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Re-using Sprout Growing Medium and Other Agricultural By-products for Compost Production

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Annually, a large volume of sprout growing media is wasted following use, which can result in serious environmental pollution at sprout production areas as well as resource wastage. Sprout growing media are often made from difficult to biodegrade lignocellulose-rich materials; however, they also have high organic matter (OM) content and rich nutrients, making them reusable in many applications. Therefore, taking full advantage of spent sprout growing media (SSGM) and combining it with other agricultural by-products could produce organic fertiliser and environmentally-friendly solution with high economic efficiency. The present study involved 4 experimental formulas for thermophilic composting (1 control formula with 100 % SSGM and three mixed formulas with 60 % SSGM and 40 % different by-products such as straw, cow dung and soybean residue). During the composting process, the physicochemical properties changes of composting heaps were determined. The temperature of compost heaps reached their maximum after 3 d (45 – 72 °C), then gradually reduced to the value equal to the environmental temperature at the end of composting. Moisture content, pH, organic matter and C: N ratio ranged between 57.57 - 69.23 %, 5.16 – 6.96, 29.72 - 82.37 % and 12.06: 1 – 30: 1, respectively. After 63 d of composting, the nutrient content of composts increased with the highest value of total nitrogen (1.46 %) and potassium (4.24 %) using formula CT2, highest total phosphorus using formula CT4 (1.5 %), and highest OM using formula CT4 (55.44 %). The heavy metal content (Cu, Zn, Pb, Cd, As) of all compost products was under permitted standards, and they were not contaminated with pathogenic bacteria (*Salmonella spp.*, *E. coli*). The evaluation of compost maturity based on using seed germination and root growth testing indicated that compost products were mature. The results of this study indicate that the treatment of SSGM according to formula CT2 is most suitable for producing high-quality compost and solving the problem of waste causing environmental pollution in sprout production areas.

1. Introduction

Vietnam is a country with long-standing agricultural production. Every year, the number of agricultural by-products discharged into the environment is very large. Many of these by-products remain untreated for their effective re-use, this can cause resource wastage. In recent year, the sprout production industry has grown in many localities of Vietnam. The main characteristic of sprout production is short-term harvesting (after 5 -7 planting d). Therefore the amount of spent sprout growing media (SSGM) released from production facilities daily is very large. Most growing media are only used once and then discarded directly into outdoor heaps at production areas, resulting in environmental pollution. Currently, in Vietnam, not many methods exist to treat sprout growing media in Vietnam. In several areas, SSGM was mixed with lime and other residues to make hydroponic media or to apply to fruit trees (Bui, 2011). Sprout growing media are often made from difficult to biodegrade lignocellulose-rich materials, though they also have a high organic matter (OM) content and rich nutrients; as such, they can be reused for many purposes. Therefore, taking full advantage of SSGM and combining it with other agricultural by-products to produce organic fertilizer represents an environmentally-friendly solution with high economic efficiency. Composting is one of the most desirable methods for treating waste to produce organic fertilizer (Sanadi et al., 2018). The C: N ratio of the initial material mixture recommended for composting is 20: 1 – 40: 1 dry weight (Gar and Tothill, 2009). A higher C: N ratio leads to a slowing of the decomposition process, while a lower ratio causes higher NH_3 emissions (Anwar et al., 2015).

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To the best of the authors' knowledge, using a combination of SSGM and other agricultural by-products to produce compost has not been researched to date. Using a combination of SSGM and other agricultural by-products, the present research was undertaken to take full advantage of SSGM.

2. Materials and methods

2.1 Composting materials

SSGM (used growing medium derived from coconut coir pith and discarded sprouts roots and lower stems) was taken from sprout production facilities in Hanoi city, Vietnam. Additional agricultural by-products such as dry cow dung, rice straw and soybean residue used for mixing with SSGM were also taken in Hanoi city. Organic materials (except dry cow dung) were pre-treated by cutting into small pieces approximately 2 – 3 cm in length, which were then dried under sunlight. Total organic carbon, total N and the moisture content of all dry materials were determined before composting. A microbial preparation (COMPOST MAKER) with additives was produced at the Soils and Fertilizers Research Institute, Vietnam and includes strains of cellulose-degrading, insoluble phosphate-dissolving, proteolysis, fermentation and deodorization microorganisms.

