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Effect of biochar addition method on ammonia volatilization and quality of chicken manure compost

Mahmoud G. M. Abd EL-RAHIM[1,2], Sen DOU[1], Liu XIN[1], Shuai XIE[1], Ahmed SHARAF[1], Abdourazak ALIO MOUSSA[3], Mamdouh A. EISSA[4], Abdel-Rahman A. MUSTAFA[5], Gomaa A. M. ALI[6], Mahdy H. HAMED[7]

[1]Jilin Agricultural University, College of Resources and Environment Sciences
Changchun 130118, Jilin, China
E-mail: dousen1959@126.com

[2]Al-Azhar University, Faculty of Agriculture
Assiut 71524, Egypt

[3]Jilin Agricultural University, Plant Biotechnology Center
Changchun 130118, Jilin, China

[4]Assiut University, Department of Soils and Water
Assiut 71526, Egypt

[5]Sohag University, Department of Soils and Water
Sohag 82524, Egypt

[6]Al-Azhar University, Faculty of Science
Assiut 71524, Egypt

[7]New Valley University, Department of Soils and Water
New Valley 72511, Egypt

Abstract

Composting chicken manure causes negative impacts on environmental ecosystem by increasing ammonia (NH_3) emissions. Split addition of maize straw-derived biochar (Bi) during composting of chicken manure may promote the composting process, increase the quality of produced compost and reduce NH_3 volatilization. To build composting piles, fresh chicken manure and maize straw were mixed (2:1 w/w). Biochar (10% w/w) was applied to the compost piles in different addition modes: one-time applied biochar (OTABi), 10% at the beginning of the trial, and split-applied biochar (SABi), 2.5% at 0, 3, 7 and 15 days of the composting. In addition to the control (without biochar) treatment, measurements of NH_3 emissions were performed in a bench-scale composting experiment. To evaluate the phytotoxicity and maturity of the compost, germination tests were performed in Petri dishes. Compared with the control and OTABi treatments, SABi had a great positive effect (by 40% and 33%) on the final general characteristics of the compost and reduced the cumulative NH_3 emissions. Although OTABi treatment had faster degradation during composting, it did not enhance humification. In the mature compost, the humic substances of SABi treatment were 17% and 40% higher than control and OTABi treatments. In addition, in SABi, the values of humic acid carbon (HAC) and humification index (HI) were significantly higher than in other treatments. By the end of composting, both biochar application modes exhibited low water-extractable organic carbon and high seed germination index compared with the control treatment.

This study suggests that during chicken manure composting split application of biochar is a crucial practice for reducing N loss, mitigating NH_3 emissions and enhancing humification.

Key words: composting characteristics, germination index, humification, NH_3 volatilization.

Introduction

The fast development in chicken farm production has generated large quantities of chicken manure resulting in significant environmental and health concerns (Wang et al., 2019). Processing of such waste using new technologies has been rapidly developing all over the world. Recently, the recycling of animal waste and post-harvest materials has been received economic and environmental attention (Sarkar et al., 2016). Composting is a useful technology based on biochemical conversion of agricultural waste into the humified

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organic matter under aerobic conditions (Višniauskė et al., 2018; Ayilara et al., 2020). It can also reduce the mass and volume of the waste, destroy the pathogens and weed seeds and provide organic fertilizer for sustainable agriculture (Luo et al., 2014). As a process, composting can be divided into two phases: 1) biooxidative phase, which involves the mesophilic and thermophilic stages of composting process; and (2) cooling and maturation, while most of the organic matter transformations occur during the biooxidative phase (Awasthi et al., 2017).

The acceptance of chicken manure compost as a fertilizer and/or as soil amendment depends on the chemical composition and the consistent composition of the mature compost. The soil properties could be enhanced by chicken manure, where it increases organic matter content, soil nutrients, aeration, soil reaction buffering, water holding capacity, cation exchange capacity and microbial activity (Vandecasteele et al., 2014). However, adding an additive with the composting mixture has a crucial function in the biochemical transformation and maturity of compost. Biochar is a porous carbon matter produced from agricultural waste pyrolysis under limited oxygen conditions (Oni et al., 2019; Campos et al., 2020). Biochar is the common additive for accelerating decomposition reactions of composting substrates. Regardless of biochar's role as a bulking agent, amending compost with biochar is a powerful technique to reduce odours and greenhouse gaseous emissions, diminish leaching of nutrients into waterways and groundwater and conserve nutrients in the compost in forms that can help promote soil health and plant vigour.

