RESEARCH ARTICLE

Recycling of biogas wastewater to organic fertilizers and influence of organic fertilizers on maize, mung bean growth and yield under the field conditions

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Abstract: The objective of the study was to utilize the biogas effluents to produce solid and liquid organic fertilizers, as well as evaluate their effect on the growth and yield of corn and mung beans under field conditions. For liquid organic fertilizer, biogas effluents were mixed with fish emulsion and beneficial bacteria while biogas effluents-absorbing coal slag was mixed with sugarcane filter, fishmeal and beneficial bacteria to create solid organic fertilizer. Liquid organic fertilizer was irrigated with a dose of 5 L/1000 m^2 while solid organic fertilizer was applied with a dose of 1 ton/ha with 75% recommended NPK formula for maize and mung bean. The results showed that applying solid or liquid organic fertilizer formulated from biogas effluents with other amendments helped to reduce the amount of recommended NPK fertilizer by 25%, but still maintained growth and yield of maize and mungbean equivalent to the control treatment fertilized with 100% recommended NPK. In conclusion, the amount of organic matter and N, P, K in biogas effluents from biogas digesters can be utilized to produce organic fertilizers which not only help to reduce chemical fertilizers, but also solve the environmental problems and create new friendly value-added products for practicing sustainable agricultural production.
Keywords: Biogas effluents, liquid organic fertilizer, solid organic fertilizer, maize, mung bean

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1 Introduction

Along with the development of the livestock industry, the amount of waste from the pig farming barns has also increased, causing a significant impact on the natural environment. Many solutions have been proposed to minimize pollution such as building a biogas digester associated with livestock raising is one of the most important solutions to animal waste management (Viet et al., 2017). In the Mekong Delta, biogas models have been widely developed for many years. Although the construction of biogas digester systems has the advantage of providing biogas for households cooking, the liquid waste or sewage from biogas tanks has still been discharged directly into a river. This effluent contains high amounts of COD, BOD, nitrogen, phosphorus and microorganisms. This causes pollution for the receiving water bodies in many localities (Nga et al., 2013; Giang et al., 2021). According to Chang et al. (2022), as a byproduct of anaerobic fermentation of animal manure, crop residues, biogas residues can be utilized as high-quality organic fertilizer for farming and vegetable production. Another important thing is that the organic fertilizer can be 2 to 3 times cheaper for the farmer than the fertilizer produced industrially. There have been some studies on using biogas effluents as fertilizer for many crops such as broccoli and lettuce (Vinh, 2010), chili (Nu et al., 2015, Nga et al., 2015) and tomato (Giang et al., 2021). These studies were carried out and showed good effects on growth and yield of crops. Similarly, Duyen et al. (2012) showed the positive effect of biogas-effluent absorbed charcoal on the growth and yield of lettuce. Thus, biogas effluents are a potential source of raw materials for commercial organic fertilizer production, however, this practice has not yet received much attention.

The recycling of different organic residues into organic fertilizers has increased in recent years. Among them, anaerobic digestion for biogas production produces a large amount of liquid digestate, which contains high amounts of nutrients, such as nitrogen, potassium and phosphorus, and micronutrients in plant-available forms. Many researches have proved the fertilization benefit of digestates (Dragicevic et al., 2018) and effect of application of digestates on improvement of soil quality, crop yields, and soil microbial communities has been documented.

In addition, coal slag is a product of the coal burning process of households and food stores, but there is no way to treat or utilize it efficiently. Coal slag has a high content of K, Al, Fe, Cu and Zn, and it also contains a small amount of organic matter, total nitrogen and total phosphorus (Nghia and Thu, 2017). The use of this material to absorb nutrients such as nitrogen, phosphorus, potassium and other trace elements present in biogas digesters for biogas effluents treatment is one of the promising approaches. This helps to solve the problem of solid waste of coal slag, liquid of biogas effluent and to improve economic efficiency from creating new valuable organic fertilizer products. Therefore, the aim of this study was to find a production process to produce liquid and solid organic fertilizer from biogas waste, coal slag, sugarcane filter and as well to determine their effect on the growth and yield of maize and mungbean under field conditions.

2 Materials and Methods

2.1 Materials

Biogas effluents samples were collected from pig farm households which had biogas digesters with a volume of 13 m^3 at Phu Khanh Hamlet, Phu Thu Ward, Cai Rang District, Can Tho City,Vietnam. Biogas effluents were taken at the outlet of the biogas digesters. Samples were divided into 3 batches, 10 days apart. Fish emulsion was used as a mixing material to produce liquid organic fertilizer. These products came from Tran Tien Chemical Company, Vietnam. The nutritional composition of this product was listed as crude protein $\geq 32\%$, fat $\leq 10\%$, moisture $\leq 55\%$. Sugarcane filter was collected from the Phung Hiep Sugar Factory, Hau Giang district, Vietnam and used as a raw mixing material to create solid organic fertilizer. Coal slag used to absorb biogas effluent was collected from small restaurants in Can Tho city, Vietnam. Fish meal was a product of Phi Quan marine fishmeal company, Vietnam containing crude protein content $\geq 60\%$, fat 8%, and moisture 10%.

2.2 The quality of collected biogas effluents

After collecting, the biogas residues were determined for some microbial, physical, and chemical parameters to assess the level of pollution and nutrient composition of wastewater from biogas digesters. Number of pathogenic bacteria such as *E. coli, Coliform, Salmonella* in biogas effluents was evaluated by the MPN method (Michael et al., 1999) and counting method for the number of colony forming units on SS agar by Taylor and Harris (1965).

