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In-vessel Composting of Vegetable Waste and Compost Application Trial on Lettuce (*Lactuca Sativa L.*)

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The increasing transportation costs of the vegetable waste generated from wholesale markets in Vietnam propose a decentralized waste treatment approach as *in-vessel* composters for more effective recycling of organic waste into valuable composts. Two *in-vessel* composters (rotary drum reactors–RDR and aerated cubic boxes–ACB) were designed to study different composting mixtures, consisting of 70 % (v/v) vegetable waste (VW) and 30 % additives (either napier grass–NG or corncob-derived biochar–CB and sugarcane bagasse–SB). The results show that compost temperatures maintained over 55 °C for four consecutive days in both *in-vessel* systems, and peak temperatures were 65.4 °C – 68.5 °C at RDR and 63.4 °C – 66.5 °C at ACB depending on each mixing ratio. The mature compost derived from 70 % VW + 10 % SB + 20 % CB at ACB contained 2.5 % total N, 0.828 % available P_2O_5 and 3.75 % available K_2O. This compost met three of the four quality criteria specified for traditional organic fertilizer in Vietnam, including a pH value (7.5), organic matter content (60.1 %), and C/N ratio (10.9). A pot experiment was conducted to study the effectiveness of compost as a total (100 % compost) or partial (25 % to 75 %, w/w) mineral nitrogen fertilization substitute on lettuce (*Lactuca sativa* L.). The treatments of 75 % compost + 25 % chemical fertilizer (CF); 50 % compost + 50 % CF, and 25 % compost + 75 % CF resulted in a high vegetable yield of 1124.7–1335.2 g/m^2, which were similar to 100 % CF treatment, revealing that compost could help to reduce from 25 % to 75 % of the chemical N fertilizer.

1. Introduction

Organic agriculture in Vietnam is an area of special interest to the government to ensure the agricultural development of savings, safety, efficiency, and sustainability. Using high-quality compost (organic fertilizer) is the basis for sustainable development, improving soil fertility, increasing crop yield, and especially contributing to environmental protection. Composting is widely recognized as one of the most efficient methods of converting organic waste into soil organic fertilizer. *In-vessel* composting generally describes a group of methods that confine the composting materials within a building, container, or vessel. However, the quality of the compost made from *in-vessel* composters is still poorly understood in Vietnam.

Ho Chi Minh City is the largest consumer market in the southern region of Vietnam. In particular, agricultural products are an essential commodity, concentrated and distributed at wholesale markets in very large quantities. According to data from the Department of Natural Resources and Environment of Ho Chi Minh City, the collection and transportation of solid waste generated at Thu Duc agricultural wholesale markets is 80 t/day, Hoc Mon market is 50 t/day, and Binh Dien market is 40 t/day (DONRE, 2017). Despite many efforts by the city government, many community projects trying to reduce waste have been implemented, but the problem of pollution around wholesale markets is still ongoing.

The objective of this study was to: *i)* determine the optimum mixture ratio of vegetable waste generated from the wholesale markets in Ho Chi Minh City and co-substrates for composting using two comparative *in-vessel* systems in pilot scale, and *ii)* evaluate the quality of self-made compost and its potential substitution for chemical fertilizer through trial application to lettuce (*Lactuca sativa* L.) under controlled conditions.

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2. Materials and Methods

2.1 Feedstock characterization

In this study, vegetable waste (VW) is considered the main substrate (70 % of total volume), while napier grass-NG, sugarcane bagasse (SB), and corncob-derived biochar (CB) were added as co-substrates (30 % of each) for both ACB and RDR systems. VW was collected at Thu Duc agriculture wholesale market located in Ho Chi Minh City. After being separated well from non-biodegradable materials (plastic bags, fruit foam net, etc.), VW was shredded before mixing with other co-subtrates. For VWs in runs 6 to 10, it was further dewatered using a centrifuge machine at 2800 rpm for ten minutes and dried until moisture contents reduced to 52.6 % – 55.4 %. Dried NG and SB were chopped to 3 – 5 cm in length. The CB was carbonized under limited oxygen conditions at a temperature of around 400 °C using the Top-Lid Updraft Drum (TLUD) method. The properties of composting materials are shown in Table 1.

