Journal of Science and Technology in Civil Engineering, HUCE, 2026, 20 (1): 47–58

STUDY ON TREATMENT OF HUMAN WASTE USING CO-COMPOSTING WITH AGRICULTURAL WASTE TOWARD TO RESOURCE RECOVERY

Do Hong Anh[a,*], Nguyen Viet Anh[a]

[a] *Faculty of Environmental Engineering, Hanoi University of Civil Engineering, 55 Giai Phong road, Bach Mai ward, Hanoi, Vietnam*

Article history:
Received 02/10/2025, Revised 04/3/2026, Accepted 19/3/2026

Abstract

According to World Health Organization guidelines, human waste needs to be composted for 1–2 years before being reused. In Vietnam's climatic conditions, along with the custom of adding fillers (lime, ash, etc.), the Ministry of Health has a requirement for hygienic latrines that human feces should be composted for at least 6 months to destroy pathogens before agriculture uses. In fact, not only in areas specializing in growing vegetables and crops, but also in rice growing areas, the above incubation period is not followed, so the risk of exposure is very high. This study evaluates the co-composting of waste from dry latrines using mixing methods to optimize decomposition and pathogen die-off. To shorten the composting time while still ensuring the safe reuse of excreta in agriculture, the study on the aerobic composting model combined with mixing waste from latrines with agricultural waste was taken place and shown that after 4 months of composting, the composted material is obtained, ensuring hygiene and safety according to the instructions in Circular 41/2014/TT-BNNPTNT on Regulations on main quality indicators and limiting factors in organic fertilizers and other fertilizers, reduced the required time by 2 months as recommended by the MOH and 8 months by the WHO.

Keywords: co-composting; well mixed; agricultural waste; human excreta; safe reuse.

https://doi.org/10.31814/stce.huce2026-20(1)-04

1. Introduction

According to QCVN 01:2011/BYT [1], a dry toilet is a system for collecting and treating human feces and urine on-site; a hygienic toilet is one that ensures the isolation of human feces, prevents untreated feces from coming into contact with animals and insects, is capable of destroying pathogens in feces, does not cause unpleasant odors, and does not pollute the surrounding environment; a dry toilet is one that does not use water for flushing after each bowel movement, the fecal pile is covered with ash, and the feces are stored and treated under anaerobic composting conditions. Composting is the process of converting organic waste into a nutrient-rich soil amendment, included four phases: latent phase, which corresponds for the micro-organism to acclimatize and colonize; growth phase, which is characterized by the rise of biologically produced temperature to mesophilic level; thermophilic phase, in which the temperature rise to the highest level for most effective of pathogen destruction, proteins, lipids, and complex polysaccharides such as cellulose and hemicellulose are rapidly broken down by the heat produced; maturation phase, where the temperature decrease, in which the fermentation takes place is slow and favor humification, that is, the transformation of some complex organic to humic colloids closely associated with minerals and finally to humus [2]. During the composting process, microorganisms consume oxygen and produce carbon dioxide and water, in addition to

*Corresponding author. *E-mail address:* anhdh@huce.edu.vn (Anh, D. H.)

carbon dioxide, ammonia and other volatile compounds are also produced. Nitrification reaction ammonia, a by-product from waste in form of ammonium ion, is biologically oxidized to become nitrite and finally nitrate. Microorganisms in a typical aerobic compost pile include three main types: bacteria, actinomycetes, and fungi. The primary agents are bacteria, particularly thermophilic bacteria, actinomycetes and fungi are also present, found in significant numbers during the steady-state phase of aerobic composting. Approximately 100,000 types of fungi have been found in aerobic compost piles [3]. The composting process is an eco-friendly and sustainable way to manage organic waste and it can have a number of benefits for the environment. Composting can help to improve soil quality, and conserve water. It can also help to reduce the amount of waste that goes to landfills, which can help to protect human health and the environment [4].

The types of dry toilet currently being used in Vietnam are all designed to isolate waste from the soil and groundwater environment, so this can be a limitation for the decomposition process in the septic tank due to the lack of diversity in the microbial population [5]. In addition, the lack of uniform mixing of waste with addition materials such as ash and lime reduces the ability of pathogen die-off [6]. Innovative dry toilets developed around the world show complex equipment and require a lot of energy [7]. Human excreta, if not collected and treated hygienically, will pollute water sources, food, the environment and cause many diseases, including diarrhea, worms, skin, gynecological, eye and other diseases. Vietnam economy mainly relies on agriculture with the habit of using human excreta to fertilize for the field, besides, the low awareness of hygiene causes serious environmental pollution.

Adult feces contains 25% of the solid mass being mainly organic matter including: microbial biomass (25%–54%) [8], protein or nitrogen-containing compounds (2%–25%), carbohydrates or undigested food (25%), undigested lipids (2%–15%) [9]. Therefore, the carbon content in feces is 44%–55% by dry weight, and volatile organic matter is 92% by dry weight, the nitrogen content in feces is about 5–7% [8, 9]. In the rural areas of the Red River Delta, with the habit of reusing human excreta as fertilizer, most households using dry toilets have this need. Therefore, ensuring hygiene and safety when reusing this type of waste is necessary. The research results show that the process of decomposition and pathogen die-off in a single vault latrine with added ash and lime (a type dry of toilet commonly used in rural areas of the Red River Delta) is very limited. After nine months of incubation, pathogenic microorganisms in the toilet still do not meet the standards of the MOH (Ministry of Health) and WHO (World Health Organisation) [6]. Other results showed that aerobic composting is a potential solution for pathogen die-off but it requires up to 4 months of composting time and addition of biological seeding [10, 11].