Biogas effluents was analyzed for physical and chemical components such as: suspended solids (TSS), pH, Carbon, BOD, COD, total nitrogen, available nitrogen (NH_4^+, and NO_3^-), total phosphorus (P), available phosphorus (P_2O_5), total potassium (K), and available potassium. Beside, trace elements including Mg, Ca, Fe, Zn, Cu, heavy metals including lead (Pb), cadmium (Cd), and aerobic bacterial numbers were also evaluated to determine the quality of biogas effluents as well as to build an organic fertilizer production process. The quality of collected biogas effluents was evaluated by VietNam's National Technical Regulation (QCVN No.62-MT:2016/BTNMT National Technical Regulation on the effluent of livestock).

2.3 Making the organic fertilizer from biogas effluent and others

2.3.1 Liquid organic fertilizer

The materials used to make liquid organic fertilizer consisted of biogas effluent, fish emulsion and beneficial bacterial strains such as nitrogen fixation bacteria, phosphate solubilizing bacteria, synthesizing IAA and silicate solubilizing bacteria (*Bacillus aquimaris*, *Burkholderia* sp., *Bacillus megaterium*, *Ochrobactrum ciceri*). Fish emulsion was mixed with biogas effluent in different ratios to find out one best mixture ratio to meet the quality standard for organic fertilizer by Decree No.108/2017/ND-CP of Vietnam. The experiment was arranged in a completely randomized design with 5 treatments and 3 replicates. The treatment names were listed in Table 1.

Table 1. The different mixing ratios between biogas effluents and fish emulsion

Number	Treatment	The ratio: biogas effluent and fish emulsion (w/w)
1	T1	50% biogas effluent + 50 % fish emulsion
2	T2	60% biogas effluent + 40 % fish emulsion
3	T3	70% biogas effluent + 30 % fish emulsion
4	T4	80% biogas effluent + 20 % fish emulsion
5	T5	90% biogas effluent + 10 % fish emulsion

The liquid mixture was analyzed for pH, organic matter, total nitrogen, effective nitrogen, total phosphorus, effective phosphorus, total potassium and available potassium to select the most suitable ratio to make liquid organic fertilizer. Then, the best liquid mixture ratio was inoculated with beneficial bacteria including nitrogen fixing bacteria, phosphate solubilizing bacteria, IAA synthesis and silicon solubilizing bacteria (*Bacillus aquimaris*, *Burkholderia* sp., *Bacillus megaterium*, *Ochrobactrum ciceri*) to achieve a final density of 10^6 CFU/mL.

The liquid organic fertilizer was analyzed for physicochemical parameters including: pH, organic matter, total nitrogen (N), available nitrogen (NH_4^+, NO_3^-), total phosphorus (P), available phosphorus (P_2O_5), total potassium (K), available potassium, Magnesium (Mg), Calcium (Ca), Iron (Fe), Copper (Cu), Zinc (Zn). The microbiological parameters included the total number of aerobic bacteria, the number of nitrogen-fixing bacteria, phosphate solubilizing bacteria and silicon solubilizing bacteria. In addition, the population of human intestinal pathogenic bacteria such as *Coliform, E. coli* and *Salmonella* were also analyzed and evaluated. Analytical parameters were evaluated according to Vietnam's Organic Fertilizer Standards (Decree No.108/2017/ND-CP regarding issuance of fertilizer management in Vietnam).

2.3.2 Solid organic fertilizer

Solid organic fertilizer was made based on available materials like biogas digester, coal slag, sugarcane sludge, fish meal, and beneficial bacterial strains including *Bacillus aquimaris*, *Burkholderia* sp., *Bacillus megaterium*, *Ochrobactrum ciceri*. Firstly, coal slag was dried at 105°C for 8 hours and crushed by a mill then sieved through a 2 mm sieve. Next, the coal slag absorbs the biogas effluent at a ratio of 1:1 by weight. Then, biogas effluent adsorbing-coal slag was mixed with sugarcane filter in different proportions as shown in Table 2.

Table 2. The different mixing ratios between sugarcane filter and biogas effluent absorbing coal slag to produce solid organic fertilizer

Number	Treatment	The ratio between sugarcane filter and biogas effluent absorbing coal slag (w/w)
1	T1	70% sugarcane filter + 30% biogas wastewater-absorbing coal slag
2	T2	80% sugarcane filter + 20% biogas wastewater -absorbing coal slag
3	T3	90% sugarcane filter + 10% biogas wastewater-absorbing coal slag

All the products of solid organic fertilizers including different mixing ratios were analyzed for physico-chemical composition such as moisture, pH, organic matter, total nitrogen (N), available nitrogen, (NH_4^+, NO_3^-), total phosphorus (P), available phosphorus (P_2O_5), total potassium (K), available potassium. The results of these parameters were evaluated according to Vietnam's Organic Fertilizer Standards (Decree No.108/2017/ND-CP). After checking the quality of solid organic fertilizer products, the most appropriate mixing ratio which met the standardized criteria was selected for inoculating with beneficial bacteria with a target of 10^6 CFU /mL and finally, fish meal with an amount of 16.7% (w) was also added to increase the nutritional content of the final solid organic fertilizer. Finally, the solid organic fertilizer was then analyzed physico-chemical and microbial parameters to evaluate according to Decree No.108/2017/ND-CP of Vietnam.