Applying biochar with composting substrates has become common and effective (Vandecasteele et al., 2016; Awasthi et al., 2020). Biochar can enhance the performance of composting by increasing pile porosity, improving air permeability and ensuring an aerobic environment, adding more stable C, slow-releasing biogenic elements, reducing the emitted greenhouse gases, shortening thermophilic composting stage duration, restraining odours, remediation of heavy metals and organic pollutants from the natural resources, improving composting performance and humification process as well as accelerating the microbial activities and creating a value-added product (Steiner et al., 2010; Vandecasteele et al., 2016; Liu et al., 2017). Biochar addition (10%) leads to compost formation with better chemical and biochemical characteristics, as it enhances degradation rate and the sorption of labile compounds into the biochar (Jindo et al., 2012). In addition, biochar has also been used to reduce NH_3 volatilization, enhance the humification process during composting and increase the stability of the final product (Dias et al., 2010; Jindo et al., 2016; Xiao et al., 2017). Jindo et al. (2016) reported that mixing biochar with poultry manure at the beginning of the composting improved the final compost and the composition of the organic matter fractions. The chemistry of biochar during composting depends on the characteristics of biochar raw material, pyrolysis conditions, application rate and application mode (Vandecasteele et al., 2016; Xiao et al., 2017). The recommended application level of biochar that can accelerate organic matter decomposition ranged from 5% to 10% dry weight basis (Liu et al., 2017; Akdeniz, 2019). In contrast, the addition of excess amounts (>20%) of biochar may interfere with organic waste biodegradation (Liu et al., 2017). Biochar has been used as an additive at the beginning of composting or blending with mature compost (Vandecasteele et al., 2016).

Several studies have been focused on the effect of blending biochar with the composting mixture on NH_3 emissions and organic matter degradation. However, there is a shortage of the available reports concerning the impact of biochar application mode on the NH_3 volatilization, decomposition and humification of composting organic matter. We assume that the split addition of biochar during composting may cause changes in the surface properties of biochar and promote the composting process.

This research aimed to study: (1) the effect of different application modes of maize straw biochar on the composting characteristics of chicken manure; (2) the changes in the number of humic substances, e.g., humic and fulvic acids fractions during the composting; (3) the impact of biochar application mode on the mitigation of ammonia (NH_3) emissions during the composting process; (4) the effect of biochar application mode on the quality and maturity of the produced compost.

Materials and methods

Composting feedstocks. Fresh chicken faeces were collected from a caged chicken farm located under a continuous egg production system in the Experimental Station of Jilin Agricultural University, Jilin province, Northwest of China. Maize straw was collected from the experimental field in the summer season of 2018. To obtain pieces with a length of 1–5 cm, maize straw was air-dried and chopped. Maize straw-derived (fine particles <2 mm) biochar (Bi) was purchased from Liaoning Jinhefu Agricultural Science and Technology Co. Ltd., China. Biochar was manufactured by pyrolysis of maize straw at 300–400°C temperature under limited oxygen conditions. The composting experiment was performed in June 2018 at the experimental field (43°49′5″ N, 125°24′8″ E) of Jilin Agricultural University, Jilin Province, Changchun city, Northeast of China. The soil in the experiment zone was classified as Chernozem (WRB, 2014; Zádorová et al., 2021), and its characteristics were: acidity (pH) 7.2, available nitrogen (N) 132.23 mg kg^{-1}, phosphorus (P_2O_5) 18.56 mg kg^{-1} and potassium (K_2O) 98.42 mg kg^{-1}. The selected physical and chemical properties of composting feedstocks are shown in Table 1.

Composting start-up. The composting treatments were one-time applied biochar (OTABi), split-applied biochar (SABi) and without biochar (control). Each composting pile had dimensions of 1.20 m length × 1 m width × 0.8 m height with a total volume of 0.95 m^3. Each pile consisted of 170 kg of fresh chicken faeces mixed with 43 kg of air-dried maize straw at a ratio of 1:2 dry weight basis representing the composting mixture. Each pile was treated with 10% of biochar as follows: OTABi – 10% biochar one-time that was blended with the composting mixture at the beginning of the composting, SABi – 2.5% in four doses that were mixed with the composting materials at 0, 3, 7 and 15 days and no biochar was added (Liu et al., 2017). The composting piles were turned manually every three days during the first week and then once every two weeks up to the end of the experiment (65 days). During the composting process, the temperatures of the pile were continuously recorded every hour using a temperature logger ZDR-11 (Hangzhou Zeda Instrument Co. Ltd., China). To monitor the biological activity, the thermocouple probe was inserted into the centre of the pile at a depth of 30 cm. During the process, the moisture content of each pile treatment periodically was adjusted to 55–60% (Jindo et al., 2016). When the temperature of all piles decreased to the ambient, the compost was considered mature. All composted piles lasted for 65 days.

