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Evaluation of Recycling and Reuse Animal Waste Treatments Towards Circular Agriculture: A Case Study in Northern Mountain of Viet Nam

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Developing circular agriculture is a common trend around the world to reduce emissions and sustainable development in agricultural production. In Vietnam, circular agriculture has been paid attention to, especially in the livestock sector. This study was conducted in Tran Yen district, Yen Bai province – a northern mountainous district of Vietnam to evaluate livestock waste management activities and the effectiveness of three treatment methods to recycle and reuse livestock waste. The results presented that livestock waste management solutions such as using biogas, composting and vermiculture are common methods used by farmers. All three of these treatment methods have an important role to play in recycle and reuse livestock waste towards circular agriculture. In addition, these solutions have investment costs and technical requirements suitable to the actual production conditions of Vietnamese farmers, so they are highly sustainable. In the coming years, the Government of Vietnam needs practical policy and technical support to improve livestock waste management solutions, promote the circular economy of livestock waste.

Key words: Circular agriculture, Livestock waste, waste recycle, waste reuse, Vietnam

INTRODUCTION

Circular agriculture (CA) or circular economy applies to agricultural systems based on the idea of circular economy, using theories and principles from ecology industry to find ways to reduce natural resource consumption and waste generated in the environment by cycle of materials and energy (Imke and Martin, 2018). It can be consided that CA is agricultural production in a closed cycle in which waste or by–products of one production process are inputs to another process to minimize waste discharge into the environment. From the ecological aspect, circular agriculture is an ecological concept based on the principle of optimizing the use of all agricultural biomass with the aim of the material cycle; reduce both natural resources use and waste discharge into the environment.

From an ecological opinions, CA is an ecological concept based on the principle of optimizing the using of agricultural residues with the aim of cycling of raw materials; reducing both the use of natural resources and the discharge of waste into the environment (Mónica *et al*., 2020). CA plays an important role in the sustainable development of each country such as: i) minimizing the consumption of natural resources by closing material and energy flows in the production process; ii) reduce waste and greenhouse gas emissions through the reuse of agricultural by–products and waste; iii) reduce production costs by saving the cost of inputs and environmental treatment costs. It can be presented that CA is a win–win solution where the Goverment can both solve agricultural environmental problems and establish a sustainable agricultural model with economic efficiency for farmers.

The trend of CA is expending in over the world. In the European Union, circular economy has been prioritized in 6 aspects including: Plastics, food waste, materials; construction and dismantling; biomass fuels and bio–products (EC, 2015). Among them, food waste, biomass and bio–products are directly related to CA. In Germany, CA is carried out in a top–down approach with the basic foundation of the law "Waste management and circular production" that promulgated in 1996. This law has provided a legal framework for agricultural production activities in Germany to produce in a circulation, waste and residues are cycled, reused, recycled and disposed on the suitable ways with the assimilation capacity of the natural environment. In particular, the generation electricity from biofuels from agricultural waste is the most successfull achievement of Germany's Government. In contrast, the approach to CA in the Netherlands is bottom–up, the Dutch government encourages innovations and solutions to implement CA at manufacturing plants, especially for biomass fuels and food waste. In addition, the Dutch Government implements policies to promote and establish the markets for circular materials and products (ISDN, 2018). For Denmark, CA is approached in a symbiotic approach on a regional scale, agricultural production activities are integrated into eco–industrial parks, agricultural wastes is raw material for power plants and biofuels (Francis and Erkman, 2001). In North America and Canada are two typical examples of implimenting CA, In Canada, the program "Farm Environmental Plan" was implemented the first time in Ontario state in 1992, this program focuses on solving environmental problems of farms, especially developing appropriate waste management methods, increasing the activites on how to circulated waste and orientating farms to develope forward ecological and environmental protection (Carruthers and Tinning, 1999). In addition,