2.4 Evaluation of the effect of final formulated organic fertilizers on growth and yield of maize and mung bean under the fields conditions

The field experiment was conducted at Co Do district, Can Tho City, Vietnam for two model crops, mungbean and maize. The experiment was carried out from January 12, 2022 to March 15, 2022. Each experimental plot was 250 m^2 (50 m width x 50 m length), the distance between rows and plants for maize and mungbean was 60 cm x 30 and 40 cm x 15 cm, respectively (Figure 1). Each hole of the plant contained 2 seeds. The experiment was arranged in a randomized complete block design with 5 treatments and 4 replicates. Information about the treatment name and composition was listed in Table 3.

Figure 1. Experimental layout on maize and mungbean in the field in Co Do district, Can Tho City, Vietnam

Table 3. The treatments of experiments conducted under field conditions

Treatment	Details of treatments
T1	100% NPK Control *
T2	75% NPK
T3	75% NPK + solid organic fertilizer (1 ton/ha)
T4	75% NPK + liquid organic fertilizer (5 l/1000 m^2)
T5	75% NPK + solid organic fertilizer (1 ton/ha) + liquid organic fertilizer (5 l/1000 m^2)

Note: The recommended chemical fertilizer formula for maize and mung bean were 150 N + 100 P_2O_5 + 60 K_2O and 40 N + 60 P_2O_5 + 60 K_2O, respectively.

The liquid organic fertilizer was applied at the root of crop with a dosage of 5 liters/1000 m^2 for each irrigation time and in total there were 4 application times of liquid organic fertilizer including 5 days before sowing, 15, 30 and 45 days after sowing while the solid organic fertilizer was applied directly into the soil only once at the day of sowing with a dose of 1 ton/ha. Also, cultivation techniques of maize and mung bean were followed by farmers practices including the use of hands and bio-pesticides to control weeds, pathogens and pests. The experiment was set up for 60 days for both corn and mung beans. The chemical fertilizer application schedule and composition of each specific application for maize and mungbean are presented in Table 4 and Table 5, respectively.

Table 4. Fertilizer schedule for maize in the field

Fertilizer kinds	Weight (kg/ha)	1st time basal application (0 DAS)	2nd time (15 DAS)	3rd time (30 DAS)	4th time (45 DAS)
N	150/112.5	0	20%	40%	40%
P	100/75	100%	0	0	0
K	60/45	0	20%	40%	40%

Note: DAS: days after sowing

Table 5. Fertilizer schedule for mung bean in the field

Fertilizer kinds	Weight (kg/ha)	1st time basal application (0 DAS)	2nd time (15 DAS)	3rd time (30 DAS)	4th time (45 DAS)
N	40/30	0	20%	40%	40%
P	60/45	100%	0	0	0
K	60/45	0	20%	40%	40%

Note: DAS: days after sowing

Collected parameters: For the maize, agronomic parameters consists of plant height, number of leaves, stem diameter were taken at day 45 after sowing and ear length, ear diameter, number of rows/ear, grain numbers/row and grain numbers/ear, grain weight/ear, fresh 1000 grain weight, ear yield, grain yield were determined at the harvesting time (60 days after sowing). For mungbean, collected parameters including plant height, number of leaves, number of ear, ear length, number of grain/ear, 1000 grain weight and grain yield were taken at day 60 after sowing.

2.5 Data analysis

The data were analyzed by ANOVA with MINITAB software with 16.2 versions.

3 Results and Discussion

3.1 Quality of collected biogas effluents

3.1.1 Microbial composition

The analytical results about pathogenic bacteria including *E. coli*, *Coliform* and *Salmonella* showed that biogas waste samples in Cai Rang district, Can Tho city, Vietnam contained *E. coli* and *Coliform* up to 42200 and 198100 MPN/100 mL, respectively while *Salmonella* numbers were not detected in this sample. Thus, it can be seen that the density of *E. coli* and *Coliform* in surveyed biogas effluent samples exceeded the critical values according to Viet Nam's National Technical Regulation for the effluent of livestock with a permited values of these microorganisms not over 3000 MPN/100 mL (QCVN 62-MT:2016/BTNMT).

The results of this study are consistent with those obtained by Hong et al. (2012), who indicated that the density of *Coliform* in the output wastewater of the biogas digester was 10^7 MPN/100 mL, which exceeded many times as compared to the limits of Viet Nam's National Technical Regulation QCVN 62-MT:2016/BTNMT. Similarly, Vil et al. (2020) reported that the density of *E. coli* bacteria in biogas waste samples in livestock households ranged from 6000 to 90000 MPN/100 mL while the *Coliform's* density was ranged from 12000 to 16000 MPN/100 mL, even exceed the critical level for the effluent of livestock according to the standard of Viet Nam. Based on this regulation these biogas effluent samples did not meet the standards and could not be used directly for irrigation on farming. Therefore, it is necessary to treat pathogenic microorganisms such as *E. coli, Coliform* in wastewater from biogas digesting systems Chang et al. (2022).