According to Zhang's study results, the C/N ratio is one of the important indicators at the initial of manure composting, which can be regulated by bulking materials such as straws, sawdust, and corn stalks to improve microbial activities for composting research at the lab scale [12]. However, the utilization of bulking materials in composting (1) can increase the volume of raw materials (decrease the volume of pig manure to be treated) due to their low density; (2) results in elevated composting costs, including transportation expenses and the procurement costs of bulking materials; and (3) possibly extends the composting period due to the refractory property of lignocellulose [13, 14]. Mature compost inoculation appears to meet these needs. It is widely recognized that inoculating external microbial agents into the composting process can alter bacterial community succession, enhance enzyme activities, and improve the temperature [15]. Therefore, mature compost inoculation could accelerate the inactivation of pathogens, the degradation of carcasses, and the maturation of the compost pile humification process, to reduce the composting duration and is suitable for the farming practices of rural areas in the Red River Delta. In order to strengthen environmental pollution control, control epidemics, protect people's health, and recover useful resources in waste for agriculture uses, this study evaluates the process of decomposing waste from dry toilet under co-composting conditions, with mixing, to find suitable solutions to improve the decomposition process, reducing of composting duration time for safe reuse of human excreta in agriculture.

2. Material and methods

2.1. Composting material

Faeces were collected from ventilated single-vault latrines where the feces dropped in a storage chamber which was built of bricks plastered with cement mortar, placed under the concrete floor. The storage chamber was used to store the faeces to which about 100 g of particular additive (either ash or lime powder) was sprinkled after each defecation. 200 kg of faeces from single-vault latrines with added ash and lime during use was collected from households in Kim Bang Commune, Ninh Binh province. It was mainly collected from the top of the latrine storage chamber, with most of it being new waste with a retention time of 0 to 3 months. After being removed, the waste was bagged and transported to Hanoi on the same day.

a. Additives

Organic waste: selected for the compost experiment is agricultural waste common in the Northern rural area included dried rice straw and water hyacinth. The process of preparing raw materials from agricultural waste is carried out as follows: 8.5 kg of dried rice straw, just collected from the field after the spring crop in Ngoc Hoi commune, Thanh Tri, Hanoi; 20 kg of water hyacinth collected from the pond area of Ngoc Hoi commune, Thanh Tri, Hanoi. Both dried straw and water hyacinth were cut into 2 cm long pieces.

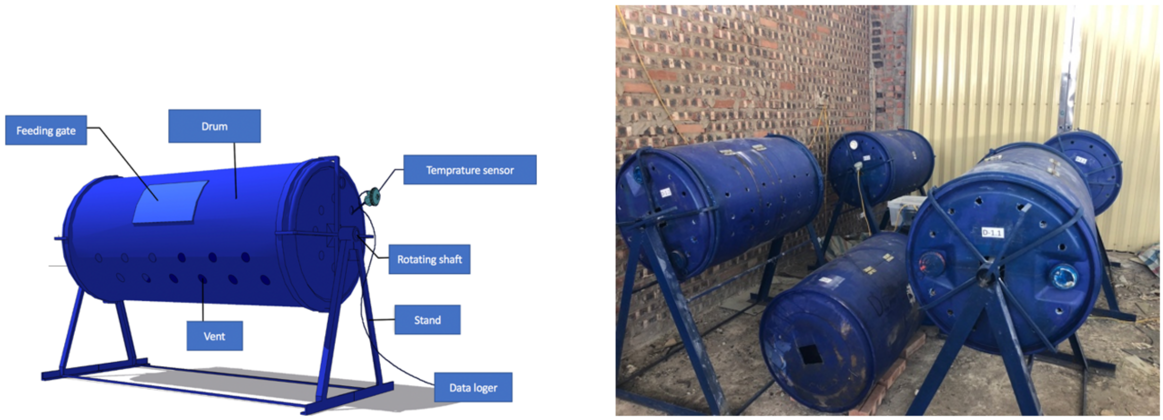
Biological additives: The selected bio-additive is Sagi-bio which has been licensed by the General Department of Environment since 2013. It includes useful strains of microorganisms belonging to the group of mesophilic *Streptomyces* actinomycetes (optimal growth temperature 15 °C – 37 °C) that strongly synthesize extracellular enzymes (cellulases, amylases and proteinases) capable of producing antibiotics, inhibit mold, Gram-negative bacteria, *Lactobacillus* bacteria has a strong inhibitory effect on pathogenic bacteria (Coliform, *Salmonella*).

b. Worm egg preparation

Selected pig feces were highly positive for *Ascaris* egg. Pig feces samples containing *Ascaris* eggs will be mixed thoroughly with tap water and filtered through sieves with pore sizes of 500, 200, 100 µm to separate large trash. The water passed through the sieve will be stored in a bucket and settled, then decant the water above, the sediment at the bottom of the bucket after passing through a 100 µm sieve will be filtered through a sieve with pore size 20 µm. The *Ascaris* eggs remaining above this sieve will be collected into a 50 ml falcon tube, then centrifuged at a speed of 70 rpm for 5 minutes with the purpose of letting the eggs settle to the bottom of the falcon tube, decanting the water and float above then fill nearly full 0.05 M H_2SO_4 solution into the falcon tube. Store *Ascaris* egg solution at 4 °C [16], check and determine the content of worm eggs in the final solution. *Ascaris* egg content in the final researching solution is 67×10^3 eggs·ml^{-1}. Then this solution is put into 130 tea bags with a filter hole diameter of 20 µm [17], to create a *Ascaris* egg density equivalent to 200 eggs/bag, put 3 µl of the above solution into the tea bags with a filter pore size of 20 µm [18]. Before being loaded into the experiments, the *Ascaris* egg teabag will be placed in a rattan ball to avoid tearing during the mixing process. This method has been applied in a number of studies by Peter Jensen [17] and Tu Vu-Van [19].