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the Canada's Government has issued strict regulations on environmental protection on farms, supported technic and finance for farms that participating in Farm Environmental Plan (FEP), which is consided to be the main reason for the success of FEP. Currently, FEP has been applied in almost regions of Canada and this is considered one of the meaningful directions to help Canada approach the goals of renewable energy development and sustainable development. Meanwhile, the US implements CA with a market–based approach, i.e. the government, enterprises and other legal entities are free to participate in business and provide goods services according to the regulation of supply and demand. As a result, many business models of environmental protections, natural resource management, climate change, and circular products were formed and developed (Nam and Hanh, 2019). In addition, the "Zero Waste" strategy is implemented by many US states with the goal of no longer generating waste into the environment by 2030. The U.S. government also encourages circular initiatives and expands the good circular practices; establish policies to promote public–private cooperation in food waste management, agricultural waste collection and treatment; recycling of agricultural waste and by–products, these activities Facilitate the development CA in the US (Regions of Climate Action, 2017). In Asia, some countries such as India, China and Japan have promoted activity of CA and achieved innitial successes. In India, agricultural production generates a large amount of residue, about 500 tonnes per year (Bhuvaneshwari *et al.*, 2019). However, this amount of residue is currently not fully utilized, Indian farmers often burn residue in the field, that causes of air pollution and soil emission, thereby leading to adverse effects on human health. With that reasons, the India' Government has promoted of biogas technology. This solution is expected to help India make efficient use of agricultural waste and by–products, while generating large amounts of biogas (65 billion m3/year) (Mittal *et al.*, 2019). However, the shortage of waste supply chains in agriculture, coupled with the availability of simple and cost–effective agricultural waste pretreatment technologies, makes the biogas model from waste and Agricultural by–products are main barriers in developing a circular economy in agriculture based on biogas technology in India. (Kapoor *et al*, 2020). In contrast, China is a country that has implemented agriculture at all three levels: macro (national, regional, provincial), medium (symbiotic groups) and micro level (fatories, enterprises). In the agricultural production, at the macro level, has been implemented CA since 2005. At the medium level, agriculture in China focuses on designing and building agroecological models and trading markets for agricultural waste and by–products. At the micro level, cleaner production and ecological design have applied. CA in China is strongly supported by laws such as the Law on Promoting the Circular Economy, the Law on Cleaner Production and the Law on Environmental Protection (Su *et al.*, 2013). A typical program in China for CA is reducing greenhouse gas emissions through recycling of liverstock waste. This program have approved of 62.30% of livestock farms. However, the level of emission reduction has only reached 42.50% of the total emissions generated, due to limitations in technology in waste recycling and lack of synchronization in harmonious between livestock and cultivation activities (Ruishi *et al.*, 2019). In Japan, CA is based on recycling activities at the national scale. The Japanese government established The Basic Law for Establishing a Recycling – Based Society in 2002 that applies to all aspects of life and society. As a result, 70–80% of agricultural waste and by–products are recycled and reused as raw materials for other production processes (Nam and Hanh, 2019). The above studies have showen that the trend of agriculture production is to save natural resources, minimize environmental pollution and adapt to climate change. CA will be the seclected of the most countries in over the world in the coming years to achieve the goal of sustainable agricultural development, adapting to the comtext of climate change.

In Viet Nam, the added value of the agricultural sector increased by 3.88% in 2023 compared to the previous year. Agricultural production is quite good due to favorable weather and improved farming techniques. Production of grain reached 47.9 million tons, an increase of 0.8 million tons compared to the previous year, of which rice production reached 43.5 million tons, an increase of 795 thousand tons due to increased rice productivity in all seasons. With the above agricultural production, it means that generates a large amount of residues annually such as: rice husk and rice straw about 40.8 million tons per year; stems and cobs about 9.2 million tons; coffee pods 1.17 million tons; sawdust about 1.12 million tons... (General Statistics Office of Vietnam, 2022). These residues have the ability to make good use of different purposes such as fuel, litter, animal feed, compost ... However, most of these residues are not used, but are burned in the field or thrown directly into the environment, causing natural resource waste and environmental pollution.

In the livestock sector, according to data reported by the Ministry of Agriculture and Rural Development (2020), the total amount of waste generated from some main livestock is about 60 million tons of solid waste and 114 million m3 of wastewater. This amount of waste is the main caurse of environmental pollution if it is not treated and managed appropriately. Currently, the main treatment methods of livestock waste in Vietnam are: biogas; composting; food processsing; seperate liquid and solid; collecting for sale ... (Cong *et al.*, 2018; Son *et al.*, 2021). However, the current treatment methods of livestock waste in Viet Nam are still inadequate and caurse natural resources degradation and environmental pollution. The ability to circulate and reuse livestock waste plays an important role in solving environmental pollution, minimizing greenhouse gas emissions and saving costs for agricultural production. In fact, in Vietnam there are already many different techniques to enhance circulation and reuse of livestock waste such as: using livestock wastewater to irrigate crops (Giang *et al.*, 2021; Van and Son, 2018), raising worms (Cong and Thu, 2018), fish farming (Son *et al.*, 2014) and raise black soldier flies (Scientific name Hermetia Illucens) (Linh and Nhien, 2022), biogas (Nam *et al.*, 2021; Huong *et al.*, 2020). However, there are currently no studies comparing the economic, technical and environmental effects of these treatment methods at the farm conditions. This study was conducted to analyze the advantages and disadvantages of some popular methods of recycling and reusing livestock waste in Vietnam, including: raising worms, composting and biogas as a basis for proposing appropriate treatment methods for livestock waste towards reducing greenhouse gas emissions, reusing of nutrients in liverstock waste towards circular agriculture in Viet Nam.