3.1.2 Physical and chemical composition of biogas wastewater samples

The results presented on Table 6 showed that the nutrient contents in the biogas wastewater were 3 times higher than the critical level by Vietnam's standards on COD, BOD, TSS (QCVN 62-MT:2016/BTNMT). In which suspended solids, the chemical oxygen demand (COD), and the biological oxygen demand (BOD) exceeded 4.45 times, 2.86 times, and 2.24 times higher than the critical level by QCVN 62-MT:2016/BTNMT. In addition, the analytical results also indicated that the nutrient sources in biogas wastewater was quite high. Total nitrogen and total phosphorus in wastewater from biogas digesters were 1.5 and 7 times higher than those permitted in the standards, respectively. Furthermore, in biogas wastewater, there was a presence of macronutrients, and micronutrients such as NH_4^+, NO_3^-, PO_4^{3-}, organic matter, K_{total}, available K, Ca, Mg, Fe, Zn, Cu,... The heavy metal concentration including Pb, and Cd was not detected in the biogas effluents. These results indicate that biogas effluents had potential for utilization as nutrient sources for making organic fertilizers.

This result was consistent with the study of Nga and Dat (2014) which showed that the quality of wastewater from the biogas digester did not meet the standards for discharging the wastewater into the environment since PO_4^{3-}, N-NO_3^-, N-NH_4^+, and COD in samples were ranged 37.2 - 51.1 mg/L, 0.30 - 1.14 mg/L, 105.6 - 217.9 mg/L, and 464.4 - 2,552.1 mg/L, respectively. If this wastewater was directly discharged into the receiving water body, it would cause pollution for the water source and degrade the environmental quality of the

Table 6. The physical, chemical, and biological composition of biogas effluent samples

No.	Items	Values	QCVN 62-MT
1	pH	7,37	5,5 – 9,0
2	COD (mg/L)	860	300
3	BOD (mg/L)	224	100
4	TSS (mg/L)	667	150
5	N (mg/L)	220	150
6	P (mg/L)	41,9	6
7	$N\text{-}NH_4^+$ (mg/L)	6,65	-
8	$N\text{-}NO_3^-$ (mg/L)	4,81	-
9	Carbon (%)	0.01	-
10	$P\text{-}PO_4^{3-}$ (mg/L)	19,4	-
11	K^+ (mg/L)	85,6	
12	K (mg/L)	111	-
	Secondary and micro elements		-
13	Mg (mg/L)	32,1	-
14	Ca (mg/L)	54,4	-
15	Fe (mg/L)	0,170	-
16	Zn (mg/L)	0,049	-
17	Cu (mg/L)	0,053	-
	Heavy metals		
19	Lead (Pb) (mg/L)	ND	-
20	Cadmium (Cd) (mg/L)	ND	
21	Aerobic bacteria (CFU/mL)	$9{,}7.10^5$	-

Note: ND: not detected

receiving water bodies. In particular, the eutrophication phenomenon of water sources and high *Coliform* numbers may be dangerous for human and animal health. However, this high nutrient content in biogas digester wastewater should be utilized as a source of nutrients for other objects, for example, making organic fertilizers because of its relatively high nutrient contents and no heavy metals (Nga and Dat, 2014; Viet et al., 2017). Similarly, the study of Koszel and Lorencowicz (2015) reported that biogas wastewater contained many nutrients for soil and plants, and heavy metal free and Chang et al. (2022) indicated that biogas wastewater had a great potential for making organic fertilizer due to its richness in mineral nutrients. Meanwhile, Pertiwiningrum et al. (2017) reported that the sludge from biogas production could not yet be used as organic fertilizer because of its low nutrients and therefore, it needs to be modified. Moreover, the amounts of antibiotics, pathogens, and other toxic contaminants in biogas wastewater also need to be considered in the future. The quality of organic fertilizer from biogas effluent can be improved by mixing with rice husk charcoal (Pertiwiningrum et al., 2017). Moreover, many studies have successfully utilized biogas digester wastewater to make organic fertilizer and it can replace a part of chemical fertilizers on alfalfa, corn and other cereal crops (Ortenblad et al., 2002; Rodhe et al., 2006; Smith et al., 2007; Moller and Stinner, 2009; Pertiwiningrum et al., 2017; Sigurnjak et al., 2017).

3.2 Production of liquid organic fertilizer from biogas effluents and others

3.2.1 Nutrient composition of formulated liquid organic fertilizer

The results of quality composition of 5 different treatments of liquid organic fertilizers were presented in Table 7 showed that the nutrient compositions of 5 treatments were significantly different when compared together ($p<0.05$). For the pH value of the products, four out of five different formulated liquid organic fertilizers met the prescribed standards for liquid organic fertilizer (pH>5), except the treatment containing 90% biogas wastewater: 10% fish emulsion (v/v) did not meet the VietNam's National Technical Regulation. Regarding the percentage of organic matter, the results showed that two treatments containing 50% of biogas digester: 50% of fish emulsion and 60% of biogas digester: 40% of fish emulsion met the standards of Decree No.108/2017/ND-CP for liquid organic fertilizer. The organic mater values of these two treatments was 27.5% and 21.4%, respectively, whereas the other treatments had lower organic matter contents (less than 20%). In addition, there was a statistically significant difference ($p<0.05$) in the total and available N, P, and K among 5 treatments. The results indicated that the more fish emulsion added into the biogas wastewater, the more nutrient content of N, P, and K achieved in the liquid organic fertilizers. However, to utilize as much as the amount of biogas effluents, the treatment received 60% of biogas effluents + 40% of fish emulsion (v/v) was selected for further modification step to meet the required standard regarding the nutrient contents in the liquid organic fertilizer product.