2.2. Experiment set up

There are 8 drums made of composite with diameter of 500 mm, length of 900 mm, volume of 220 liters, around the body of the drum, 4 rows of holes are punched (diameter 10 mm) along the length of the drum spaced between the holes are 150 mm. On the body of the barrel, there is a triangular material intake door, size 250 × 250 mm. Inside the barrel, there are V-shaped stainless-steel sheets arranged staggered for the purpose of mixing the compost materials evenly during processing. The drums are placed on an X-shaped steel rack with a rotating shaft made of 20 mm diameter steel pipe attached to bearings at both ends. The experimental incubations are shown in Fig. 1.



(a) drum (b) experimental incubations

Figure 1. Experimental incubation for composting

Based on the C/N ratio of the individual materials, conduct a preliminary calculation of the volume loaded into the drums to ensure the C/N ratio of the mixture is in the range of 25–30/1 [3]. A C/N ratio of 25–30/1 is suitable for composting, as carbon is the energy source and nitrogen is responsible for building cell structures. High nitrogen levels increase the risk of ammonia evaporation. A C/N ratio higher than this range hinders microbial growth due to nutrient deficiency. The compost pile will heat up less, and the decomposition process will be slower. At the laboratory, weigh each type of material to load into the drums according to the weight ratio according to Table 1 below.

Table 1. Composition materials of the experiments

Material	Weight (kg)						
	D0-1 D0-2	D1-1 D1-2	%	D2-1 D2-2	%	D3-1 D3-2	%
Faeces	40	40		21.6		21.6	
Lime powder	0	3.5	8	2	8	2	8
Dried rice straw	0	0		4.1	10	4.1	10
Water hyacinth	0	0		9.6	25	9.6	25
Sagi-bio	-	-		-	-	0.01	-
Total	40	43.5		37.3		37.3	

Each drum is filled with 13 rattan balls containing *Ascaris* eggs tea bags. The remaining 12 *Ascaris* egg tea bags are preserved in 0.05 M sulfuric acid solution in the laboratory refrigerator as a control sample. All drums are equipped with automatic temperature sensors connected to the data logger.

2.3. *Experimental design*

Experimental procedures are presented in detail in Table 2. Samples were taken in duplicate and analytical results were calculated with the average value.

Table 2. Experimental procedures

	D0-1 D0-2	D1-1 D1-2	D2-1 D2-2	D3-1 D3-2
Operation	No mixing	The drums were rotated 5–10 times at 0, 3, 7, 14, 28, 90, 120 days		
Sampling	Samples were taken at 0, 14, 28, 90, 120 days			
Analysis parameter	pH, TS/VS, *E. coli*, OC, TN, TK, PO_4-P, NH_4-N at 0 and after 120 days Take out 02 tea bags from drums and 01 blank tea bag, count the viable/non viable egg in each tea bag			

2.4. *Analytical method and sampling preparation*

The sample was pre-processed by drying at 37 °C and homogenizing with a grain mill. Sludge characteristic such as TS, VS, OC, PO_4-P, NH_4-N, TN, were assessed according to Vietnamese Standard Methods issued by Circular No10:2021/BTNMT. *E. coli* were analysis following the Vietnamese standard method issued by Circular No 27:2016/BNNPTNT. Temperature data was recorded in data logger automatically. Viable helminth eggs were counted via microscope after using NaOH 5% and $NaNO_3$ saturated solution for floating [20].

3. Results and discussions

3.1. *Effect of manure treatment*

Fig. 2 below shows the variation of temperature in drums over experiment time.