STUDY AREAS AND RESEARCH METHODS

Study area

The study was conducted in Tran Yen district, Yen Bai province – A northern mountainous district of Vietnam. Tran Yen is the southern district of Yen Bai Province that consisting of 21 communes. The livestock is an important economic sector in agricultural production in this district. In 2022, the total cattle was over 65,865 heads, poultry 1,755,560 heads, the average annual growth rate of main cattle was over 3.0%, the production of beef was 6,318 tons, poultry was 4,821 tons. Therefore, the livestock has contributed the economic growth for this district. However, the livestock production is mainly grazing in the mountainous areas, the amount of livestock waste has not been treated. Moreover, this district has been efforting to become a new rural district with the agricultural produciton is the main sector, therefore, the livestock development is causing environmental problems in this area.

Methodologies

Data collection

Secondary data collection: Data and documents related to natural, economic and social conditions; the number of livestock; the situation of livestock waste management at the Tran Yen district including Department of Agriculture and Rural Development; Department of Natural Resources and Environment and other related departments.

Questionnaire survey: In this study, a questionnaire was developed to collect information on the characteristics of livestock farms such as raising processes, waste generation rate and waste management of livestock in Tran Yen district. The survey was conducted in 03 Representative communes on livestock of the district, including Hoa Cuong, Y Can and Hung Thinh. The survey households were randomly selected from the list of farms provided by the Department of Agriculture and Rural Development. The total number of survey was 90 farms, 30 farms per commune.

Method for estimating the volume of waste generated

In this study, we used the average waste generation coefficient for livestock issued by the Ministry of Natural Resources and Environment of Vietnam (Table 3) to estimate the amount of waste generated in Tran Yen district. The estimated formula is as follows:

$$TW = A1xEF1 + A2xEF2 + \ldots + An\ x\ EFn$$

Where: TW = Total waste (tons.day–1); $A1 \ldots An$ = Number of livestock 1 ... Number of livestock n (head); $EF1 \ldots EFn$ waste generation coefficient of livestock 1 ... livestock n (kg/head).

Experimental design

To evaluate the effectiveness of treatment methods to reuse and recycle livestock waste, the study conducted 3 experiments including: 1) Vermiculture (*Perionyx excavatus*) to treat livestock manure; 2) Composting; and 3) Biogas. The experimental conditions are familiar with local condition of livestock farms. The details of each experiment are presented in the following part. It is note that in the study site, farmerss often put togather manure of buffalo, cow and pig at the corner of the garden, therefore, this study would like to treat mixed livestock manure that is similar with traditional treatments of farmers and local conditions in the Northmoutain areas of Viet Nam for all three experiments.

Experiment vermiculture to treatment livestock manure: The experiment of treatment livestock manure by vermiculture was arranged in 3 buckets initially put 2 kg of mix livestock manure, with 0.3 kg of earthworm (*Perionyx excavatus*). During the expereient period, the black net was covered to prevent the directly light that cause the growth of worms. Vermiculture are raised for a period of 60 days, adding manure to feed the worms once every 03 days. In the first 30 days feed about 0.2 kg of manure. Over the next 30 days, increase the amount of feed to 0.3 kg of manure as the need for food of worms also increases with the level of growth. The experiment monitored the growth rate of worms after 30 days and 60 days of raising, monitored the temperature, observed the color of manure before and after the experiment, and used senses to check the smell of manure before and after treatment.