Table 1: Physicochemical and biological properties of composting materials in the study

Parameters	VW_{RDR}†	VW_{ACB}††	NG	SB	CB
Moisture content (%, d.b.)	81.7–91.2	52.6–55.4	25.3	2.5	1.8
Bulk density (kg/m^3)	252–397	360–437	330	80	130
pH_{H2O} (1:5, w/v)	7.07–7.19	6.97–7.11	7.3	6.8	7.7
EC (1:5, w/v) (mS/cm)	2.97–3.21	3.05–7.22	8.62	1.90	4.89
Salinity (1:5) (‰)	1.52–1.62	1.54–3.64	4.59	0.95	2.34
Org-C (%)	–	44.2	51.6	57.3	7.3
Total N (%)	–	2.41	0.83	0.28	0.82
C/N	–	18.3	62.2	204.6	8.9
E. coli (MPN/g)	–	1.2×10^6	–	–	–
Salmonella (MPN/25g)	–	nd	–	–	–

(†vegetable waste for runs 1 to 5; ††dewatered vegetable waste for runs 6 to 10; nd = not detected)

2.2 Experimental Setup

Composting experiment

Ten composting runs in sequence, the first runs 1–5 using RDR and the second runs 6–10 using ACB systems, were performed on a small scale at the Experimental Site of the Faculty of Agronomy, Nong Lam University Ho Chi Minh City (NLU). The first runs began on October 15, 2023, and the later runs began on December 24, 2023; all runs ended after 30 days. Detailed information and weight of ingredients for the ten composting runs are given in Table 2.

Table 2: Volumetric mixing ratio (%), rotation, and aeration conditions of composting runs

Composting runs	VW	NG	SB	CB	Rotation	Aeration
RDR						
Run 1 (control)	100 (55.3)				○	○
Run 2	70 (38.9)	30 (13.9)			○	○
Run 3	70 (38.9)	20 (9.2)	10 (0.9)		○	○
Run 4	70 (38.9)	10 (4.6)	20 (1.9)		○	○
Run 5	70 (38.9)		30 (2.8)		○	○
ACB						
Run 6 (control)	100 (18.8)				×	○
Run 7	70 (13.1)		30 (1.9)		×	○
Run 8	70 (13.1)		20 (1.3)	10 (1.2)	×	○
Run 9	70 (13.1)		10 (0.6)	20 (2.4)	×	○
Run 10	70 (13.1)			30 (3.6)	×	○

(× = not include, ○ = include; numbers in parentheses ( ) indicate the fresh weight of each material in kg unit)

Basically, two *in-vessel* composters differed in structure and aeration conditions (the ACB used 92 L–static bins while the RDR used a 200 L rotary drum). In both systems, air was introduced into the compost bins to accelerate microbial decomposition activities but not cause heating loss. The pipes were connected to the air blowers with a capacity of 0.64 m^3/min. The airflow timing and cycling were intermittently supplied with a pre-set cycle of 1 minute of aeration and a 19–minute pause using a timer relay. The rotary speed for RDR is 1–3 turns/min/day. The schematic diagram of two *in-vessel* composters is presented in Figure 1.

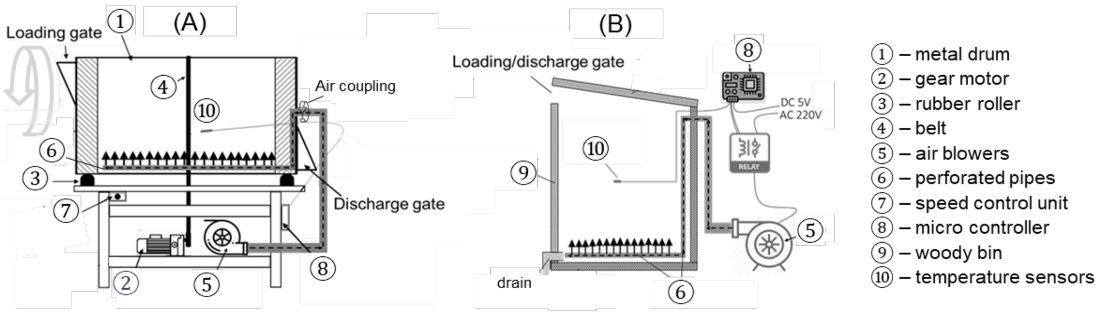

Figure 1: Schematic diagram of rotary drum reactor-RDR (A) and aerated cubic box-ACB (B)