Table 7. The nutrient values of five different formulated liquid organic fertilizer products

Items	Unit	Treatments containing different ratio between biogas effluent (%) and fish emulsion (%) (v/v)					F	Decree No. 108/2017
		50:50	60:40	70:30	80:20	90:10		
pH	-	5.17^a	5.17^a	5.11^b	5.04^c	4.93^d	*	≥5
Organic matter	%	27.5^a	21.4^b	16.4^c	11.4^d	5.92^e	*	≥20
Total N	%	3.31^a	2.71^b	2.16^c	1.47^d	0.76^e	*	-
Available N	%	0.71^a	0.544^b	0.329^c	0.290^c	0.119^d	*	-
Available P	%	0.559^a	0.449^b	0.328^c	0.243^d	0.118^e	*	-
Total P	%	0.583^a	0.475^b	0.370^c	0.245^d	0.136^e	*	-
Available K	%	0.709^a	0.587^b	0.535^c	0.343^d	0.132^e	*	-
Total K	%	0.466^a	0.356^b	0.219^c	0.211^c	0.110^d	*	-

3.2.2 Nutrient compositions of the liquid organic fertilizer (LOF) product after modification

Although the best treatment for formulation of liquid organic fertilizer was identified as a combination between 60% biogas digester: 40% fish emulsion, in this ratio, the total and available phosphorus and potassium in this were still lower than the requested standard. Therefore, 5.5% KH_2PO_4 was added into this formulation to increase the nutrient content of phosphorus and potassium as well as balance the amount of nutrients of the final product. Moreover, some beneficial bacterial strains such as *Bacillus aquimaris*, *Burkholderia* sp., *Bacillus megaterium*, *Ochrobactrum ciceri* were also introduced into the liquid fertilizer with a total cell number of 10^7 CFU/g. Then the final product of liquid organic fertilizer was checked again for the nutrient composition. The results of the evaluation for the nutrient components as well as the quality criteria of fertilizer after modifying are presented in Table 8. Generally, the parameters of nutrient quality met the standards of Decree No.108/2017/ND-CP for liquid organic fertilizer. In addition, limiting factors such as heavy metals and harmful bacteria were not detected in the finished liquid organic fertilizer. Thus, the liquid organic fertilizer produced from the recycling of biogas waste achieved the prescribed nutritional standards and can be used to evaluate its effect on the growth and yield of crops under the field conditions.

Table 8. The nutrient contents of liquid organic fertilizer product after modification

Parameters	Unit	Value	Decree No. 108/2017 ND-CP
Proportion of LOF	g/mL	1.14	-
pH		5.32	> 5
Organic matter	%	21.1	≥ 20
Available N	%	0.4	-
Total N	%	2.5	-
Available P	%	2.76	-
Total P	%	2.81	-
Available K	%	2.06	-
Total K		2.32	-
Secondary and micro elements			
Magnesium (Mg)	mg/kg	260	-
Calcium (Ca)	mg/kg	ND	-
Iron (Fe)	mg/kg	10.2	-
Copper (Cu)	mg/kg	1.26	-
Zinc (Zn)	mg/kg	8.9	-
Bacteria			
Aerobic bacteria	CFU/g	$2.53.10^9$	-
Nitrogen fixing bacteria	CFU/g	$3.60.10^5$	-
Phosphate solubilizing bacteria	CFU/g	$4.40.10^5$	-
Silicate solubilizing bacteria	CFU/g	$5.10.10^5$	-
Limiting factors			
Arsenic (As)	mg/kg	2.91	≤ 10.0
Lead (Pb)	mg/kg	0.356	≤ 200
Cadmium (Cd)	mg/kg	ND	≤ 5.0
Mercury (Hg)	mg/kg	ND	≤ 2.0
Salmonella	MPN/100mL	ND	-
E. coli	MPN/100mL	ND	-

Note: ND: not detected

3.3 Production of solid organic fertilizer from biogas effluents and others

3.3.1 Nutrient composition of formulated solid organic fertilizer

Table 9. Nutrient contents of 3 different formulated solid organic fertilizer products

No.	Items	Unit	The mixing ratio between biogas effluents-absorbing coal slag (%) and sugarcane filter (%) (w/w)			Decree No. 108/2017 ND-CP
			30:70	20:80	10:90	
1	Moisture	%	25.1^a	26.5^a	26.7^a	≤30
2	pH	-	6.68^a	6.49^b	6.46^b	≥5
3	Organic matter	%	34.7^b	36.7^a	37.4^a	≥20
4	Available N	%	0.063^a	0.075^a	0.075^a	-
5	Total N	%	1.02^b	1.25^a	1.30^a	-
6	Available P	%	1.69^c	2.03^b	2.27^a	-
7	Total P	%	4.17^c	4.63^b	5.31^a	-
8	Available K	%	0.735^a	0.619^b	0.563^b	-
9	Total K	%	1.84^a	1.55^b	1.41^b	-