Sampling and chemical analysis. After turning the composting piles, to obtain a composite sample (~700 g), three sub-samples from the top, bottom and middle of the pile were collected and homogenized at 0, 3, 7, 15, 30, 45 and 65 days of composting. Each composite

Table 1. Physical and chemical properties and elemental composition of composting raw materials and biochar

Substrate	pH (1:10)	EC dS cm^{-1}	C	N	H	HAC	FAC	C:N	OM	MC
			%			g kg^{-1}			%	
Chicken faeces	6.55 ± 0.00	2.56 ± 0.04	27.00 ± 2.02	6.20 ± 0.11	3.80 ± 0.03	21.00 ± 1.16	27.10 ± 2.67	4.51 ± 0.32	48.01 ± 3.22	73.20 ± 3.30
Maize straw	5.40 ± 0.00	1.65 ± 0.00	40.99 ± 3.14	1.00 ± 0.03	3.90 ± 0.04	53.01 ± 3.55	57.00 ± 3.55	39.00 ± 3.72	71.23 ± 4.14	8.01 ± 0.02
Biochar	9.88 ± 0.01	1.31 ± 0.00	59.02 ± 3.04	1.20 ± 0.03	1.80 ± 0.01	9.02 ± 0.60	4.10 ± 0.54	51.42 ± 3.20	102.00 ± 4.17	20.00 ± 2.00

EC – electrical conductivity, C – carbon, N – nitrogen, H – hydrogen, HAC – humic acid carbon, FAC – fulvic acid carbon, C:N – carbon to nitrogen ratio, OM – organic matter, MC – moisture content; ± values mean standard deviations (n = 3 replicates)

sample was divided into two parts. The first part was immediately stored at 4°C temperature for phytotoxicity assessment; the other was air-dried, glandered and then passed through a 0.250 mm sieve for chemical analyses and humic substances determinations. Humic substances are mainly heterogeneous compounds derived from the complexation of carbonaceous components such as lignin, carbohydrates and amines.

The acidity (pH) was determined in a suspension of 1:10 (w/v) dry weight basis compost to deionized water ratio after shaking for 1 h, equilibrium for 1 h and then centrifuged at 3500 rpm for 15 minutes. Electrical conductivity (EC) was determined in a filtrate solution of 1:10 (w/v) by EC meter apparatus. Water extractable organic carbon (WEOC) was determined in 1:10 (w/v) water extract using a total organic carbon (C_{tot}) analyser TOC-VCSN (Shimadzu, Japan). The elemental composition of the raw material was measured using an analyser (Elemental Analyser GmbH Inc., Germany).

Extraction of humic substances (HSs). HSs were extracted by the International Humic Substances Society (IHSS) recommended method for extracting the HSs from natural organic sources. In brief, 1 g of 0.250 mm dried sample plus 30 ml of alkaline mixture solution (0.1 M NaOH + 0.1 M $Na_4P_2O_7$ at pH ~ 14) were filled into a 100 ml centrifuge tube and shook at 145 rpm for 1 h under inert gas (N_2) conditions. Then the suspension was centrifuged at 3500 rpm, filtered through 0.45 µm filter paper and transferred into a 50 ml volumetric flask. The residual solid sample was washed with 20 ml of the same alkaline mixture, then centrifuged and filtered. After that, to complete the volume to 50 ml, it was transferred into the same flask. From the extracted HSs solution, 30 ml were acidified by 12 M HCl at pH 1 overnight to precipitate humic acid (HA) fraction. After filtration through 0.45 µm filter paper, the coagulated part represented HA, while the supernatant represented the fulvic acid (FA) fraction. The HA part was dissolved in hot solution 0.05 M NaOH and transferred into a 50 ml volumetric flask. As well, FA was completed by 0.05 N H_2SO_4 into a 50 ml volumetric flask. Finally, the potassium dichromate method determined HSs and HA carbon content, while FA was measured by analyser TOC-VCSN analyser (Shimadzu, Japan).

Humification index (HI) was calculated from the alkali extracts (HSs and HA) as follows:

$HI = \left(\frac{HSs}{Ctot}\right) \times 100$ (Volungevičius et al., 2019) (1); percentage of HA $PHA = \left(\frac{HA}{HSs}\right) \times 100$ (2); and degree of polymerization $DP = \left(\frac{HA}{FA}\right)$ (Iqbal et al., 2015) (3).

Germination index (*GI*) was used to estimate phytotoxicity and maturity of the compost (Buhaiov et al., 2018). Twenty seeds of Chinese cabbage were sown in sterilized Petri dishes that contained 10 ml of the water extract (1:10) of the mature compost and covered by Whitman filter paper. The experiment was conducted at 25°C temperature for 3 days in the dark (Zhang, Sun, 2016). Germination index (GI) was calculated using the following equation (Tiquia et al., 1996):

$$GI = (SGS \times RLS)/(SGC \times RLC) \times 100,$$

where SGS is the seed germination of the sample (%), RLS – the root length of the sample (mm), SGC – the seed germination of control (%), RLC – the root length of control (mm).