Pot culture experiment

In Feb 2024, a pot culture using compost A (harvested from run 9) was conducted at the NLU to study the effectiveness of the produced compost application on lettuce. Sandy soil (25 kg, w.b.) was passed through a 2-mm sieve and loaded into a plastic pot (L65 cm × W42 cm × H16 cm) at the lower layer. For the top (0 – 3 cm) layer, approximately 8.3 kg of sandy soil was mixed well with either compost and/or chemical fertilizer at different application rates depending on each treatment, as seen in Table 4. All treatments (except for control-T_1) received the same 10 g N/m^2. Compost was amended as basal application during soil preparation, while chemical fertilizers were additionally applied at 7, 14, and 21 days after transplanting (DAT). The experiment was arranged in a completely randomized design (CRD) consisting of seven treatments and three replications. Lettuce was cultivated at a density of 10 plants per pot, and vegetables were harvested after 30 days of cultivation.

Sample analysis

The raw materials and composts were analyzed for the parameters using Vietnamese standard methods as follows: moisture content (105 °C for 24 h); pH_{H2O} (1:5 of fresh sample: water, w/v); EC and salinity using a pH-EC–salinity meter; organic matter (TCVN 9294:2012), total N (TCVN 8557:2010), As (TCVN 8467:2010), Cd (EPA SW-846/METHOD 3050B), Pb (EPA SW-846/METHOD 3050B), Hg (TCVN 8882:2011), *E. coli* (TCVN 6846:2007); and *Salmonella* spp. (TCVN 4829:2005). The temperature of the compost was recorded daily using temperature sensors. The mean values of vegetable yield were compared according to Fisher's protected least significant difference test at $P < 0.05$ using EXCEL® macro add-ins DAAASTAT version 1.512 (Onofri and Pannacci, 2014).

3. Results and discussions

3.1 Composting temperature

Basically, in both two *in-vessel* systems, the compost temperatures immediately increased at the beginning of the composting process and reached peaks of 68.6 °C at RDR and 66.5 °C at ACB on the first day. The compost temperature was maintained above 55 °C for four consecutive days, then gradually cooled down and somewhat returned to the ambient temperature from day 15 to day 30, indicating that composts could enter the stable curing stage (Figure 2). There was no clear difference between different mixtures; however, the thermophilic stage of RDR was likely to be shorter for a few days than that of ACB. The high temperature in the thermophilic stage is necessary to effectively destroy pathogens, weed seeds, and insect larvae (Tahseen et al., 2020).

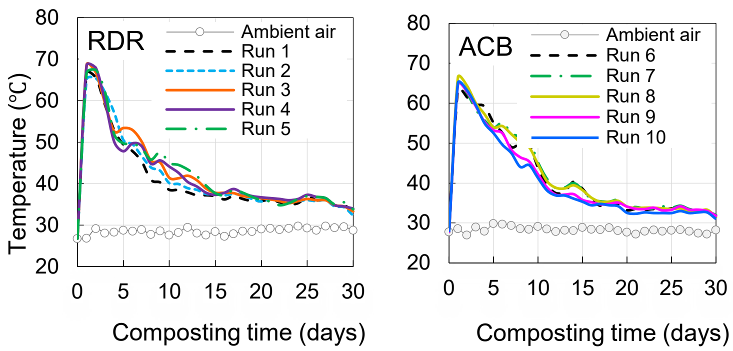

Figure 2: Changes in temperatures during the composting process using two in-vessel composters