Experiment composting for livestock manure: Arrange 3 compost piles with the volume of each compost pile consisting of 10 kg of mixed manure with 1 kg of dry straw; 1 kg of rice husk, 15 grams of Emuniv. The duration of the experiment was 45 days. In the first 5–7 days compost piles were aerobic condition and maintained the humidity about 50–60%. After that, add probiotics, and covered with nylon. The experiment monitored criterias include the amount of manure before and after, the temperature and humidity of the compost pile, used senses to check the color and smell of the compost manure.

Experiment on using Biogas tank for livestock manure: Select 03 representative households have about 10–30 head of cattle and pigs per household and use biogas tanks for waste treatment. Input and output data of these household were recorded including type of livestock; investment cost of biogas system; benefits from the use of biogas; type of feed; the amount of livestock wastewater (liters/day); volume of biogas tank (m3); operating condition of the biogas tank; quaity of wastewater of post–biogas; and difficulties of apply biogas treatment.

Sampling and analysis methods

To evaluate the effectiveness of three different treatment methods, waste samples before and after each treatment were collected and analysed at Viet Nam National Universtiy of Agriculture to compare the characteristic of waste. A total of 18 waste samples were taken (9 each). Detailed information is described in table 1.

All samples were analyzed in the laboratory of the Green Growth Research Institute, Vietnam National University of Agriculture. Specific methods of analysis for each indicator are indicated in table 2.

Methods for evaluating the effectiveness of waste treatment measures

The effectiveness of waste treatment methods is assessed in three aspects: economy, technology, and environment. Specific evaluation criteria include:

Economic efficiency: Investment costs, valued products, labor and profitability of the solution.

Technical efficiency: Difficulty/ease of implementation, convenience, timing, possibility solutions.

Environmental efficiency: the amount of treated waste, the color and smell of waste after treatment.

RESULTS AND DISCUSSIONS

Current status of livestock and waste management in Tran Yen district

Livestock situation

According to statistics data in 2023, the total number of main livestock herds of Tran Yen district is over 4.3 thousand buffaloes; 1.5 thousand cows; over 60,000 pigs and more than 1.7 million poultry of all kinds (chickens, ducks, geese) (Table 3). These are common and typical types of livestock in the Northern of Vietnam.

There are more than 700 business farms including nearly 266 pig farm, 71 buffalo and cow farm and more than 370 poultry farms. According to the surveyed results, fams are raising a combination of 2–3 types of livestock. Specifically, farms that are raising only one type of livestock are 24 in total 90 survey farms (26.7%); Farm that combinated of 2 or more types of livestock reached 73.3% (of which a combination of 2 types of livestock is 43.3% and 3 types is 30%).

Table 1. Number of samples and indicators

TT	Treatment methods	Pre-treatment *(No of sample)*	Post-treatment *(No of sample)*	Analysis parameters
1	Vermiculture (Solid waste)	3	3	Humidity; pH; Total Nitrogen; Total phosphorus; C/N ratio; Organic matter (OM); Heavy metals (As, Pb, Hg, Cd)
2	Composting (Solid waste)		3	
3	Biogas (Wastewater)	3	3	pH, TSS, COD, BOD5, Total Nitrogen, NH_4^+ – N, NO_3^- –N, Total phosphorus, Coliform, Heavy metals (As, Pb, Hg, Cd)
	Amount	**6**	**9**	

Table 2. Methods for analyzing solid waste and and wastewater samples

Solid waste		Wastewater	
Parameter	**Analysis Methods/Standards**	**Parameter**	**Analysis Methods/Standards**
Humidity	ISO 11465:1993	pH	Measured on site by a portable pH meter (D–50 Series, Horiba, Co. Ltd)
pH	SMU 4500H, B:2017	TSS	SMU 2540B : 2012
Total nitrogen	SMEWW4500. Norg. A. B. C	COD	SMU 5220C: 2012
Total phosphorus	ISO 6878: 2004	BOD5	SMU 5210B: 2012
OM	ISO 23265: 2022	Total nitrogen	SMEWW4500. Norg. A. B. C
As	SMU 314B:2017	Total phosphorus	ISO 6878: 2004
Pb	SMU 3125 B:2017	As	SMU 314B:2017
Hg	SMU 3112B:2017	Pb	SMU 3125 B:2017
Cd	SMU 3120B:2017	Hg	SMU 3112B:2017
Coliform		Cd	SMU 3120B:2017

Amount of waste generated

According to the estimated results, the average amount of waste generated from livestock for whole district is nearly 86 thousand tons of manure (solid waste) and over 787 thousand m3 of wastewater per year (equivalent to 235 tons solid waste and 2,157 m3 wastewater per day) (Table 3). That is causing a major pollution if it has not managed and treated. Because manure and wastewater contain a lot of total suspended solid, high concentration of biodegradable organic matter and nutrients (Nitrogen and Phosphorus), especially the water environment (Tra *et al*., 2013). However, livestock waste should be used and managed in order to reduce the use of chemical fertilizers, environmental pollution and greenhouse gas emissions (Giang *et al*., 2021).