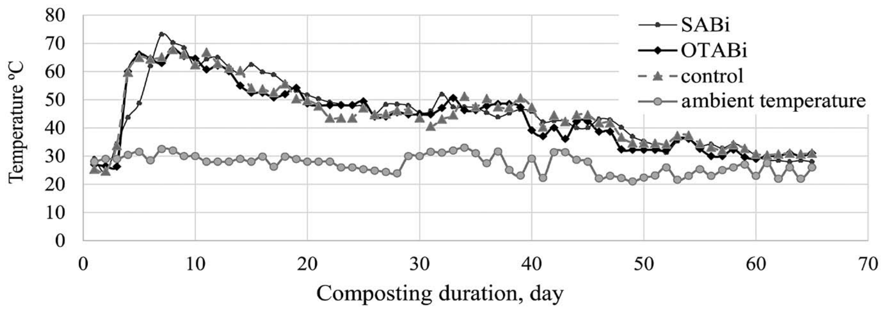
Measurements of ammonia (NH_3) emissions. To establish the effect of biochar addition mode on NH_3 emissions, a bench-scale composting experiment was carried out for 28 days at 25 ± 0.5°C temperature to control the measured parameters. The same treatments (OTABi, SABi and control) that used in the windrow composting system were conducted in glass vessels (Nakhshiniev et al., 2014). Each glass vessel was contained 60 g (32 g chicken manure + 18 g maize straw), and the vessels were treated with OTABi, SABi or without biochar (control). The volatilized NH_3 was briefly trapped in 2% $B(OH)_3$ (boric acid) solution, then titrated with 0.05 M HCl (hydrochloric acid). The composting treatments were studied in 5 replicates. The concentrations of NH_3 trapped emissions were measured via the titration method (Martins et al., 2021).

Statistical analysis. The collected data were checked by Kolmogorov-Smirnov (K-S) (Chakravarti et al., 1967) for normality before the analysis of variance (ANOVA) test, and no changes were needed. The statistical analysis was performed using the software *Minitab*, version 17.3.1 (Informer Technologies Inc.). The significant differences between treatments were tested via ANOVA and completed by Tukey test at $p < 0.05$ significance level. For data analysis and drawing, software *OriginPro*, version 8.5 SR1 (Origin Lab Corporation, USA) was used.

Results

Effect of biochar application mode on the characteristics of composting. The temperature behaviour of the composting piles is shown in Figure 1. At the beginning of composting, the temperature increased slowly for all the treatments until they reached the thermophilic stage after two days. During the process, the maximum recorded temperatures in OTABi, SABi and control treatments were 73.5, 66.5 and 68.20 °C, respectively. The highest temperatures were observed in SABi treatment.

At the beginning of composting, the initial pH values in SABi and control treatments were proportionally neutral (6.76 and 7.08), but OTABi exhibited a slightly alkaline pH (8.48). During the biooxidative phase, the measured pH values increased in all the treatments

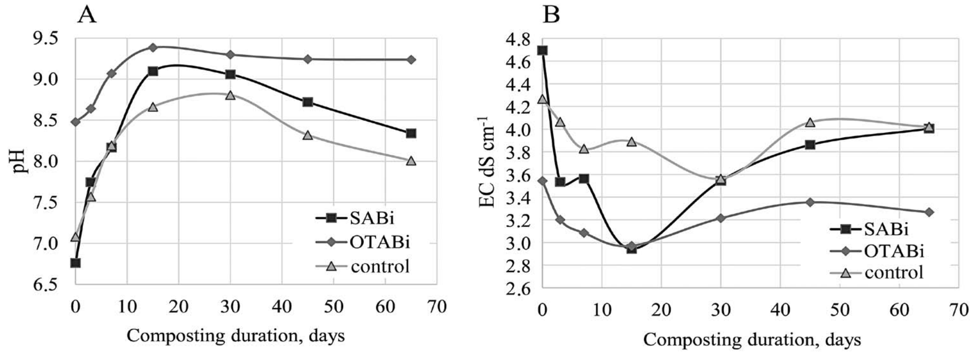


Note. Error bars show the standard deviation of 5 replicates.

Figure 1. Temperature behaviour of the composting piles split-applied (SABi), one-time applied (OTABi) and without biochar (control)

and reached the maximum values by day 14 with 9.06 and 9.30 for SABi and OTABi, respectively, while the control treatment reached 8.81 by 30 days. The measured pH values revealed high significant variations ($p < 0.01$) between the various addition modes of biochar (Figure 2A). By the time, pH values of all the treatments were slightly decreased after day 30, except for the OTABi treatment. At the end of composting (65 days), both biochar application modes exhibited somewhat alkaline pH values. Although the SABi treatment had alkaline pH values (8.34), it was by 0.9 pH unit lower than in the OTABi treatment (9.24). The lowest pH value (8.00) showed the control treatment.

Electrical conductivity (EC) of compost can reflect its validity as an amendment for soil fertility and agricultural production. As shown in Figure 2B, the initial EC values were 4.72, 3.54 and 4.26 dS cm^{-1} for SABi, OTABi and control treatments, respectively.



Note. Error bars show the standard deviation of 5 replicates.

Figure 2. The acidity (pH) (A) and electrical conductivity (EC) (B) behaviour of the split-applied (SABi), one-time applied (OTABi) and without biochar (control) during composting

Effect of biochar addition mode on the content of humic substances (HSs). The active fractions of HSs are HA and FA. The carbon contents of HSs, HA and FA are illustrated in Figure 3A–C. At the initial stage, SABi and control treatments showed high initial contents (97.10 and 95.13 g kg^{-1}, respectively) of HSs carbon, while OTABi demonstrated the lowest initial HSs (69.88 g kg^{-1}).