2.2 Experimental design for composting

The composting process was carried out in 120 L plastic containers with lids. Each plastic container was drilled with 25 holes (1 – 2 cm diameter) on the sides, with 8 holes (1 cm diameter) at the bottom and 5 holes on the lid. A plastic basin was placed under each plastic container to catch the leachate. The incubation system was designed to ensure that the composting process would be conducted under aerated conditions, while the collected leachate could also be used to water the compost pile when it became dry. The study established four experimental formulas for thermophilic composting: one control formula with 20 kg (100 %) of SSGM and three mixed formulas in proportions (weight basis) of 12 kg (60 %) SSGM and 8 kg (40 %) of another by-product such as rice straw, cow dung or soybean residue (see Table 1). Each formula was supplied 200 g of COMPOST MAKER and was adjusted to a near-neutral pH using 1 L of 1 % lime water. The initial moisture content and C: N ratio of mixtures were also adjusted to reach approximately 60 % and 30: 1, respectively, to facilitate the decomposition of organic compounds by microorganisms. After mixing the materials, the lids were covered on incubation containers. The mixtures were turned once per week for aeration and substrate homogenization.

Table 1: Experimental formulas for composting

Formulas	Materials (%)	Microbial preparation (g)
CT1 (control)	100 % SSGM	COMPOST MAKER (200 g)
CT2	60 % SSGM + 40 % Rice straw	COMPOST MAKER (200 g)
CT3	60 % SSGM + 40 % Cow dung	COMPOST MAKER (200 g)
CT4	60 % SSGM + 40 % Soybean residue	COMPOST MAKER (200 g)

2.3 Sampling and physicochemical and biological analysis

Samples were collected every 7 d to determine the moisture content, pH value, and C: N ratio. Samples collected on the final day of incubation were used to determine the physical, chemical and biological characteristics of the final compost products. Compost samples comprised of sub-samples taken from three different points in a pile and evenly mixed to ensure typical sampling. Ambient and composting pile temperatures were measured daily at 4 p.m. by using a digital thermometer. Determination of the lignocellulosic composition of SSGM was conducted according to the procedure described by Mansor et al. (2019). Moisture content was determined using the gravimetric method. The pH in H_2O was measured according to TCVN 5979:2007 – ISO 10390:2005). Total carbon and OM (%) were determined using the Walkley-Black method (TCVN 9294:2012). Total nitrogen was analyzed using the Kjeldahl method (TCVN 8557:2010). Total phosphorus was analyzed according to the spectrophotometric method (TCVN 8563:2010). Total potassium was measured using a flame photometer (TCVN 8562:2010). Heavy metals (Cu, Zn, Pb, Cd) were determined by flame absorption spectrometric methods (TCVN 6496:2009 – ISO 11047:1998) and As was determined using atomic absorption spectrometry (TCVN 8467:2010 – ISO 20280:2007). Pathogenic bacteria (*E. coli, Salmonella spp.)* were tested according to TCVN 6846:2007 – ISO 7251:2005 and TCVN 4829:2005 – ISO 6579:2002.

2.4 Method for the assessment of compost maturity

Compost product maturity was assessed using seed germination and root growth tests presented in method 05.05-B of Test Methods for the Examination of Composting and Compost (TMECC) (Thompson, 2002). A 1: 3 (w/v) mixture of compost samples and distilled water was shaken for 1 h and passed through filter paper. A 10x dilution was made with 10 mL of filtrate and 90ml of distilled water. Then, 10 mL of each test solution (distilled water, 10x diluted extract and full-strength extract) was added to 7.5-cm filter paper placed in a sterilized 9-cm Petri dish. Ten radish (*Raphanus sativus* L.) seeds were evenly spaced on the paper in each dish. The dishes were sealed with Parafilm and incubated in the dark for 48 h at 25 °C. Experiments were repeated five times. After the incubation period, the root lengths and number of germinated seeds were determined. Indicators with distilled water were used as a control. Germination index (GI) was calculated as Eq(1):

$$GI = \frac{Mean\ seed\ germination\ for\ treatment}{Mean\ seed\ germination\ \ for\ control} \times \frac{Mean\ root\ length\ for\ treatment}{Mean\ root\ length\ for\ control} \times 100\ \% \quad (1)$$