Current status of livestock waste management

In the study site, 03 popular treatment methods of livestock wastewater include biogas (18.9%), dumping into septic tanks (5.6%) and discharging into biological lakes (2.2%) in the total number of surveyed households. Out of a total of 30 pig–raising households, about 80% of households need livestock wastewater treatment. Meanwhile, for solid waste, the results of the survey showed that currently livestock waste here is treated by different methods according to the popularity of composting (60.7%), biogas (30.4%) and direct irrigate to crops (22.5%), in addition, households also dump directly into fish ponds, sold and a very few households that do not treat waste and discharge directly into the environment (Figures 1 and 2). However, depending on the type and number of livestock, the treatment methods are different. Composting and direct apply to plants are common method for chicken manure, in addition, it has been also sold to outside collectors. Meanwhile, biogas is selected by the most of the pig farms and is as well as than other methods. Livestock farms that are larger in scale than the average of surveyed households (more than 1000 chickens, 100 pigs) have selected biogas and composting. In contrast, livestock farm that are smaller in scale (less than 50 chickens, 03 pigs, only 01 cattle) have applied of composting and direct use for crops.

Thus, it can be seen that the methods of waste management in the circular economy have been applied and implemented quite popularly in Tran Yen district. In particular, the most common methods that aboved mentioned include composting, biogas and direct use for crops. Among these solutions, direct use for crops has been recommended by Ministry of Agriculture and Rural Developmet of Vietnam due to the potential risk of safe food and environmental pollution. Therefore, 03 treatment methods for livestock waste selected in this study to evaluate the effectiveness toward circular economy for livestock developemt in Tran Yen district include: Composting, velmiculture and biogas.

Evaluation of livestock waste treatment efficiency

Results of pilot models

(1) *Treatment of livestock manure with vermiculture:* The experiment monitored for a period of 60 days, the change in color and smell of manure after treatment. During raising earthworms, light is adjusted suitable with the growth of earthworms. The results showed that the amount of earthworms developed well and increased in amount and weight over time, in the beginning, the weight of earthworms was 0.3 kg, after 30 days, the weight of earthworms increased to 0.63±0.06 kg and increased to 1.2±0.1 kg by day 60th.

(2) *Treatment of livestock manure by composting:* For composting, the temperature of the compost pile was also monitored for 45 days of experiments. During composting, manure quality is observed such as moisture, smell, color and porosity. Especially, the smell of manure decreases over time, after 25 days of experiment, the compost pile was no smell. The amount of compost weighed after 45 days of the experiment averaged 11.5 kg of organic fertilizer. Heavy metal parmeters in organic fertilizer meet the requirements according to QCVN 01–189:2019/BNNPTNT (Table 4).

The results shown in Table 4 that the pH is neutral, high organic matter, a acceptable C/N ratio and the concetration of heavy metals are below the standard, so it can be safely used to fertilize soil and crops. However, after the treatment, the nutrient content (especially N) was decreased compared to before, which causes the C/N ratio in the treated manure to increase, other parameters are almost unchanged. The quality of compost after vermiculture is somewhat better than composting such as N, P and organic matter are all higher, although the higher levels are not significal difference.

Table 3. Estimate the toatal of solid waste and wastewater generated from livestock in Tran Yen district

Livestock	Number of livestock *(head)*	Solid waste generated ratio* *(kg/head/day)*	Wastewater generated ratio *(liters/head/day)*	Amount of solid waste generated* *(tons/year)*	Amount of wastewater generated *(m^3/year)*
Buffalo	4,332	15	10	23,718	15,812
Cattle	1,498	10	8	5,468	4,374
Pigs	60,035	2	35	43,826	766,947
Poultry	1,755,560	0.02	–	12,816	–
Total				**85,827**	**787,133**

Note: (*) Waste generated ratio used from the reports of the Ministry of Natural Resources and Environment of Vietnam