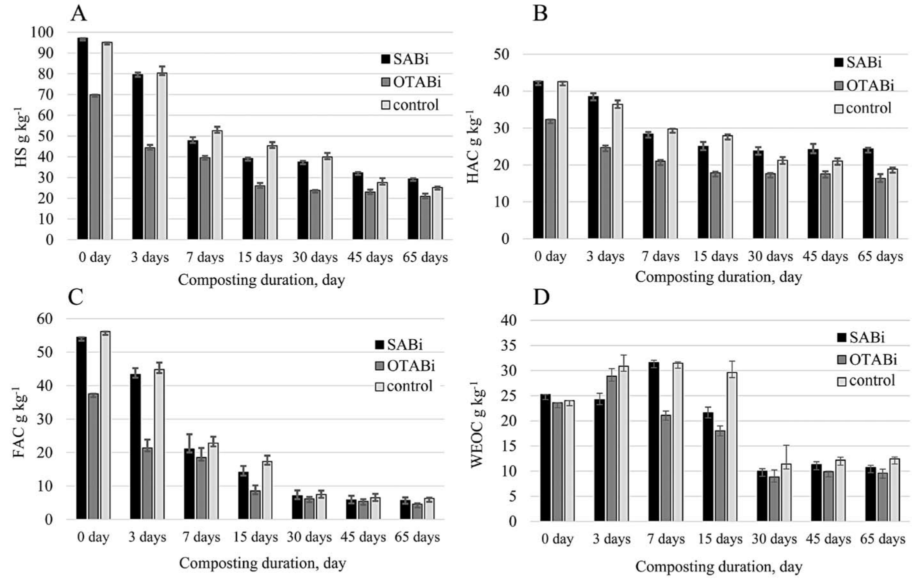
As shown in Figure 3B, the initial concentrations of HA showed relatively similar values for SABi and control treatments, while OTABi had the lowest initial concentration of HA. During the composting process, the carbon content of HA degraded gradually during the first 30 days and then relatively increased only in the SABi treatment. In contrast, HA remained constant in OTABi and control treatments until the end of composting. The FA concentration dramatically declined in both biochar application modes and the control treatment during the first four weeks of composting (Figure 3C). After 30 days of composting, all the treatments exhibited proportionally stable FA values until the end of the process.

Effect of biochar application mode on compost quality. Degree of polymerization (HA to FA ratio), humification index (HI), percentage of HA (PHA) and water extractable organic carbon (WEOC) were used as useful indexes to evaluate compost stability and maturity.

During the experiment, the HA:FA periodically increased for both biochar application modes and control treatment. After 45 days of composting, the HA:FA revealed stable values for all biochar application modes, and it did not change until the end of composting. By the end of the composting process, SABi had a higher HA:FA, while control treatment had the lowest one. In addition, a significantly higher ($p < 0.05$) HA:FA had SABi than OTABi. The changes of HI and PHA for both biochar application modes and control treatments are shown in Table 2. In general, both OTABi and SABi application modes exhibited an increase in HI and PHA during the composting compared with the control treatment. At the mature compost, SABi had significantly higher ($p < 0.05$) HI and PHA rates than other treatments.

Water extractable organic carbon (WEOC) represents the favourable carbon source for microbes and is considered an operational parameter for assessing compost maturity. As shown in Figure 3D, the concentration of WEOC increased from day 0 to 3 in OTABi, whereas the increase extended to 7 days in SABi and control treatments. After the short increase, all the WEOC in all the treatments sharply decreased until day 30, and then they showed unchanged values up to the end of the composting.

Germination index (GI) is an effective test to assess the validity of compost. In addition, the relative root elongation is also a suitable parameter to evaluate the maturity of compost. Chinese cabbage seeds were used to investigate the toxicity of compost. In the present



Note. Error bars show the standard deviation of 5 replicates; means in the same column followed by the same letter are not significantly different.

Figure 3. The effect of split-applied (SABi), one-time applied (OTABi) and without biochar (control) on changes in humic substances (HSs) (A), humic acid carbon (HAC) content (B), fulvic acid carbon (FAC) (C) and water-extractable organic carbon (WEOC) (D) during composting

Table 2. Effect of biochar application mode on humification index, percentage of humic acid (HA) and humic to fulvic acid (FA) ratio as quality parameters of the compost