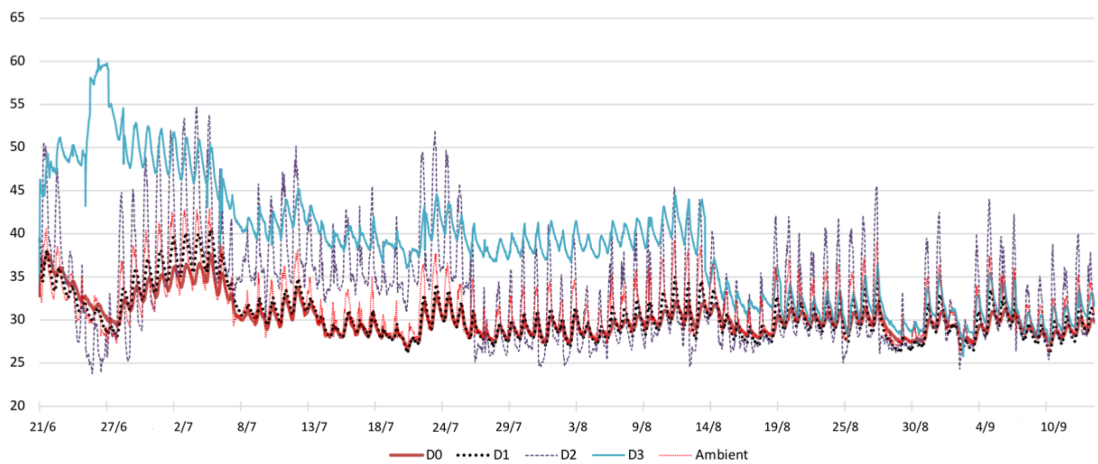


Figure 2. Temperature of the drums during the first 3 months of the experiment

The D2 and D3 drums had a temperature increase during the experiment that was 8 to 10 °C higher than the air temperature. The D3 drum with seeding had a temperature increase to 60 °C on the 5th day of incubation. This temperature lasted for about 1 day and then gradually decreased. With that temperature, the effectiveness of destroying pathogens in the model was quite high, as shown in Fig. 3. This result is similar to the study of Cheng et al. when conducting composting of chicken manure and molasses, the temperature on the first day rose to 50.9 °C in day 13 and decreased to the ambient temperature of 33.5 °C [21, 22]. The experiment result of Trpetckul and colleagues when composting with coconut tree trunks and cow dung showed that, in early days of composting, the temperature reached 56 to 58 °C and the temperature maintained for 9 to 11 days before dropping to the ambient temperature [23]. The D2, due to non seeding, has a slower temperature increase and the highest temperature achieved is lower than tank D3, however, the time to maintain the temperature in the tank higher than the air temperature is quite long, about 2 months. At this phase, in the presence of thermophilic microorganisms, easily biodegradable organic matter is utilized, and hydrocarbon chains are broken down, causing the temperature of the compost pile to rise, temperatures ranging between 45–55 °C with peaks reaching sometimes up to approximately 80 °C [24] create favorable conditions for the pathogen die-off. In the D0 and D1, no temperature change (compared to ambient temperature) was observed during the entire experimental period, and the temperature in these drums even tended to be lower than air temperature and fluctuated less during the day. Despite the same aeration regime (mixing), the heating process in D1 did not occur, indicating that the microbial respiration process was limited by reasons such as the C/N ratio being unsuitable for aerobic composting (C/N was 5–10 respectively) [25]. The temperature achieved in D2 and D3 is the result of microbial respiration. Although the temperature's level and the maintenance time in the D3 model were lower than in the studies by Cheng et al. and Trpetckul, the pathogen control efficiency of the experimental model yielded equivalent results. This suggests that the frequency of mixing during the stabilization phase significantly contributed to the pathogen control efficiency of the compost pile.

3.2. Factor effecting on pathogen die off

a. *E. coli* assessment

Fig. 3 below shows that, after 4 weeks, the pathogen die off in the D2 and D3 which mixed by human excreta and agricultural waste was achieved a 3 log of reduction, *E. coli* density remaining in the compost sample after 4 weeks was 9.7×10^2 CFU/gTS and 3.7×10^2 CFU/gTS meeting the requirements according to the regulations on main quality indicators and limiting factors in organic fertilizers issued with Circular 41/2014/TT-BNNPTNT on *E. coli* indicators [26]. David et al. study had shown the same result when evaluate the microbial die-off in a waste composting latrine, a 4-log reduction in *E. coli* was observed over the first sixteen weeks of composting at both locations and depths, after which *E. coli* was undetectable [27]. The pathogen die-off efficiency in D2 and D3 drum was lower than that in the study by Son Dang T.T. [28], it is possible that the drum has holes in it, causing the temperature in the drum to quickly dissipate, not giving enough time to destroy pathogen.

The reason why *E. coli* in initial sample of the mixed drum was higher than that of the control drum (D0) was because the bedding material (duckweed taken from a pond near a residential area) had a pre-existing amount of *E. coli*. Comparison with the reduction efficiency of D0 drum (control sample) shows that the pathogen die off efficiency in mixed drums (D2, D3) is higher than that in non-mixed one. After 4 weeks of composting, the density of *E. coli* in control drum (D0) decreased below 1 log while mixed drum (D2, D3) was 3 log reduction, and after 6 weeks, the density of *E. coli* in all drums met the requirements according to Circular 41, which shows that turning exterior portions into the self-heating drum interior aids exposure of all portions of the mass to destructive temperatures. For this reason, drums either need to be turned periodically or configured to ensure that all raw manure is exposed to time–temperature conditions that will meet acceptable pathogen reduction limits. Similar results were also obtained by Millner in his 2014 study, adding straw to cow manure compost resulted in *E. coli* and *Salmonellae* were reduced from 8 to 9 $\log_{10}$ CFU g^{-1} to undetectable levels within 7 days in all drum sections except for the manure-only drum in which 3–4 logs of reduction were obtained [21].

After 2 hours of lime addition, the *E. coli* density in D1 met the standards according to WHO guidelines [29] and regulations of the Ministry of Agriculture and Rural Development 2014 on organic microbial fertilizers. Fig. 3 also shows that, in all 3 types of drums, the *E. coli* decreased by 2–3 logs between weeks 4 and 6, this result may be a consequence of the rapid decrease in humidity in the drums, at the time of sampling (week 6) the humidity in drums D0, D2, D3 were 32%, 22%, 28.2% and 23% respectively, which are unfavorable conditions for the survival of pathogenic bacteria.