The analytical results for the nutrient contents of the three treatments are presented in Table 9 showed that there was a significant difference regarding the nutrient contents in solid organic fertilizers and all three treatments corresponding to 3 different solid organic fertilizer products met the Vietnam organic fertilizer standards for moisture, organic matter and pH. Particularly, moisture content of 3 final products varied between 25.1% and 26.7%, and was still within the allowable critical level of Decree No.108/2017/ND-CP (moisture 30%). In addition, the pH of the 3 final solid organic fertilizer products also met the standards of Decree 108 (pH>5), in which the treatment containing 30% biogas wastewater absorbing coal slag: 70% sugarcane filter (w/w) was found to be the highest pH value (pH = 6.68), and significantly different from the 2 other treatments ($p<0.05$). Especially, it is worth noting that the organic matter contents in all three treatments were 1.5 times higher than the required value by the Decree No.108/2017/ND-CP (organic matter>20%), varied between 34.7% and 37.4%, however, they were not statistically significant difference regarding the organic matter contents when compared with each other. It was also clear that when increasing sugarcane filter amount in the solid organic fertilizer, the amounts of organic matter contents, total nitrogen, available N, total P and available P would be increased accordingly whereas total K and available K contents tended to be opposite. Moreover, no significantly difference about nutrient composition was found among three treatments, thus the treatment containing 30% biogas wastewater absorbing coal slag and 70% sugarcane filter (w/w) was selected as the final formula for making solid organic fertilizer because with this formula, more amount of biogas effluents will be recycled. However, according to No.108/2017/ND-CP, the total N, P, K values of these three treatments were still lower than required values. Therefore, it is necessary to modify the formulation to meet the requested contents of total N, P, and K in the final solid organic fertilizer products.

3.3.2 Nutrient compositions of the solid organic fertilizer (SOF) product after modification

After adding 16.7% fishmeal (w), and beneficial bacterial strains with final density of 10^7 CFU/g to the selected formula for final solid organic fertilizer containing 30% biogas wastewater absorbing coal slag and 70% sugarcane filter (w/w) to increase the total nitrogen content based on the results from the section 3.3.1, the results of the nutrient components of final solid organic fertilizer products which are presented in Table 10 have been improved and met the Vietnamese standards for organic fertilizers. Specifically, the organic matter of solid organic fertilizer product reached 44.5%, 3 times higher than the prescribed level. All N, P, K forms were much higher than before and met the requested standards. The density of beneficial microorganisms in this final product such as nitrogen fixing bacteria, phosphate solubilizing bacteria, and silicate solubilizing bacteria also reached 10^6 CFU/g. Moreover, limiting factors and heavy metals such as arsenic, mercury and *Salmonella* and *E. coli* were not detected in this final product while theo concentrations of lead and cadmium were lower than the critical levels. Thus, final solid organic fertilizer product from recycling of biogas digester wastewater, coal slag, fishmeal, and beneficial bacterial strains has met the nutrient standards in accordance with national regulations.

According to Brotodjojo and Arbiwati (2018) organic fertilizer is very important for plant life because it can help to

Table 10. The nutrient contents of final solid organic fertilizer product after modification

No.	Items	Units	Values	Decree No.108/2017 ND-CP
1	Moisture	%	29.7	≤ 30
2	pH	-	7.46	> 5
3	EC	mS/cm	24.1	-
4	organic matter	%	44.5	≥ 20
5	Available N	%	0.56	≥ 20
6	Total N	%	2.81	-
7	Available P	%	2.92	≥ 2
8	Total P	%	5.00	≥ 2
9	Available K	%	2.83	-
10	Total K	%	5.55	≥ 2
	Secondary and micro elements			
11	Magnesium (Mg)	%	0.639	-
12	Calcium (Ca)	%	7.68	≥5
13	Iron (Fe)	%	1.62	≥50
14	Copper (Cu)	mg/kg	83.5	≥50
15	Zinc (Zn)	mg/kg	271	≥50
16	Sodium (Na)	%	0.229	≥5
	microorganisms			
17	Aerobic bacteria	CFU/g	3.93×10^9	$\geq 10^6$
18	Nitrogen fixing bacteria	CFU/g	3.65×10^6	$\geq 10^6$
19	Phosphate solubilizing bacteria	CFU/g	8.16×10^6	$\geq 10^6$
20	Silicate solubilizing bacteria	CFU/g	2.97×10^6	$\geq 10^6$
	Limiting factors			
21	Arsenic (As)	mg/kg	ND	≤ 10.0
22	Lead (Pb)	mg/kg	39.9	≤ 200
23	Cadmium (Cd)	mg/kg	2.64	≤ 5.0
24	Mercury (Hg)	mg/kg	ND	≤ 2.0
25	*Salmonella*	MPN/g	ND	0
26	*E.coli*	MPN/g	ND	$< 1.1\times10^3$

Note: ND: not detected

improve soil structure, increase water holding capacity and living conditions in the soil. Organic matter in crop residual increased the infiltration of water into the soil and nutrient availability that can increase crop production. Organic matter in the soil affects physical, chemical and biological properties of soil. Interestingly, both solid and liquid organic fertilizers in this study met the standards of Decree No.108/2017/ND-CP for organic fertilizer production so it was also necessary to evaluate their influences on the crop growth and yield under the field conditions.

3.4 The influence of two kinds of organic fertilizers (liquid and solid) on the growth and yield of maize under the field conditions

Results of evaluating the influence of solid and liquid organic fertilizer products on growth and yield of maize under the field conditions are presented in Table 11 and Table 12. Overall, both two types of biogas organic fertilizer had a significant effect on the growth and yield of corn. In general, treatment applied with these organic fertilizer products had significantly better results than the control treatments received only chemical fertilizers. However, the treatments applied singly solid organic fertilizer and liquid organic fertilizer were not significantly different ($p<0.05$) regarding the growth when compared to together at day 45 after sowing.