3.2 pH, Electrical Conductivity–EC and Salinity

The mixtures had initial pH values of 6.65 – 7.18 at RDR and 6.79 – 7.15 at ACB, fluctuated and increased during the first half, and almost remained stable during the second half of the composting process (Figure 3). The increase in pH in the first half can be caused by the rapid decomposition of organic compounds leading to the emission of NH_3 (Jayanta et al., 2021). Composting resulted in an increase in EC and salinity by double at the end of the composting process at both RDR and ACB systems. The addition of 30 % of co-substracts at ACB was found to reduce EC and salinity values during the composting process compared to the control with 100 % VW. In general, the EC and salinity values of the final composts at ACB were two times higher than those at RDR (Figure 3) due to higher values in the input raw materials (Table 1). Many studies suggest that an EC of less than 4 mS/cm in the final compost indicates no inhibition of seed germination and signifies maturity (Yilin et. al., 2024). However, previous research demonstrated that the application of compost with high EC values and a limited NaCl concentration could be beneficial to plant growth when properly applied (Matthew et. al., 2020).

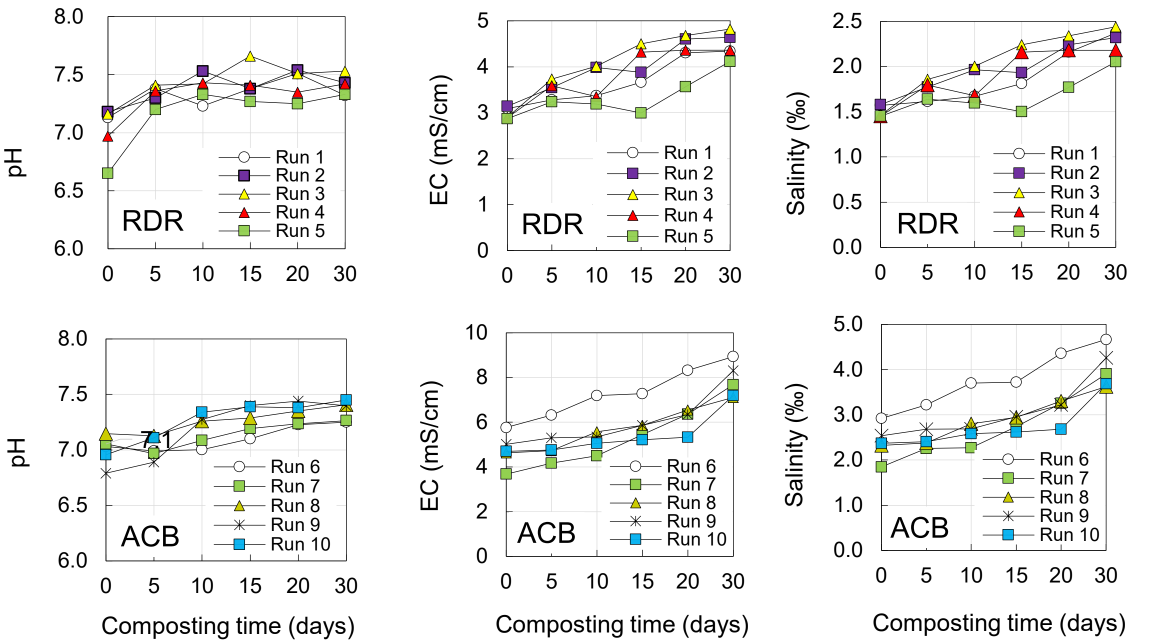

Figure 3: Changes in pH, EC, and salinity during the composting process using two in-vessel composters

3.3 Physicochemical and biological properties of composts

The physicochemical properties of composts at the end of the composting process are summarized in Table 3. The results were compared to the national technical regulation on fertilizer quality (QCVN 01-189:2019/BNNPTNT). The high organic matter (51.4 %–94.9 %) at two *in-vessel* systems was the most remarkable result in this study, which was higher from 2.6 to 4.7 than the requirement of OM ≥ 20 %. The mature compost derived from 70 % DVW + 10 % SB + 20 % CB at ACB had a total nitrogen content of 2.5 %; available phosphorus and potassium contents of 0.828 % and 3.75 %, respectively. Thus, this compost met three of the four quality criteria specified for traditional organic fertilizer, including a pH value, organic matter content, and C/N ratio of 7.5, 60.1%, and 10.9, respectively. This compost also met Vietnamese organic fertilizer standards of heavy metal limits (As, Cd, Pb, Hg) and maximal limits for *E. coli* and *Salmonella.*

The results in Table 3 showed that the moisture contents of the finished composts were from 72.8 % to 80 % at RDR and from 38.9 % to 49.0 % at ACB. Thus, vegetable waste dewatering can reduce moisture content, and even minimize its amount for transportation to composting sites. Despite the efforts for dewatering in the original vegetable waste (Runs 6 to 10), the aeration conditions such as airflow rate and its cycling were perhaps not to be optimally controlled.