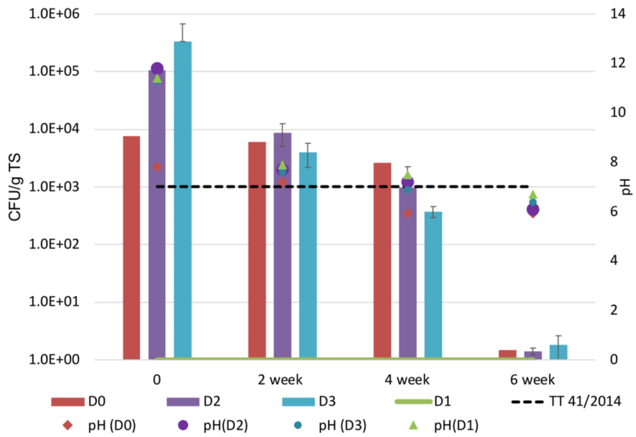


Figure 3. *E. coli* density in experiments

b. *Ascaris* viability assessment

Fig. 4 below shows that the rate of inactivated *Ascaris* egg in drums D2 and D3 is higher than that in drums of D0 and D1 and much higher than that in the control sample in the laboratory, which shows that the aerobic composting process, combined with the mixing and increasing the temperature of the drum, has significantly increased the inactivation rate of *Ascaris* eggs [17, 27].

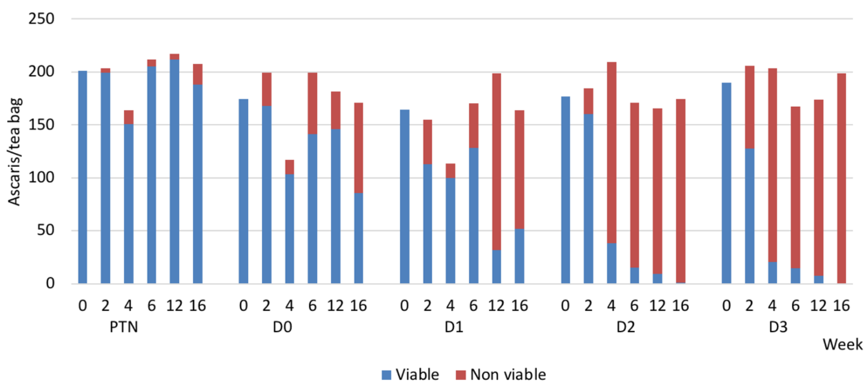


Figure 4. The changing of *Ascaris* eggs over time and according to composting conditions

The number of *Ascaris* egg in the control sample in the laboratory and the blank sample in the D0 which simulates the double vaults composting latrine shown that, the number of inactivated eggs increased during the composting process (Fig. 5 below), after 4 months the *Ascaris* eggs had a mortality rate of 9% and 50% respectively, which showed that the addition of lime and ash during the use of the latrine also contributed significantly to the effectiveness of killing worm eggs during the incubation process, however, the rate of occurrence was slower than D1, D2, D3.

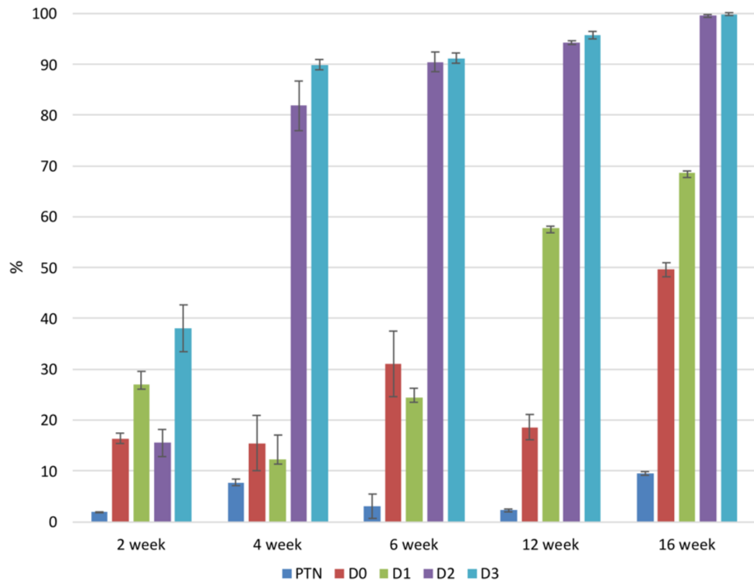


Figure 5. Efficacy of *Ascaris* egg removal in experiments

After 4 months, with blank drum (D0), the amount of *Ascaris* eggs in the compost sample was still high, the efficiency of inactivating eggs was only 50%, the amount of worm eggs decreased by 1 log, this result is similar to Jensen's study [17]. However, the composting condition of pretreatment with lime (D1) showed better inactivation efficiency than D0 (70% reduction of egg) and the *Ascaris* eggs in the D1 sample is still 58 viable eggs/gTS. Composting drum of D2 and D3 were significantly more effective in inactivating eggs, with rates of 99.9 and 99.6% respectively. In addition, the density of *Ascaris* eggs in samples of D3 and D2 were 0.3 and 0.8 viable eggs/gTS, respectively, and met the requirement of WHO guidelines, 2006. It was shown that the maximum temperature increase of 55 °C – 60 °C and maintained from 40 °C – 45 °C for 2 months is an important factor in destroying worm eggs [30]. The amount of *Ascaris* eggs in the compost sample decreased by 2 log after 4 months, those results are comparable to those of other studies using similar isolation methods to evaluate *Ascaris* inactivation [27, 30, 31] and this study achieved more effective than David's [27], it is possible that the addition of ash and lime during latrine use resulted in a higher rate of inactivated worm eggs during the incubation process.

3.3. Nutrient content of composted sample

Table 3 below shows the nutrient content of composted material after 4 months of composting in aerobic condition with or without the additional material and biological seeding according to some typical indicators.