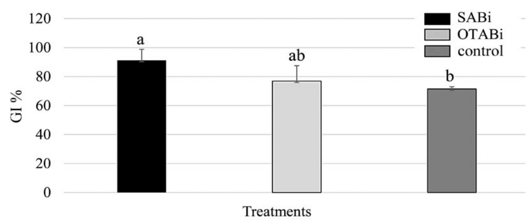
Time, day	Humification index	Percentage of HA	HA to FA ratio
	Split-applied biochar (SABi)		
0	13.02 ± 0.44 a	43.95 ± 1.35 a	0.78 ± 0.04 a
3	13.94 ± 0.14 a	48.42 ± 1.53 b	0.90 ± 0.10 a
7	13.54 ± 0.52 a	59.54 ± 2.39 a	1.35 ± 0.06 a
15	14.62 ± 0.87 a	63.99 ± 3.56 ab	1.80 ± 0.29 a
30	16.90 ± 1.62 b	63.54 ± 3.94 b	3.46 ± 0.91 a
45	22.21 ± 0.61 a	74.85 ± 0.33 b	4.23 ± 0.71 a
65	23.01 ± 0.78 a	82.98 ± 4.27 a	4.28 ± 0.16 a
	One-time applied biochar (OTABi)		
0	10.35 ± 0.21 c	44.78 ± 0.56 a	0.84 ± 0.04 a
3	11.42 ± 0.08 b	55.76 ± 0.84 a	1.17 ± 0.16 a
7	11.78 ± 0.07 b	53.16 ± 2.45 b	1.14 ± 0.11 a
15	12.52 ± 0.00 b	68.80 ± 1.16 a	2.10 ± 0.14 a
30	19.14 ± 0.77 a	74.06 ± 1.69 a	2.87 ± 0.25 a
45	19.27 ± 0.98 b	76.43 ± 0.97 a	3.25 ± 0.18 a
65	18.66 ± 0.34 b	78.16 ± 1.36 b	3.59 ± 0.28 b
	Without biochar (control)		
0	11.94 ± 0.18 b	38.78 ± 2.02 b	0.66 ± 0.04 b
3	11.30 ± 0.09 b	45.36 ± 1.11 c	0.81 ± 0.04 a
7	11.94 ± 0.39 b	56.63 ± 1.89 ab	1.31 ± 0.10 a
15	15.37 ± 0.35 a	61.69 ± 0.92 b	1.61 ± 0.06 a
30	14.77 ± 0.25 c	53.51 ± 4.59 c	2.88 ± 0.36 a
45	18.34 ± 0.56 b	76.38 ± 0.74 a	3.24 ± 0.13 a
65	20.22 ± 0.53 b	75.09 ± 1.92 b	3.03 ± 0.30 b

Note. ± values mean standard deviations (n = 3 replicates); small letters mean the significant difference at 0.05 level.

study, the GI of Chinese cabbage seeds that were sown in the water extract (1:10) of fresh mature compost was 94.49, 78.63 and 73.37 % for SABi, OTABi and control treatments, respectively (Figure 4). The highest GI value was observed in the SABi treatment.

Effect of biochar application mode on the mitigation of ammonia emissions. The daily and cumulative NH_3 emissions from both biochar application modes under the bench-scale composting experiment are shown in Figure 5.

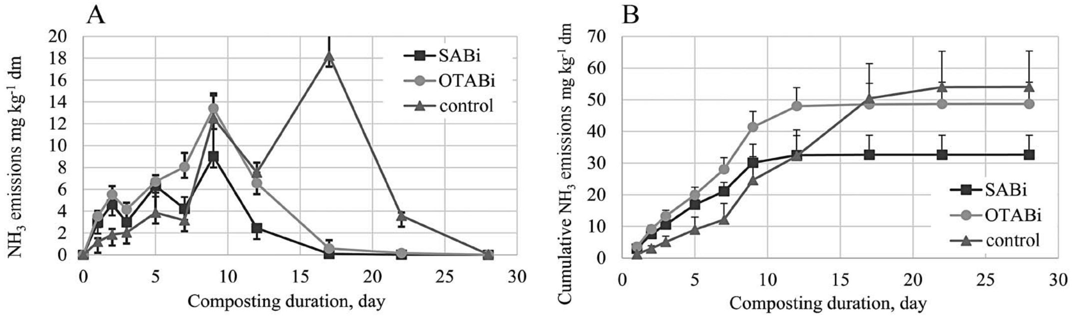
The daily NH_3 emissions increased during the first 9 days in the SABi and OTABi treatments, while the control treatment recorded an increase in ammonia emissions over 18 days (Figure 5A). The highest NH_3 emissions were observed in the control treatment. Although both biochar application modes decreased



Note. Error bars show the standard deviation of 5 replicates; means in the same column followed by the same letter are not significantly different.

Figure 4. Effect of split-applied (SABi), one-time applied (OTABi) and without biochar (control) on germination index (GI) of the mature compost

NH_3 emissions, the SABi treatment had the lowest NH_3 emissions. The crucial period for monitoring NH_3 emissions occurred mainly between 4 to 8 days of composting. In addition, the minimum cumulative NH_3 (32.6 mg kg^{-1}) was observed in the SABi treatment, which presented the addition of biochar in small doses at a different time during composting (Figure 5B). In contrast, the control treatment had the maximum cumulative NH_3 emissions (54.0 mg kg^{-1}). Moreover, the SABi treatment reduced the cumulative NH_3 emissions by 40% and 33% compared with the control and OTABi treatments, respectively.