3.4 Plant height, number of leaves, and soil EC

Figures 4A & 4B show that the effectiveness of fertilizer application on plant height and number of leaves of lettuce was clear from 20 – 30 DAT. At harvest time, plant height at T_7 (26.2 cm) was significantly higher (P < 0.001) than T_1 (13.4 cm) and T_3 (21.4 cm), but was not significantly different from the other treatments. The combinations between compost A and chemical fertilizer at T_5, T_6, and T_7 resulted in a similar plant height of 100 % CF, indicating the potential substitution of compost for chemical fertilizer.

Table 3: Physico-chemical and biological properties of compost products using two in-vessel composters

Parameters	Composting runs					QCVN†
RDR	Run 1	Run 2	Run 3	Run 4	Run 5	
pH_{H2O} (1:5, w/v)	7.32	7.43	7.53	7.42	7.33	≥ 5.0
EC (1:5, w/v) (mS/cm)	4.34	4.64	4.82	4.36	4.12	
Salinity (‰)	2.37	2.32	2.44	2.18	2.05	
Moisture content (%)	80.0	79.5	73.7	72.8	79.0	≤ 30.0
Organic matter (%)	–	–	80.9	–	–	≥ 20.0
Total N	–	–	2.26	–	–	–
C/N	–	–	16.3	–	–	≤ 12.0
E. coli (MPN/g)	nd	–	nd	–	–	< 1.1 × 10^3
ACB	Run 6	Run 7	Run 8	Run 9††	Run 10	
pH_{H2O}	7.23	7.24	7.35	7.44	7.38	≥ 5.0
EC(1:5) (mS/cm)	8.93	7.68	7.11	8.31	7.20	
Salinity (‰)	4.67	3.90	3.62	4.26	3.69	
Moisture content (%)	46.5	37.7	39.9	40.9	46.3	≤ 30.0
Organic matter (%)	80.9	94.9	78.0	60.1	51.4	≥ 20.0
Total N	2.26	2.62	2.57	2.50	2.37	
C/N	16.3	16.5	13.8	10.9	9.9	≤ 12.0
Available P_2O_5 (%)	–	–	–	0.828	–	
Available K_2O (%)	–	–	–	3.75	–	
As (mg/kg)	–	–	–	nd	–	≤ 10.0
Cd (mg/kg)	–	–	–	0.82	–	≤ 5.0
Pb (mg/kg)	–	–	–	nd	–	≤ 200.0
Hg (mg/kg)	–	–	–	nd	–	≤ 2.0
E. coli (MPN/g)	–	–	–	< 0.18	–	< 1.1 × 10^3
Salmonella (MPN/25g)	–	–	–	nd	–	absence

(† QCVN 01–189:2019/BNNPTNT; ††The run produced the compost A)

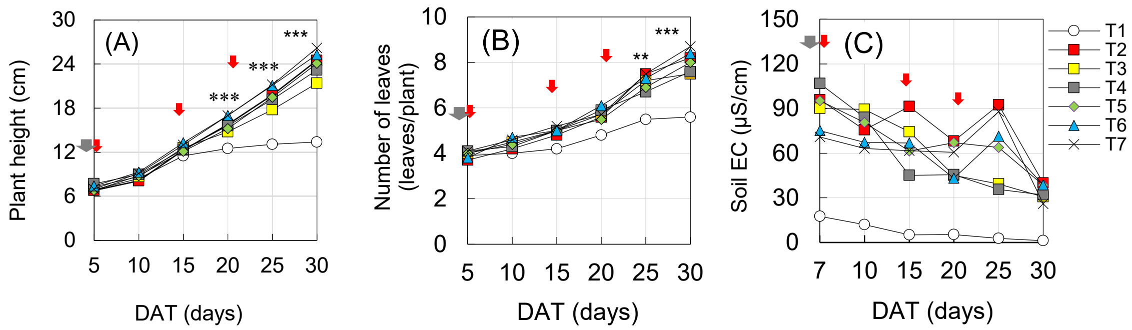

Figure 4: Plant height (A), number of leaves (B), and soil EC (C) as affected by different fertilizer treatments. Base application with compost; Additional application with chemical fertilizer