The pH in all drums D1, D2, D3 are in the neutral pH range, suitable for plant growth conditions. During high temperature composting, there is significant nutrient losses – particularly nitrogen about 45% – 75%, that is a major challenge, diminishing the compost's fertilizer value [32]. It is the same with this study result's which is nitrogen loss in D1, D2, D3 is about 70%, 45% and 71% respectively. Extensive studies have shown that ammonia volatilization is the primary cause of nitrogen loss during high-temperature aerobic composting, accounting for 79–94% of nitrogen loss which occurs in the thermophilic phase, estimated to account for 40–70% of the initial nitrogen content [33]. However, the composted material still contains a certain amount of nutrients, for example: the total nitrogen concentration in D1, D2, D3 is still remain at amount of 0.39%, 0.57% and 0.28% respectively, the organic carbon (OC) is 0.35%, 0.83% and 0.69% respectively calculated on dry matter.

Table 3. Nutritional composition of materials before and after composting

	Unit	D0					D1				
		Before composting		After composting		E%	Before composting		After composting		E%
TS	%	57.9 62.2 / 60.1	±3.04	81.3 81.5 / 81.4	±0.13		60.0 61.3 / 60.7	±0.92	88.3 90 / 89.2	±1.2	
VS	%TS	5.9 7.4 / 6.7	±1.06	8.9 9.1 / 9.0	±0.14		6.8 6.8 / 6.8	±0	11 11 / 11	±0	
OC	g/kg TS	11.5 11.6 / 11.5	±0.05	4.2 4.3 / 4.3	±0.06	0.29–0.3	9.2 11.3 / 10.3	±1.50	3.5 3.5 / 3.5	±0.01	0.35–0.4
T-N	g/kg TS	14.8 15.5 / 15.2	±0.53	5.3 6.0 / 5.7	±0.47	0.61–0.63	9.3 14.2 / 11.7	±3.44	3.7 4.1 / 3.9	±0.26	0.59–0.7
PO_4-P	g/kg TS	7.4 7.9 / 7.7	±0.32	2.1 2.3 / 2.2	±0.14	0.7–0.71	7.2 9.3 / 8.2	±1.51	1.4 2.3 / 1.8	±0.69	0.74–0.81
T-K	g/kg TS	16.9 19.2 / 18.0	±1.62	17.3 18.3 / 17.8	±0.67	0–0.04	17.2 19.4 / 18.3	±1.59	18.0 18.3 / 18.2	±0.23	0–0.05

	Unit	D2					D3				
		Before composting		After composting		E%	Before composting		After composting		E%
TS	%	53.4 56.5 / 55.0	±2.19	85.6 85.6 / 85.6	±0		63.6 64.8 / 64.2	±0.85	88.3 88.9 / 88.6	±0.42	
VS	%TS	8.8 11.9 / 10.4	±2.19	17.5 18.5 / 18	±0.71		8.3 12.1 / 10.2	±2.69	16.5 17.7 / 17.1	±0.85	
OC	g/kg TS	29.6 32.3 / 30.9	±1.87	7.3 9.3 / 8.3	±1.41	0.37–0.51	28.9 29.8 / 29.4	±0.60	6.7 7.1 / 6.9	±0.29	0.52–0.53
T-N	g/kg TS	7.3 11.8 / 9.6	±3.16	4.9 6.4 / 5.7	±1.07	0.33–0.45	8.4 10.4 / 9.4	±1.41	2.6 3.0 / 2.8	±0.31	0.68–0.71
PO_4-P	g/kg TS	6.2 13.3 / 9.7	±5.02	0.8 1.3 / 1.1	±0.33	0.86–0.9	8.6 10.5 / 9.6	±1.34	0.6 1.0 / 0.8	±0.32	0.9–0.93
T-K	g/kg TS	29.6 32.3 / 30.9	±1.87	26.2 28.2 / 27.2	±1.40	0.11–0.12	28.5 31.6 / 30.0	±2.25	25.4 26.7 / 26.7	±0.91	0.1–0.15

Note: $\frac{\text{min} - \text{max}}{\text{TB}}$ ± SD.

The treatment efficiency and the ratio of nutrients in the compost sample after composting according to some main indicators are shown in Fig. 6 below. The total potassium remained almost unchanged after composting, this result is similar to Polprasert [2]. For the composting model without adding agricultural waste, T-K in the composted sample decreased by 4% – 5%, and decreased by 10% – 15% for the composting model with adding agricultural waste. The amount of organic carbon decreased from 30% – 53% for drum with added agricultural waste, this result is lower than the research results of Huyen, 2010 [34]. Compost macronutrients of nitrogen in D1, D2, D3 are 0.93%, 0.73%, 0.84%; phosphorus 0.73%, 0.62%, 0.86%; potassium 0.17%, 0.29%, 0.28% respectively. This result is higher than Hidayat et al. which co-composting with mixed of cow manure, rice straw and marine organic on potassium and phosphorus [35].

The analysis data of the composted material showed that the VS/TS ratio in the composting material of drum D1 was lower than that of drum D2 and D3, which showed that the decomposition process in the drum with additional of lime only, no mixing and similar to the use of double vaults composting latrine in the Red River Delta, Vietnam had a lower decomposition efficiency than the compost piles with added bio-additive and agriculture waste. Bach's studied the relationship between the amount of VS and the amount of CO_2 produced from compost piles and found that the greater the VS in the waste, the more CO_2 is produced, and most of the substances in straw are used by microorganisms [36]. Co-composting of dry latrine and agricultural waste helps to treat solid waste generated in rural areas, making the most of resources while still ensuring safety for reuse purposes.