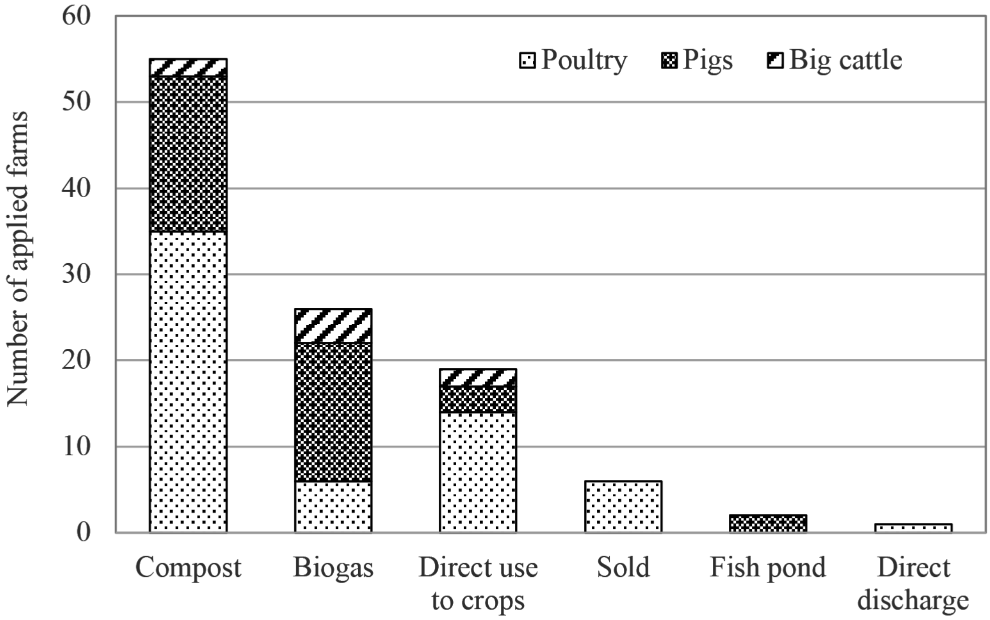

Fig. 1. Number of livestock farms applying waste treatment method by type of livestock.

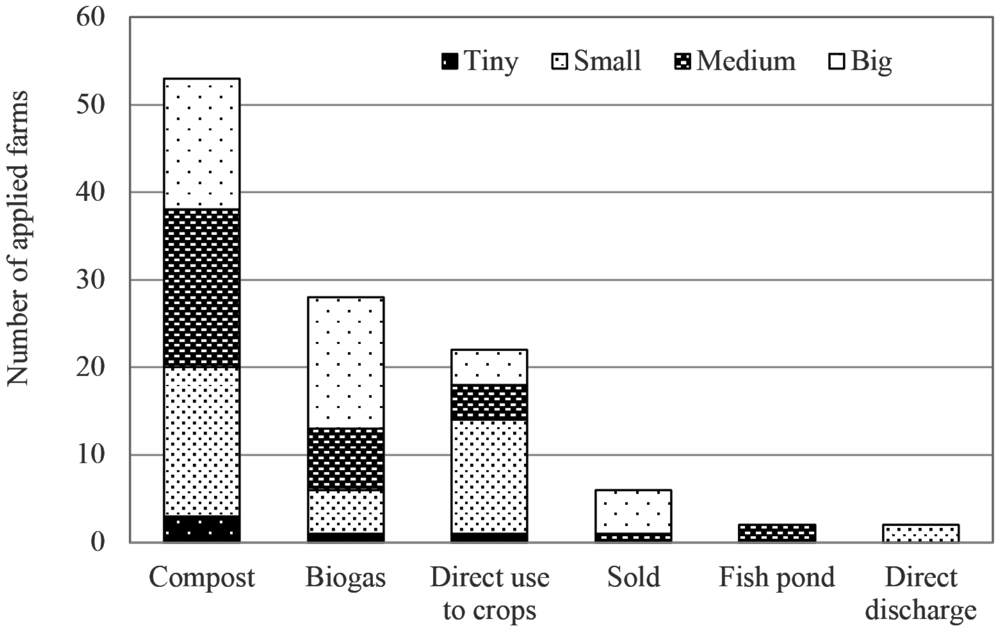

Fig. 2. Number of livestock farms applying waste treatment methods by scale.