The data on plant growth are considered to be consistent with measured soil EC values, as shown in Figure 4C. The EC of soil at amended treatments in this study ranged from 26.1 µS/cm to 106.7 µS/cm, while the EC of the unamended one fluctuated around 1.2–17.6 µS/cm. The EC values of all treatments decreased on day 30, indicating that the nutrients from fertilizer were taken up effectively until harvest time. In addition, there was no evidence that compost application caused any salinity effects on the soil during the experiment time.

3.5 Total dry weight, estimated and actual yield of lettuce

The results in Table 4 show that the total dry weight of lettuce at amended treatments (T_2 – T_7) was not significantly different (ranging from 1.2 to 1.5 g/plant), but significantly higher than that of T_1 (0.8 g/plant). The theoretical fresh yield and actual fresh yield of lettuce applied with compost (T_3) were found to be similar to commercial organic fertilizer (T_4). The combined application of compost and CF (T_5, T_6, and T_7) resulted in a higher yield compared to a single application of them. The treatments of T_5 (75 % compost + 25 % CF), T_6 (50

% compost + 50 % CF), and T_7 (25 % compost + 75 % CF) resulted in the highest actual fresh yield of 1124.7–1335.2 g/m^2, which was not significantly different (*P > 0.05*) from the 100 % CF (1312.2 g/m^2), suggesting that high-quality compost from vegetable waste could replace for 25 % to 75 % of chemical fertilizer (Table 4).

Table 4: Total dry weight, theoretical and actual fresh yield of lettuce as affected by different fertilizer treatments

Treatments	Total dry weight (g/plant)	Theoretical fresh yield (g/m^2)	Actual fresh yield (g/m^2)
T_1 (soil only)	0.8 b	345.7 c	331.3 c
T_2 (100 % CF)	1.5 a	1292.8 a	1312.2 a
T_3 (100 % Org-Fer.)	1.3 ab	842.4 b	898.7 b
T_4 (100 % compost)	1.2 ab	927.6 b	989.9 b
T_5 (75 % compost + 25 % CF)	1.3 ab	1113.7 ab	1124.7 ab
T_6 (50 % compost + 50 % CF)	1.5 a	1333.3 a	1335.2 a
T_7 (25 % compost + 75 % CF)	1.5 a	1302.9 a	1332.5 a
CV (%)	17.8	19.5	14.5
F	4.2^{*}	9.5^{***}	16.9^{***}

Values within the same column followed by the same letter are not significantly different according to the LSD test at P < 0.05.

4. Conclusions

This study determined the optimum mixing ratio of 70 % DVW + 10 % SB + 20 % CB, giving a final compost product meeting three of the four quality criteria, including pH (7.5), organic matter (60.1), C/N ratio of 10.9, and six limitation factors as required for organic fertilizer following national technical regulation on fertilizer quality. Both two *in-vessel* composting systems were effective in controlling temperatures maintained over 55 °C for four consecutive days, meeting all the requirements of inactivation of pathogens (*E. coli* and *Salmonella)* in the vegetable waste feedstock. The aeration conditions at ACB were more effective for reducing moisture in the final compost product compared to RDR. The ventilation system at RDR needs to be modified to control better the airflow and moisture inside the *in-vessel* composters. High–quality compost derived from vegetable waste could help to reduce from 25 % to 75 % of the chemical N fertilizer, indicating the effectiveness of compost in substituting for commercial fertilizer. However, the use of compost with high EC and high salinity as reported in the study should consider the appropriate application rates to ensure no damage to vegetable crops.

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