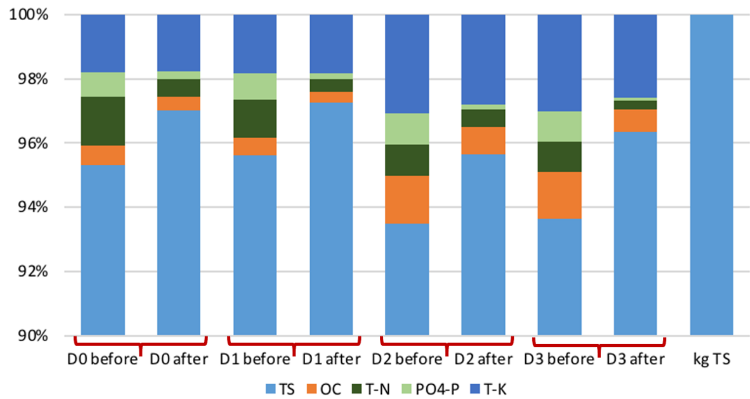


Figure 6. The ratio of substances in material before and after composting

4. Conclusions

Aerobic composting of human excreta and agriculture waste along with bio-additives will bring the benefit for the decomposition of organic matter, pathogen die-off efficiency from 2 log – 3 log is higher than the static composting model which is simulate the double vault composting toilet (1 log), and the rate of inactivated worm eggs is approximately 99% higher than the static composting model (50%). Pathogenic microorganisms, with the *E. coli* indicator, have decreased to 10^2 meeting the requirements according to WHO guidelines and Circular 41/2014 of the Ministry of Agriculture and Environment on regulations on main quality indicators and limiting factors in organic fertilizers and other fertilizers. Composted material has low moisture, can be easily packaging and transporting, and contains a certain amount of organic carbon, T-N, PO_4-P and T-K, making it suitable for reuse as soil conditioner in agriculture. It is necessary to research and commercialize drum products, from which mass production can be carried out, using locally available materials.

Acknowledgment

The authors would like to sincerely thank the Division of Water Supply and Sanitation, Faculty of Environmental Engineering, Hanoi University of Civil Engineering for providing experimental equipment, and the Provincial Medical Center, the local authorities and households in Kim Bang Commune, Ninh Binh Province for creating favorable conditions to support the research team in conducting this study.

References

[1] QCVN 01:2011/BYT (2011). *National technical standards for toilets – Conditions for ensuring hygiene*. MOH.

[2] Polprasert, C. (2007). *Organic waste recycling: technology and management*. IWA Publishing, London.

[3] Jenkins, J. C. (2005). *The humanure handbook: a guide to composting human manure*. Jenkins Publishing, Grove City, PA.

[4] Harrison, B. P., Gao, S., Gonzales, M., Thao, T., Bischak, E., Ghezzehei, T. A., Berhe, A. A., Diaz, G., Ryals, R. A. (2022). Dairy Manure Co-composting with Wood Biochar Plays a Critical Role in Meeting Global Methane Goals. *Environmental Science & Technology*, 56(15):10987–10996.

[5] Jeroen, H. J. E., Belen, T. (2013). *Project report on Cross-sectional Study on Vietnamese and Tazania latrines*. London School of Hygiene & Tropical Medicine, London.

[6] Anh, N. V., Hang, D. T., Bang, L. T. (2014). Evaluation of decomposition and pathogen die-off in a single vault dry latrine. *Journal of Science and Technology in Civil Engineering*, 20:66–74.

[7] Anh, D. H. (2019). *Research suitable solutions to improve treatment efficiency, aiming at safe reuse of waste from on-site sanitation facilities in rural areas*. Hanoi University of Civil Engineering.

[8] Guyton, A. C., Hall, J. (2000). *Textbook of medical physiology*. 12th edition, W.B. Saunders, Philadelphia, PA.

[9] Wierdsma, N. J., Peters, J. H., Weijs, P. J., Keur, M. B., Girbes, A. R., van Bodegraven, A. A., Beishuizen, A. (2011). Malabsorption and nutritional balance in the ICU: fecal weight as a biomarker: a prospective observational pilot study. *Critical Care*, 15(6):R264.

[10] Do, H.-A. (2024). Study on the characteristic of human excreta, orienting technological solutions for treatment and safe reuse for agricultural uses. *Journal of Science and Technology in Civil Engineering*, 18(3V).

[11] Do, H.-A., Anh, N. V. (2016). Evaluation results of the single-vault dry latrine waste decomposition process and testing of improvement measures. *Vietnam Water Supply and Drainage Magazine*, 6(110): 68–73.

[12] Zhang, M., He, L.-Y., Liu, Y.-S., Zhao, J.-L., Zhang, J.-N., Chen, J., Zhang, Q.-Q., Ying, G.-G. (2020). Variation of antibiotic resistome during commercial livestock manure composting. *Environment International*, 136:105458.

[13] Lu, W., Ye, R., Ming, Z., Pan, C., Abbas, Y., Stegmann, R., Wang, H. (2020). Performance Evaluation in Composting of Sewage Sludge with Different Bulking Agents. *Journal of Environmental Engineering*, 146(6):05020002.

[14] Sun, Z.-Y., Zhang, J., Zhong, X.-Z., Tan, L., Tang, Y.-Q., Kida, K. (2016). Production of nitrate-rich compost from the solid fraction of dairy manure by a lab-scale composting system. *Waste Management*, 51:55–64.