3. Results and discussion

3.1 The properties of spent sprout growing medium

SSGM was the main material used in all experimental composting formulas. Its properties were determined before incubation and indicated that SSGM had high lignocellulosic content with cellulose, hemicellulose and lignin percentages of 32.42, 6.19 and 26.54 %, respectively. This residue had a low moisture content (36.53 %) and a weak base reaction with pH 7.45. SSGM alkalinity could be affected by the growing medium pre-treatment process with lime, which was performed to alleviate the lignocellulosic content of initial material (coconut coir pith). The OM content of SSGM was quite high (76.36 %), and total nitrogen, total phosphorus and total potassium contents were 0.51, 0.52 and 0.56 %, respectively. Moreover, the C: N ratio of SSGM was 68: 1.

3.2 Changes in physicochemical parameters during composting

Temperature, moisture content, pH and C: N ratio changes during composting were monitored (see Figure 1).

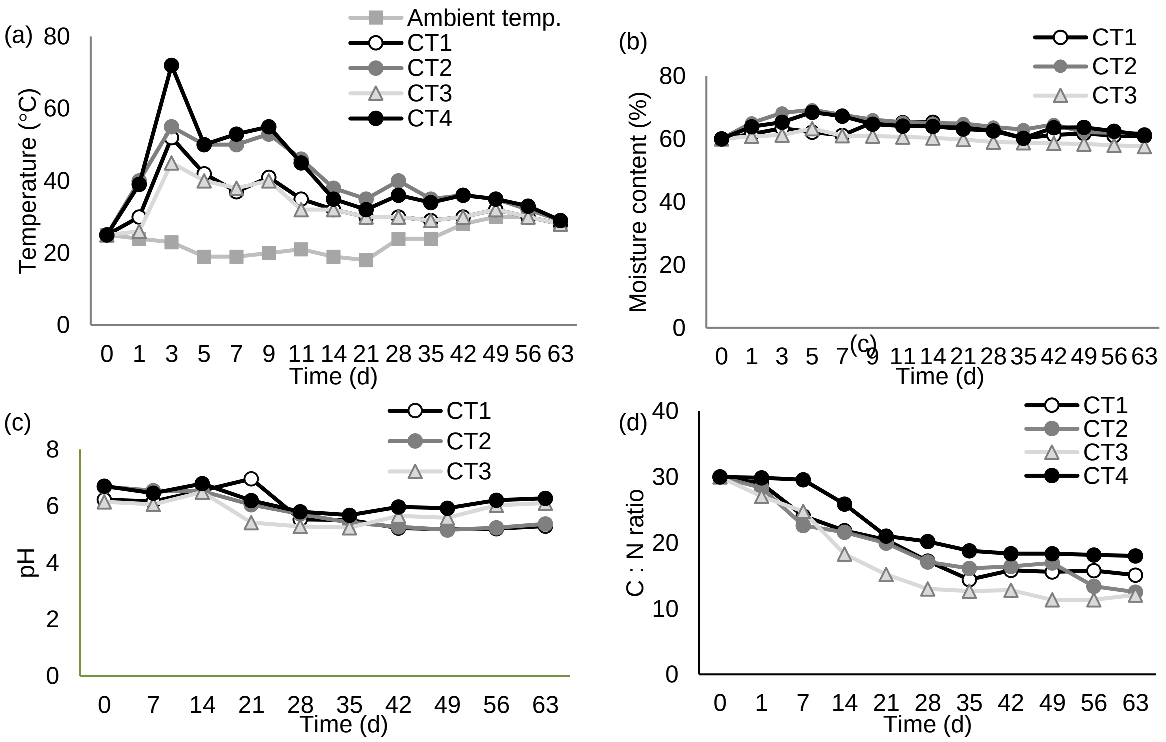

Figure 1: Changes in temperature (a), moisture content (b), pH (c) and C: N ratio (d) during the composting process