Table 11. Agronomic parameters of maize under the field conditions at Co Do district, Can Tho City, Vietnam, from January 12, 2022 to March 15, 2022

Treatments	Plant height (cm)	Number of leaves (leaves)	Stem diameter (cm)	Fresh stem biomass (g/plant)
100% NPK	202[b]	13.3	2.43[a]	572[b]
75% NPK	187[c]	13.1	2.27[b]	464[c]
75% NPK + SOF	212[a]	13.4	2.43[a]	607[ab]
75% NPK + LOF	207[ab]	13.1	2.35[ab]	648[ab]
75% NPK + SOF + LOF	209[ab]	13.5	2.42[a]	673[a]
F	*	*ns*	*	*
CV (%)	4.82	2.26	3.40	13.7

Note: Values in the same column having different letters are significant difference at 5% level of Tukey's test; SOF: solid organic fertilizer; LOF: liquid organic fertilizer

3.4.1 Agronomic parameters

The effect of two types of biogas organic fertilizers on agronomic parameters of corn at day 60 after sowing under the field conditions are presented in Table 11 showed that organic fertilizers help increase the height and fresh biomass of corn plants. In general, the treatments applied singly solid organic fertilizer product showed the highest values in plant height, while treatments with both solid and liquid biogas organic fertilizer product application gave the highest values in fresh stem biomass, and these two treatments were not significantly different from each other in terms of agronomic parameters and both were also not significantly different from the liquid organic fertilizer product application treatment. However, all 3 treatments applied organic fertilizer products had significantly higher values in plant height and fresh stem biomass as compared to those of the control treatment applied with 75% NPK, but were not statistically significantly different from han those of the positive control treatment received 100% NPK. Nevertheless, all 5 treatments did not have any significant difference regarding number of leaves at day 60 after sowing. In addition, the treatment applied with 75% of the recommended chemical fertilizers made the stem diameter significantly decreased ($p<0.05$) as compared with the 4 remaining treatments, but these treatments were not significantly different ($p>0.05$) from each other. Moreover, the treatment 75% NPK + solid organic fertilizer (1 ton/ha) + liquid organic fertilizer (5 L/1000 m^2)/1 time did not increase significantly maize growth ($p>0.05$) when compared with 2 treatments singly applied liquid or solid organic fertilizer on the same chemical fertilizer regime. Thus, through this result, it is recommended to apply either solid or liquid organic fertilizers from biogas effluents, coal slag, sugarcane filter for maize to save production costs. Moreover, application of 1 ton solid organic fertilizer or 5 L/1000 m^2 liquid organic fertilizer helped to reduce 25% of recommended NPK fertilizer. Beneficial bacteria in these solid and liquid organic fertilizers helped to increase the amount of avaiable nutrients in soil after application such as nitrogen, phosphorus, potassium, silicatethus maize performed a better in growth, development and yield.

3.4.2 Actual yield and yield components of maize

Data presented in Table 12 showed the effect of biogas organic fertilizers on yield components and actual yield of maize under the field conditions. Generally, there was no significant difference ($p>0.05$) among treatments regarding ear length, ear diameter, number of row/ear, grains number/row, and grain numbers/ear. This indicated that reducing 25% of recommended NPK and applying 1 ton/ha of solid organic fertilizer and 5 L/1000 m^2 of liquid organic fertilizer did not affect these yield components. This may be due to genetic characteristics of the maize plant. In accordance with Hidayati et al. (2018), the yeild are influenced by genotypes and the environment (including nutrients or organic matter). However, grain weight and ear weight of maize of treatments were significantly different ($p<0.05$) when compared together. This resulted in a significant difference in actual maize yield among treatments. All four treatments including 75% NPK + SOF + LOF, 75% NPK + SOF, 75% NPK + LOF, and the positive control treatment, 100% NPK had the significantly higher values in terms of ear weight, fresh grain

Table 12. The effect of biogas organic fertilizers on yield components and yield of corn under the field conditions at Co Do district, Can Tho City, Vietnam, from January 12, 2022 to March 15, 2022

Treatments	Ear length (cm)	Ear diameter (cm)	Number of rows/ear	grain number/ row	grain number/ ear	Ear weight (g)	Fresh grain weight (g/ear)	Ear yield (t/ha)	Grain yield (t/ha)
100% NPK	18.4	5.20	13.6	36.8	501	438[a]	171[a]	24.8[a]	9.70[a]
75% NPK	18.1	5.06	13.6	36.8	495	402[b]	157[b]	22.8[b]	8.88[b]
75% NPK + SOF	18.1	5.18	13.8	37.7	518	448[a]	178[a]	25.4[a]	10.1[a]
75% NPK + LOF	18.0	5.18	13.7	36.2	500	450[a]	177[a]	25.5[a]	10.0[a]
75% NPK +SOF+ LOF	18.6	5.22	13.8	36.7	516	461[a]	179[a]	26.1[a]	10.2[a]
F	*ns*	*ns*	*ns*	*ns*	*ns*	*	*	*	*
CV (%)	2.47	2.26	3.60	2.16	3.56	3.77	6.07	5.52	6.07

Note: Values in the same column having different letters are significant difference at 5% level of Tukey's test; SOF: solid organic fertilizer; LOF: liquid organic fertilizer

weight/ear, ear yield and grain yield than the treatment applied only 75% NPK, but they were not significantly different when compared these four treatments with each other. The obtained results in Table 12 and Figure 2 also demonstrated that the supplementation of biogas organic fertilizers helped to increase ear weight and grain weight by 11-14%, as compared to the treatment applied to only 75% of NPK. It was obvious that application of organic fertilizer products from biogas effluents and other sources not only helped to reduce the amount of chemical NPK fertilizer recommended by 25%, but also maintained the same yield of maize in the positive control treatment without organic fertilizer application. This means that biogas organic fertilizers can replace up to 25% of the recommended NPK.