[15] Wu, D., Yue, J., Gao, W., Wang, F., Qu, F., Song, C., Wei, Z. (2024). Functional genes are the key factors driving the Fenton-like reactions to promote the hydrolysis of lignocellulosic biomass during composting. *Industrial Crops and Products*, 210:118131.

[16] Brownell, S. A., Nelson, K. L. (2006). Inactivation of Single-Celled *Ascaris suum* Eggs by Low-Pressure UV Radiation. *Applied and Environmental Microbiology*, 72(3):2178–2184.

[17] Jensen, P. K. M., Phuc, P. D., Konradsen, F., Klank, L. T., Dalsgaard, A. (2009). Survival of *Ascaris* eggs and hygienic quality of human excreta in Vietnamese composting latrines. *Environmental Health*, 8(1).

[18] Chien, B. T., Phi, D. T., Chung, B. C., Stenström, T. A., Carlander, A., Westrell, T., Winblad, U. (2001). Biological study on retention time of microorganisms in faecal material in urine-diverting eco-san latrines in Vietnam. In *1st International Conference on Ecological Sanitation, Nanning, People's Republic of China, internet dialogue on ecological sanitation, www. ias. unu. edu/proceedings/icibs/ecosan/bui. html*.

[19] Vu-Van, T., Pham-Duc, P., Winkler, M. S., Zurbrügg, C., Zinsstag, J., Le Thi Thanh, H., Bich, T. H., Nguyen-Viet, H. (2017). *Ascaris lumbricoides* egg die-off in an experimental excreta storage system and public health implication in Vietnam. *International Journal of Public Health*, 62(S1):103–111.

[20] Cong, L. D. (2000). *Laboratory techniques, specializing in parasitology and entomology*. National Institute of Malariology Parasitology and Entomology.

[21] Millner, P., Ingram, D., Mulbry, W., Arikan, O. A. (2014). Pathogen reduction in minimally managed composting of bovine manure. *Waste Management*, 34(11):1992–1999.

[22] Ch'ng, H. Y., Ahmed, O. H., Kassim, S., Majid, N. M. A. (2013). Co-composting of pineapple leaves and chicken manure slurry. *International Journal of Recycling of Organic Waste in Agriculture*, 2(1):23.

[23] Tripetchkul, S., Pundee, K., Koonsrisuk, S., Akeprathumchai, S. (2012). Co-composting of coir pith and cow manure: initial C/N ratio vs physico-chemical changes. *International Journal of Recycling of Organic Waste in Agriculture*, 1(1):15.

[24] da Silva Gaspar, S., Assis, L. L. R. d., Prado, M. P. R. d., Pedroso Miguel, M. G., Magno dos Reis Ferreira, G., Schwan, R. F., Pasqual, M., Rigobelo, E. C., Castro, R. P., Buttrós, V. H., Dória, J. (2023). Diversity and enzymatic activity of the microbiota isolated from compost based on restaurant waste and yard trimmings. *Frontiers in Sustainable Food Systems*, 7:1013361.

[25] Finstein, M. S., Morris, M. L. (1975). Microbiology of municipal solid waste composting. *Advances in Applied Microbiology*, 19:113–151.

[26] Circular 41/2014/TT-BNNPTNT (2014). *Fertilizer management falls under the state management responsibility of the Ministry of Agriculture and Rural Development*. Ministry of Agriculture and Rural Development.

[27] Berendes, D., Levy, K., Knee, J., Handzel, T., Hill, V. R. (2015). *Ascaris* and *Escherichia coli* Inactivation in an Ecological Sanitation System in Port-au-Prince, Haiti. *PLoS ONE*, 10(5):e0125336.

[28] Son, T. T. D. (2011). Hygiene aspect of manure management and antimicrobial resistance in integrated pig-fish farms in Vietnam. PhD thesis, University of Copenhagen, Denmark.

[29] WHO (2006). *Guidelines for the Safe Use of Wastewater, Excreta and Greywater*. Volume IV, France, 60–69.

[30] Feachem, R. G., Feachem, R. G. A., Bradley, D. J., Garelick, H., Mara, D. D. (1983). *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, volume 1. The International Bank for Reconstruction and Development, The World Bank, Washington, D.C.

[31] Koné, D., Cofie, O., Zurbrügg, C., Gallizzi, K., Moser, D., Drescher, S., Strauss, M. (2007). Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Research*, 41(19):4397–4402.

[32] Chen, M., Wang, C., Wang, B., Bai, X., Gao, H., Huang, Y. (2019). Enzymatic mechanism of organic nitrogen conversion and ammonia formation during vegetable waste composting using two amendments. *Waste Management*, 95:306–315.

[33] Nigussie, A., Kuyper, T. W., Bruun, S., de Neergaard, A. (2016). Vermicomposting as a technology for reducing nitrogen losses and greenhouse gas emissions from small-scale composting. *Journal of Cleaner Production*, 139:429–439.

[34] Huyen, N. T. (2010). Research on solutions to improve the efficiency of septic tank sludge management in Vietnamese cities – a case study for Hanoi. PhD thesis, Hanoi University of Civil Engineering, Hà Nội.

[35] Hidayat, B., Sebayang, N. U. W., Jamilah, Akbar, A. M. (2023). Co-composting cow manure, rice straw with marine organic waste: characterization of compost quality. *IOP Conference Series: Earth and Environmental Science*, 1182(1):012029.

[36] Bach, P. D., Shoda, M., Kubota, H. (1984). Rate of composting of dewatered sewage sludge in continuously mixed isothermal reactor. *Journal of Fermentation Technology*, 62:285–292.