(3) *Treatment of livestock manure by Biogas:* This study selected three livestock farms that raising 10–30 heads were using biogas to record input and output data. The total amount to install a biogas tank with a capacity of 12 m3 in this area is about 14,167,000 VND, enought about 25–30 livestock heads. The results of monitoring the efficiency of biogas treatment are presented in table 5.

The table 5 show that, after livestock manure was treated through the biogas, the concentration of pollutants has decreased significantly, especially COD, BOD5 and nutrients such as N and P. However, comparating to the QCVN62–MT/2016 – Vietnam's livestock wastewater regulation, there is only one pH value is satisfy the requirement while all other parameters are not. Therefore, if this wastewater is discharged into the environment, it will cause environmental pollution (Son *et al.*, 2021). However, in Vietnam QCVN01–195:2022 is issued allowing livestock farms to use wastewater for applying to crops to save nutrients contained in the wastewater (Giang *et al.*, 2021). Comarationg to the QCVN01–195:2022, all parameters such as concentration of heavy metal (As, Pb, Hg, Cd) are satisfy the

Table 4. The quality of livestock manure before and after treatment

TT	Parameters	Unit	Pre–treatment	After vermiculture treatment	After composting treatment	QCVN 01–189:2019/ BNNPTNT
1	Humidity	%	86.5	43.0	40.0	≤30
2	pH	–	7.8	7.0	7.2	–
3	N total	%	1.80	1.04	1.01	–
4	P total	%	0.18	0.20	0.19	–
5	C/N ratio		6.3	10.5	9.5	≤12
6	Organic matter (OM)	%	27.0	24.0	21.0	>20
7	As	mg/kg	1.10	1.00	1.20	≤10
8	Pb	mg/kg	6.54	6.70	6.40	≤200
9	Hg	mg/kg	0.55	0.56	0.56	≤2
10	Cd	mg/kg	1.35	1.30	1.50	≤5

Note: QCVN applies to "organic fertilizer"

Table 5. Characteristics of liquid waste before and after biogas treatment

TT	Parameter	Unit	Pre treatment	After treatment	QCVN 62–MT/2016: BTNMT	QCVN01–195:2022/ BNNPTNT
1	pH	–	6.8	7.8	6-9	5.5 – 9.0
2	TSS	mg/l	2,400	673	150	–
3	COD	mg/l	3,840	983	300	–
4	BOD5	mg/l	2,100	646	100	–
5	N total	mg/l	340	189	150	–
6	$N–NH_4^+$	mg/l	–	150	–	–
7	$N–NO_2^-$	mg/l	–	0.9	–	–
8	$N–NO_3^-$	mg/l	–	28.5	–	–
9	P total	mg/l	110	41.5	–	–
10	Coliform	MPN/100ml	25,000	12,000	5,000	7,500
11	As	mg/l	0.0024	0.0023	–	0.1
12	Pb	mg/l	0.0060	0.0058	–	0.05
13	Hg	mg/l	NA	NA	–	0.002
14	Cd	mg/l	0.0072	0.0070	–	0.01

requirement except for coliform. Thus, the potential to reuse wastewater after biogas to apply for crops is potential solution for farms if they can treat concetration of coliform. This not only helps farm save wastewater treatment costs but also take advantage of nutrients in wastewater for agricultural cultivation.

Evaluation of economic–technical–environmental efficiency

In order to compare the effectiveness of waste treatment methods, economic, technical and environmental criteria has been converted and calculated for treatment for 01 ton of livestock waste by 3 different treatment methods: vermiculture, composting and biogas. Details are presented in table 6.

In economic aspects, livestock waste treatment by biogas tanks is the most cost–intensive form mainly due to the initial construction cost. Vermiculture also has a high cost, including bying vermiculture seed about 25,000 VND/kg (substrate, parent worms, eggs); this treatment method including labor is more than 4,300,000 VND/ton of waste. Meanwhile, the cheapest treatment method is composting includes labor, supplies, buying probiotics about 1,600,000 VND/ton. The profit from the treatment of livestock waste by vermiculture is more than 11,000,000 VND/ton of waste (including earthworm manure 5,500 VND/kg and earthworm biomass 25,000–40,000 VND/kg). The profit for organic composting is 3,370,000 VND/ton. The benefit from biogas is to save about 128,000 VND per month from buying industrial gas for cooking, however, after 1 year, the initial investment in biogas will be recovered.