Recorded temperatures during composting process (Figure 1a) indicated that the temperatures of compost piles changed markedly over time and were always higher than the ambient temperature until the final week of the experimental period. During the 63 d of the composting process, the temperature of the heaps constantly changed, ranging from 25 to 72 °C. The temperature rose rapidly during the first 3 d and reached a peak in all experimental formulas on the third day after composting (52 °C in CT1, 55 °C in CT2, 45 °C in CT3, and 72 °C in CT4). This indicated the strong activity of aerobic microorganisms under favourable conditions and the rapid decomposition of OM. The piles with smaller material sizes resulted in less aeration and exhibited lower temperatures. These temperatures were only maintained during the day, then began to gradually decrease from the 4th day onward. On the 7th day, all the composting piles were turned over, and materials were redistributed and brought from lower temperature positions to higher temperature positions. This resulted in the rapid degradation of OM compounds by microorganisms (Kuok et al., 2012) and the temperatures of piles increased by more than 40 °C. During the first 9 d, pile temperatures increased sharply and were maintained at high levels, which indicated a successful transition from the mesophilic phase to the thermophilic phase in all piles. After day 9, the temperature of composting piles gradually reduced. From day 42 onwards, all pile temperatures were approximately equal to the ambient temperature. This indicated that the composting process could be ended.

Figure 1b, 1c and 1d present the variation of other physicochemical properties of the compost piles during aerobic incubation such as moisture content, pH and C: N. ratio. During the composting process, the moisture content was always tested to ensure that the optimum conditions were maintained for microorganisms. According to the Cornell Waste Management Institute (1996), the optimum moisture content for composting is 40 - 60 % by weight. The moisture content was adjusted on the first day of the composting process to reach 60 % in all experimental formulas. Following 63 d of composting, the moisture content of most piles was greater than 60 %. Moisture content ranged between 60 and 65.29 % in CT1, between 60 and 69.23 % in CT2, between 57.57 and 63.24 % in CT3 and between 60 and 68.45% in CT4. This might be due to the strong hygroscopic ability of composting materials. In particular, the composting process took place under high humidity air conditions over several d, which could cause an increase in the moisture of piles. Changes in the pH values of the composting piles were used as a criterion to roughly estimate the maturity of compost (Lee et al., 2002). The initial pH of composting mixtures ranged from 6.23 to 6.7. During incubation, pH values changed between 5.18 - 6.96. During the first 7 d, the pH of all composting piles reduced slightly due to organic matter decomposition by microorganisms that led to the formation of organic acids, which then accumulated gradually in the piles. The pH started to increase from day 7 due to the strong activity of the thermophilic microorganisms that caused the degradation (Kumar et al., 2010) and evaporation of organic acids. NH_3 formed in the composting piles by the ammonification of organic compounds could combine with H_2O to create ion NH_4^+ and release OH^- into the mixtures, thus increasing the pH of the piles. After that, pH tended to decline as an amount of formed NH_3 evaporated into the air or entered the biomass of microorganisms. By the end of the composting process, the pH values in experimental formulas were 5.29 in CT1, 5.37 in CT2, 6.10 in CT3 and 6.27 in CT4. Total carbon concentration reduced continuously during the composting process, reflecting the degradation of organic materials. The total nitrogen content usually increases during the composting process due to the loss of organic matter (Lee et al., 2002). The initial C: N ratio of the composting piles was adjusted to 30: 1 and after 63 d of incubation, the C: N ratio in the four mixed formulas decreased from 1.67 to 2.49 times. At the final day of composting, the C: N ratios of CT1, CT2, CT3 and CT4 were 15.09: 1, 12.51: 1, 12.06: 1 and 18: 1.

3.3 Chemical and biological properties of compost

Some parameters evaluating the chemical and biological properties of compost products are listed in Table 2. After 63 d of composting, the OM content of all experimental formulas decreased from 1.49 to 2.1 times compared to the original starting values. At the end of incubation, OM was 29.72 – 55.44 %. The descending order of OM among compost treatments was 55.44 % in CT4, 40.18 % in CT2, 33.55 % in CT1 and 29.72 % in CT3. OM in the compost products of all formulas met the requirement of organic fertilizer quality in the Decree on fertilizer management № 108/2017/ ND-CP of Vietnam. The total nitrogen of the finished compost in experimental formulas was higher than that of the initial composting mixtures, ranging from 1.01 to 1.46 %. The descending order of total nitrogen in compost products was CT2 (1.46 %), CT4 (1.4 %), CT3 (1.12 %) and CT1 (1.01 %). This suggested that the mixing of SSGM and other agricultural by-products for a period of time could help to improve the total nitrogen content in compost. The total phosphorus content in completed compost was 0.8 – 1.5 %, while the total potassium content was 2.96 – 4.24 %. Compared to the initial composting mixture formula CT3 exhibited a decrease in total phosphorus, while formula CT1 exhibited a decrease in total potassium. The mixing of SSGM and other agricultural residues improved the total potassium content in completed compost. At the end of the composting process, the heavy metal content (Cu, Zn, Cd, Pb, As) in compost using different formulas was within the permitted limits for organic fertilizer quality according to standard 108/2017/ ND-CP of Vietnam. In all compost products, the presence of pathogenic bacteria *E. coli* and *Salmonella* was not detected therefore this result also met the requirements for organic fertilizer quality according to standard 108/2017/ ND-CP of Vietnam.

