown in numerous studies, the replacement of nursery substrates for conventional cultivation with composted agricultural waste has achieved good results (Liu et al., 2006; Yang et al., 2016). Corn stalks (Cao et al., 2012), rice husks, straw (Song et al., 2013), mushroom residue (Xu et al., 2012), grape branches (Baran et al., 2001) and willow branches (Altland and Krause, 2009) have been used as nursery substrates. Additionally, cotton stalks and slag are useful as cucumber cultivation substrates after 1:1 mixing (Zhang et al., 2013).

Agricultural cultivation is wide-ranging in China. Rice, wheat, corn and other crops produce large amounts of agricultural products as well as agricultural waste. Recently, organic agricultural

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waste recycling has received significant attention in the context of agricultural waste treatment in China (Jiang et al., 2005). Corncobs (CC) are a major cash crop in northern China. However, it is difficult to degrade CC under natural conditions. For agricultural purposes, CC are often blended with other materials to cultivate edible mushrooms but are rarely used as a substrate for vegetables (Wu et al., 2009). It is also difficult to directly use sawdust (SD), another common agricultural waste product, as a soilless cultivation substrate. Bagasse (BS) and SD are used as organic fertilizers for sugar cane planting in southern China or as agricultural culture media for flowers and mushrooms (Huang et al., 1995; Liu, 1997).

As of 2014, China's annual output was 20 million tons of BS, 45.9 million tons of CC, and 400,000 tons of SD (Wang et al., 2016; Liu et al., 2017). These represent large quantities of agricultural waste. BS, CC and SD are able to undergo composting, but the amount of time required is generally more than two months, as is the time required to obtain and consume raw materials. After the compost is completed, at least one half of the raw material will be wasted (Chandel et al., 2012; Yousefi et al., 2013; Hanajima, 2014). Traditional organic fertilizers need to be fully decomposed, and now the treatment of organic cultivation substrates is also based on completed decomposition (Yang et al., 2016; Shi et al., 2016). No one has studied the effects and causes of ending the composting process to warm plant root and induced winter plant productivity. Composting is a process of microbial activity, so we hypothesized that when the process of composting is interrupted at some time during composting, microbes will continue to activate slowly and generate heat during plant growth when incompletely composted organic materials is used for cultivation substrates, which would promote plant growth especially during low temperature season. For developing countries, the cost of artificially heating the greenhouse in winter is high and there is no way to achieve. And ending the composting time early can save the time of composting and avoid waste of materials.

Our laboratory conducted preliminary experiments and observed that the composting times of cotton straws were 30 days and that the composting products were more suitable for use as soilless culture substrates, thus eliminating the need for extended composting, reducing the cost of raw materials, and increasing output (Zhang et al., 2013). However, the reason why incomplete compost can be used as a more suitable cultivation medium is not clear. Some previous studies have shown a close relationship between microbial properties and crop productivity in agricultural production systems (Tian et al., 2011; Gao et al., 2015). During winter, the compost may heat the cucumber rhizosphere, increasing plant biomass and yield. The objective of this study was to determine the best composting time interval to render BS, CC and SD suitable for soilless cultivation; the effects of different composting materials on cucumber were investigated by studying the physical and chemical properties of the substrate. In this study, we also researched the relation between plant yields, microbial parameters, leaf net photosynthesis rate and physico-chemical parameters. High-quality compost not only improves the ecological environment but also facilitates beneficial environmental cycles, sustainable agricultural development and the safe and efficient standardized production of organic vegetables in organic soilless cultivation.

2. Materials and methods

2.1. Composting

2.1.1. Composted materials

Sawdust (*Populus* L.) and corncob (*Zea mays* Linn.) were obtained from farmland in Beijing, while bagasse (*Saccharum officinarum*) was collected from a Guangxi farm (Guangxi, China). The characteristics of these materials are shown in Table 1. Urea and $CaSO_4$ were obtained from a biological pharmaceutical company (Beijing, China). A microorganism reagent was obtained from the Jing Pu Yuan Company (Beijing, China).

2.1.2. Experimental design of composting

There were three different materials in the experiments: bagasse (BS), corncob (CC) and sawdust (SD). The compost mixtures included plant materials, urea, $CaSO_4$ and a microorganism reagent. A total of three compost treatments with four replications were tested. The composting pile was 0.8 m in height and 1.5 × 1.5 m in width. The compost of each treatment weighed approximately 300 kg and was evenly mixed before composting. Each composting mixture (300 kg) was added to 1 kg of microorganism reagent and 1 kg of $CaSO_4$. The composition of the microorganism reagent was *Bacillus subtilis*, *Aspergillus oryzae*, *Saccharomyces cerevisiae*, *Geotrichum candidum* and *Aspergillus niger*. $CaSO_4$ prevents ammonia volatilization during the composting process. After moistening of the materials, the initial C:N ratio of the compost for each treatment was adjusted to 25:1 by adding urea. Finally, the moisture content of each composting treatment was 50–60% after mixing (by weight). The volume of water that was applied per kg of BS, CC and SD was 0.25 L, 0.67 L and 0.48 L respectively. After thorough mixing, composting mixtures were placed in a greenhouse and allowed to decompose for 65 days. The composting pile was turned every 3 days by forklift before 10 days, and then the pile was turned mechanically every 10 days. An S100 temperature sensor (Shenzhen Temperature Meter Factory, Shenzhen city, China) at a height of 50 cm above the floor was connected to a digital thermometer to automatically record data. There are four replicates in the composted process. There are four piles of every material.

2.1.3. Composting sample preparation

Compost samples were taken at 3, 6, 9, 15, 25, 35, 45, 55 and 65 days after thorough mixing. To ensure representative sampling, four longitudinal sections were randomly obtained from different parts of each compost treatment, and then the samples from the same pile were mixed (Liu et al., 2011). All samples were divided into two portions; one was stored at −20 °C, and the other was sieved through 0.5 mm and stored after drying in an actual environment. One hundred kilograms of compost was removed from each treatment group at 35, 45 and 65 days and dried for subsequent planting experiments. The average ambient temperature and relative humidity during the composting process of 35, 45 and 65 days was 27 °C, 24 °C, and 21 °C and 66%, 49%, and 59% respectively. The 100-kg compost samples were tiled on the ground, turned twice daily, and dried for approximately 15 days.

2.2. Plant growth tests

2.2.1. Experimental design of plant growth tests

Cucumber (*Cucumis sativus* L.) (cv. Zhongnong No. 16) seedlings were grown in plugs until the seedlings had two true leaves; then, the seedlings were transplanted into 8-L plastic pots in a greenhouse at the Jin Liu Huan Agricultural Industrial Company (Beijing) on November 30, 2015. The height of the pot was 22.5 cm and the diameter was 34 cm. Before transplantation, the pots were filled with compost obtained from each treatment group after 35, 45 and 65 days for a total of nine treatments. Compost was mixed with vermiculite at a ratio of 1:1 (v/v). A temperature sensor (Zigvine, Beijing, China) located 10 cm above the bottom of each pot was connected to a digital thermometer (Zigvine Meter Factory, Beijing, China) to automatically record temperature data.