In terms of technical aspects, The easy of implementation and convenience of the three treatment methods are all appropriate to the technical level of people. However, the remaining difficulties of these 03 methods

Table 6. Comparison of criteria for evaluating livestock waste treatment methods

Evaluation criteria		Vermiculture	Composting	Biogas
Economic	Inital Cost (VND)	4,312,500	1,630,000	14,167,000
	Products (VND)	15,500,000	5,000,000	128,000 (Monthly gas purchase)
	Labor (public)	7	3	10
	Profit (VND)	11,187,500	3,370,000	After 1 year, the investment will be payback due to saving money to buy cooking gas.
	Payback period (months)	6	6	12
Technique	Ease of implementation	The simple technique is easy to implement, paying attention to the growing conditions of earthworms	Simple technique, easy to implement	It is not constraint for farm because they hire workers for biogas construction
	Processing time (days)	60	35–45	10 – 14
	Convenience	Difficulties in buy of seed earthworms	Easy to buy probiotics	Very convenient, easy to use
	Time cost	Labor loss in the process of feeding earthworms	It takes labor in the beginning to transport manure and compost	It does not take much labor but must be cleaned daily
	Operational problems	Fewer incidents	Fewer incidents	Sometimes it has problems and had to call technician
Environment	Amount of treated waste	Treated of 1 ton of livestock manure into earthworm compost	Treated 1 ton of livestock manure into 0.9 tons of organic fertilizer	Both solid waste and wastewater can be treated, but quality of wastewater after biogas still affects the environment
	Smell	No smell	No smell after the 25th day	slight odor
	Color	Ebony black	Dark black	Clearer

Note: The number in this table are estimated for 1 ton of waste

are: Building biogas takes time and good technical support; Using vermiculture is new knowledge to local people, about worm growing conditions, and extended rearing periods; For composting, lack of standards in evaluating the quality of post–composting products.

As for the environmental aspect, all 3 proposed solutions contribute to waste treatment, reducing environmental pollution in the direction of circular waste reuse. Livestock manure treated with composting and vermiculture of ebony black or dark black, loose color gives good quality comparable to other fertilizer products. However, some environmental problems include: Wastewater after biogas still has a bad smell and black color, gas from biogas tunnels burned up is yellow, quickly failing equipment.

Thus, it can be seen that all three treatment methods of livestock waste include biogas, composting and vermiculture to be effective in the preliminary treatment of waste so that the waste source can be reused for other purposes. These methods in the study site are a easy and natural bio–degradation process that takes organic wastes, livestock waste turns into nutrient rich food for crops, reduce amount of waste in landfills. Particularly, for the composting and vermiculture have some advantages such as low cost; creating fertile soils; decreaing the use of synthetic fertilizers which caused the environmental issue; and improving soil porosity and water retention Therefore, these methods can be considered as fundamental solution to promote circular agriculture in Vietnam. However, in order to achieve the above solutions to use renewable energy, it is necessary to improve such as: give a clear guides/documents for livestock waste treatment techniques for farmers; perfection of treatment technology, especially coliform treatment for wastewater after biogas; increase mechanization and automation in the process in order to reduce labor and scale up processing; It is necessary to have a network/connect between livestock and cultivation activities to ensure that the amount of waste generated from livestock activities is used up for the crops; composting can be done at the commercial and industrial levels, but also on a household level; need policies to support and promote the reuse of waste and circular agricultural products nationwide.

CONCLUSIONS

The results present that methods of livestock waste treatment including biogas, composting and vermiculture are effective in term of environmental, economic and social aspects. These are suitable solutions for the knowledge of farmers in Tran Yen district, Yen Bai province in particular and farmers in Vietnam in general. These measures are the basic foundation to promote using renewable energy, waste reuse in livestock towards circular agriculture in the coming years. However, it is necessary to have support and promotion policies from state agencies and technical support from scientists to improve livestock waste management method towards recycling and reusing waste on a larger scale in Viet Nam.

AUTHOR CONTRIBUTIONS

Dinh Thi Hai Van formed the research idea, designed the questionnaire for the survey, collected, analyzed the data, and drafted the manuscript. Le Thi Thu Huong analyzed the data, drafted the manuscript, commented and edited on the manuscript. Nguyen Thuy Trang collected and analyzed the data, drafted the manuscript. Mitsuyasu Yabe supervised the research, commented and edited on the manuscript. All authors read and approved the final manuscript.

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