Note. Error bars show the standard deviation of 5 replicates.

Figure 5. Effect of split-applied (SABi), one-time applied (OTABi) and without biochar (control) on the daily (A) and cumulative (B) ammonia (NH_3) emissions

Discussion

Effect of biochar application mode on the quality of compost. To evaluate compost stability and maturity, degree of polymerization (HA to FA ratio), humification index (HI), percentage of HA (PHA) and water extractable organic carbon (WEOC) as useful indexes have been widely used. In the present study, both OTABi and SABi treatments increased the quality indicators over the control treatment. Germination index (GI) of Chinese cabbage seeds was 94, 78 and 73 % for SABi, OTABi and control treatments, respectively. When GI reached 50%, the compost was regarded as mature and no longer phytotoxic. Regarding this limitation of maturity, all the tested treatments reached GI values greater than 50%, and the compost was considered phytotoxin-free. In addition, SABi had significantly higher ($p < 0.05$) GI than control and OTABi treatments suggesting that the biochar application mode affected compost maturity.

The functional role of biochar addition is to promote the decomposition of organic matter. Moreover, it can sorb the easily degradable, i.e., dissolved organic (DOC) carbon (Anyika et al., 2014). Furthermore, biochar promoted microbial activities by alleviating several inhibitors (NH_3, NH_4^+, H_2S or SO_4^{2-}) generated during composting (Vandecasteele et al., 2016). Regarding compost stability, WEOC content has a negative trend with stability of the organic matter fractions. Both biochar application modes exhibited high mature compost, while the treatment without biochar was the lowest quality. The higher degradation of DOC in biochar treated piles is clearly due to the biochar substrate or its surface property that stimulated microbial activity (Khan et al., 2014).

The total addition of biochar at the beginning of composting may cause clogging of the applied biochar's hydrophilic microspores via composting moisture and become less effective in complexation with the produced organic acids that are released during the composting. On the other hand, when biochar is applied in split doses during the active phase, the applied biochar's interior and exterior functional groups have greater chances to be physically activated through the composting gasses and heat. These activated surfaces can easily interact with the produced humic acids fraction result in complexation and more stable compounds. Moreover, the SABi had the highest polymerization degree due to the application of fresh biochar, which had more ability to react with humified matter and produce more stable materials. The hard-wood biochar-amended poultry manure compost enhanced the humification process (Jindo et al., 2016). It has been observed that the HA:FA was significantly higher in biochar treatments than in treatment without biochar (Awasthi et al., 2017). Similar results were also reported in the literature (Dias et al., 2010).

Effect of biochar application mode on the mitigation NH_3. The crucial period of monitoring NH_3 emissions occurred between 4 to 8 days of composting (Li et al., 2012). The main reason for the NH_3 loss through the volatilization mechanism is that it raises the composting mixture's acidity (pH) and temperature. The total addition of alkaline biochar (10%) at the beginning of composting raised the pile pH and caused significant increases in the NH_3 emissions. At the beginning of composting, the initial pH values in SABi and control treatments were proportionally neutral, but in OTABi exhibited a slightly alkaline pH. These highest pH values in all composting treatments are in line with the rising temperature and probably are due to the decomposition of polyproteins into NH_3 (Qasim et al., 2018).

In the SABi application mode, the evaporated gasses and water vapor (as gasification agents) could activate and accelerate the surface oxidation of biochar particles, and the number of carboxylic groups attached to the surface biochar will be increased (Feng et al., 2018). Such carboxylic groups could decrease composting pH (Basso et al., 2013). During the first 7 days, the EC values declined drastically, then slightly increased in both biochar application modes. The drop in EC values may be due to NH_3 volatilization and mineral salt precipitation (Gao et al., 2010). In contrast, the EC increment during the biooxidative and maturity phases could be attributed to the release of mineral salts through the decomposition of organic materials as well as the existence of soluble chemical salts such as potassium, sodium and chlorine as the result of the mixing of solid and liquid fractions (Silva et al., 2009). At the end of the composting period, all treatments had EC values less than 4 dS cm^{-1} indicating a good quality of the final product. This type of activation might increase the efficiency of biochar as an absorbent agent for the mitigation of NH_3 emissions. Application of pine chip biochar (20% fresh weight) to poultry litter reduced the total NH_3 and N losses by 64% and 52%, respectively (Steiner et al., 2010).

At the beginning of the composting process, the biochar addition leads to a faster decomposition rate in the biooxidative phase and lower greenhouse gas emissions (Awasthi et al., 2016). Moreover, biochar can reduce nitrogen loss via the absorption of NH_3 gaseous and water-soluble NH_4 (Rong et al., 2019). On the other side, the specific composting conditions of poultry manure-blended biochar, which are characterized by high temperatures and high pH values (above 8), favoured the volatilization of the NH_3 rather than the adsorption process on the particle surface (Dias et al., 2010). In addition, the mixing of biochar with the composting mixture at the beginning of composting enhanced the community of nitrifying and denitrifying bacteria, which can degrade aromatic compounds (Zainudin et al., 2020). Therefore, further biological studies are recommended to be carried out.