Table 2: Chemical and biological characteristics of composts

Parameters	Experimental formulas			
	CT1	CT2	CT3	CT4
OM (%)	33.53	40.18	29.72	55.44
T-N (%)	1.01	1.46	1.12	1.4
T-P_2O_5 (%)	1.4	0.9	0.8	1.5
T-K_2O (%)	3.57	4.24	2.96	4.18
Cu (ppm)	24.05	18.35	36.3	22.35
Zn (ppm)	84.85	62.15	103.9	76.2
Pb (ppm)	11.4	9.4	16.15	11.45
Cd (ppm)	0.32	0.3	0.55	0.35
As (ppm)	4.43	6.09	5.28	4.12
E. coli (MPN/g)	Negative	Negative	Negative	Negative
Salmonella spp. (MPN per 25g)	Negative	Negative	Negative	Negative

3.4 Assessment of compost maturity

The maturity test confirmed the stability of the final compost products (Manu et al., 2019). The data presented Table 3 indicate that seed germination in compost extract was quite high and was always higher than that of the control (distilled water). For all formulas, the seed germination rate in full-strength filtrate was always higher than in the 10x diluted filtrate. The root length of radish in the compost extracts was almost lower than the control even though the difference between them was not significant. The GI value of compost was greater than 80 % proposed for compost without phytotoxicity (Thompson, 2002). The GI for radish in the compost extracts of different formulas was 87.0 – 100 %, which indicated that the final compost products were mature and ready to use with plants.

The treatment of SSGM for compost production is not a simple problem due to this material being rich in lignocellulose and difficult to naturally biodegrade. Co-composting SSGM with other agricultural residues will not only take full advantage of other available local raw materials but also improve the quality of compost.

Table 3: Germination, root length and germination index for radish in compost extract

Formulas	Treatment	Mean seed germination	Mean root length (mm)	Germination index (GI)
CT1	Distilled water	9.0 ± 1.0	10 ± 2.2	-
	Filtrate (10x dilution)	9.2 ± 0.8	9.0 ± 1.0	92.0
	Filtrate (full-strength)	9.6 ± 0.6	9.0 ± 2.0	96.0
CT2	Distilled water	9.0 ± 1.0	12.0 ± 1.0	-
	Filtrate (10x dilution)	9.2 ± 0.8	11.0 ± 2.0	93.7
	Filtrate (full-strength)	9.4 ± 0.6	10.0 ± 1.0	87.0
CT3	Distilled water	9.0 ± 1.0	11.0 ± 2.0	-
	Filtrate (10x dilution)	9.0 ± 1.2	11.0 ± 1.0	100
	Filtrate (full-strength)	9.6 ± 0.6	10.0 ± 1.0	97.0
CT4	Distilled water	9.0 ± 1.0	10.0 ± 2.0	-
	Filtrate (10x dilution)	9.2 ± 0.8	9.0 ± 1.0	92.0
	Filtrate (full-strength)	9.6 ± 0.6	9.0 ± 2.0	96.0

4. Conclusions

Composting from SSGM and other agricultural by-products is an effective treatment to produce high-quality composts that are safe and effective to use with plants. The composting process occurred successfully and ended after 63 d. By monitoring changes in the composting process, analyzing physicochemical and biological parameters assessing the quality of compost, determining the limiting factors for compost and testing phytotoxicity of compost, the finished compost products demonstrated a mature status and satisfied all requirements according to Vietnamese standards. The synthetic assessment of all relevant parameters also confirmed that compost made from SSGM and rice straw was the most suitable for producing high-quality compost. This study is expected to contribute to reducing environmental pollution and establishing the sustainable development of sprout farming in Vietnam.

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