In this study, the main improvements to the composting system achieved by dividing the amount of biochar into small doses to the feedstock mixtures are: (1) mitigation of the alkaline effect of biochar during the biooxidation stage, which is the main factor causing nitrogen loss; (2) minimization of the NH_3 volatilization by 40% and 30% compared to those of control and OTABi treatments, respectively; and (3) the adopted measures, which are often used to describe humification and compost stability clarified the significant superiority of the SABi.

Conclusions

1. The biochar (Bi) application mode can significantly affect the composting process and the quality of obtained compost. One-time applied biochar (OTABi) accelerated the organic matter degradation but did not promote humic acid (HA) formation, whereas the split-applied biochar (SABi) reduced the total nitrogen loss greater than the OTABi mode.

2. In addition, dividing biochar in equal doses at different times during the thermophilic phase reduced the cumulative NH_3 emissions by 40% and 33% compared with the control and OTABi treatments, respectively. Moreover, the adopted measures used to describe humification and compost stability clarified the SABi significance superiority.

3. The obtained results showed that dividing the amount of applied biochar into small equal doses during the biooxidative stage of composting can reduce the alkaline effect of the biochar. Therefore, SABi application is the best strategy to maximize humification during chicken manure composting and mitigate nitrogen loss.

Inclusive studies are required to investigate the effect of biochar application modes on nutrient availability during composting.

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Bioanglies įterpimo būdo įtaka amoniako išgaravimui ir vištų mėšlo komposto kokybei

M. G. M. Abd El-Rahim[1,2], S. Dou[1], L. Xin[1], S. Xie[1], A. Sharaf[1], A. Alio Moussa[3], M. A. Eissa[4], A.-R. A. Mustafa[5], G. A. M. Ali[6], M. H. Hamed[7]

[1]Jilino žemės ūkio universiteto Išteklių ir aplinkos mokslų koledžas, Kinija
[2]Al-Azhar universiteto Žemės ūkio fakultetas, Egiptas
[3]Jilin žemės ūkio universiteto Augalų biotechnologijų centras, Kinija
[4]Asiūto universiteto Žemės ūkio fakultetas, Egiptas
[5]Sohag universiteto Žemės ūkio fakultetas, Egiptas
[6]Al-Azhar universiteto Gamtos mokslų fakultetas, Egiptas
[7]Naujojo slėnio universiteto Žemės ūkio fakultetas, Egiptas

Santrauka

Vištų mėšlo kompostavimas daro neigiamą įtaką ekosistemai, nes didėja amoniako (NH_3) emisija. Mėšlo kompostavimo metu dalimis įterptos bioanglies (Bi), gautos iš kukurūzų šiaudų, priedas gali paskatinti kompostavimo procesą, pagerinti pagaminto komposto kokybę ir sumažinti NH_3 išsiskyrimą. Kompostavimo krūvoms sudaryti buvo sumaišytas šviežias vištų mėšlas ir kukurūzų šiaudai (2:1 m/m). Bioanglis (10 % m/m) į komposto krūvas buvo įterpta skirtingais būdais: vieną kartą 10 % eksperimento pradžioje (OTABi) ir dalimis 2,5 % kas 0, 3, 7 ir 15 kompostavimo dienų (SABi). NH_3 emisija matuota vykdant stendinį kompostavimo eksperimentą. Siekiant įvertinti komposto fitotoksiškumą ir brandą, Petri lėkštelėse buvo atlikti daigumo bandymai. Palyginti su kontroliniu (be bioanglies) ir OTABi variantais, SABi turėjo teigiamą įtaką (40 ir 33 %) komposto bendrosioms savybėms ir sumažino suminę NH_3 emisiją. Nors OTABi variantas paspartino komposto skaidymąsi, jis nepadidino humifikacijos. Subrendusio komposto SABi variante huminių medžiagų buvo 17 ir 40 % daugiau nei kontroliniame ir OTABi variantuose. Be to, įterpus SABi, huminių rūgščių anglies ir humifikacijos indekso vertės buvo gerokai didesnės nei kitų variantų. Palyginti su kontroliniu variantu, kompostavimo pabaigoje abu bioanglies panaudojimo būdai pasižymėjo maža vandenyje tirpios organinės anglies koncentracija ir dideliu sėklų daigumo indeksu.
Tyrimo duomenys rodo, kad, kompostuojant vištų mėšlą ir siekiant sumažinti azoto nuostolius, sušvelninti NH_3 emisiją ir padidinti humifikaciją, bioanglies įterpimas dalimis yra labai svarbi praktika.

Reikšminiai žodžiai: daigumo indeksas, humifikacija, kompostavimo charakteristikos, NH_3 išsiskyrimas.