Figure 2. The ear size of 5 experimental maize treatments

3.5 The influence of two kinds of organic fertilizers (liquid and solid) on growth and yield of mung bean under the field conditions

Plant height and number of leaves, biomass can be used to reflect the relative growth of plant. Nutrient status may affect the plant growth Hidayati et al. (2018). This experiment showed that nutrients in organic fertilizers from biogas wastewater had an greeat effect on mungbean plant. In fact, the statistical analysis results presented in Table 13 and Figure 3 illustrated that biogas organic fertilizers had a positive effect on the growth and yield of mung beans under the field conditions. The plant height and number of leaves of mung bean of all treatments were not significantly different ($p>0.05$) when compared with each other whereas the remaining parameters including grains number/pod, pod number/plant, dry stem biomass, 1000-grain weight, and grain yield were significantly different among treatments ($p<0.05$). Among treatments, the treatments fertilized with solid organic fertilizer or liquid organic fertilizer or both solid organic fertilizer and liquid organic fertilizer gave statistically significant higher values in terms of growth and yield and yield components of mungbean as compared to those of the control treatment applied only 75% NPK ($p<0.05$), but equivalent to those of the positive control treatment applied only 100% NPK. Especially, the addition of organic fertilizers either solid or liquid form heldped to increase the fresh biomass of mung beans by 34.2-54.3%, grains number in pod by 9.9-14%, pod number per plant by 10.8-42.9%, grain weight by 20.3-21.7%, and grain yield of mungbean by 42.3-53% as compared to the control treatment applied only 75% NPK. This may be due to mainly it being attributed to grain number, pod numbers per plant and 1000-grain weight. This result proved that supplementation of solid organic fertilizer/liquid organic fertilizer or both of them can reduce

Table 13. The agronomic parameters, yield components and actual yield of mung beans under the field condition at Co Do district, Can Tho City, Vietnam, from January 12, 2022 to March 15, 2022

Treatments	Plant height (cm)	No. of leaves	Dry stem biomass (g)	Grains numbers/pod	Pod numbers/plant	1000- grain weight (g)	Grain yield (t/ha)
100% NPK	77.9	10.3	24.7^{bc}	12.4^{a}	25.2^{bc}	84.3^{a}	3.13^{a}
75% NPK	73.6	10.7	21.9^{c}	11.4^{b}	23.1^{c}	68.6^{b}	2.43^{b}
75% NPK + SOF	74.4	10.7	31.4^{a}	12.5^{a}	33.0^{a}	83.5^{a}	3.46^{a}
75% NPK + LOF	75.6	10.1	33.8^{a}	13.0^{a}	26.6^{b}	82.6^{a}	3.51^{a}
75% NPK + SOF + LOF	75.5	10.3	29.4^{ab}	12.8^{a}	25.6^{bc}	82.5^{a}	3.72^{a}
F	*ns*	*ns*	*	*	*	*	*
CV (%)	3.89	6.93	17.3	5.26	13.6	9.17	16.6

Note: Values in the same column having different letters are significant difference at 5% level of Tukey's test; SOF: solid organic fertilizer; LOF: liquid organic fertilizer

by 25% recommended chemical NPK fertilizer. Similarly, these results also showed that application of solid organic fertilizer (1 ton/ha) or liquid organic fertilizer (5 L/1000 m^2) helped to reduce up to 25% recommended NPK fertilizer. This means that both solid and liquid organic fertilizers are good nutrient sources and this also may be partly due to the beneficial bacterial group in organic fertilizer improved the amount of N, P and K. That led to an increase of available nutrients in soil for mungbean plants to absorb for their better growth and yield because beneficial bacteria could fix nitrogen, solubilize phosphorus, silicate and synthesize phytohormone, IAA (Dragicevic et al., 2018). This results consistent with the study of Abbas et al. (2011); Bandani et al. (2014) who reported that organic fertilizers helped to increase plant height, number of sub branch and number of pods per plant and graint yeild of mungbean plant.

Figure 3. The ear size of 5 experimental mungbean treatments

In short, after one experimental crop under the field conditions to evaluate the influence of organic fertilizer products from biogas wastewater, coal slag, fish emulsion, and beneficial bacterial strains on growth and yield of maize and mungbean, the achieved results showed very compatible and this indicated that organic fertilizer had a great effect on growth, yield components and actual yield of plants. In addition, organic fertilizers also helped to reduce 25% NPK recommended fertilizer formula but the plant still gave the same growth and yield as the positive control treatment applied only 100% NPK recommended fertilizer. It was clear that all two kinds of organic fertilizer formulations had the same effect on plant growth and yield. This could be explaned by the fact that both two types of biogas organic fertilizers helped to increase the total nutrient and available nutrient in the soil and this led to increase the yeild of maize and mung bean (Dragicevic et al. 2018). However, Dragicevic et al. (2018) implied that whether or not the application of biogas digestates as organic fertilizer source could make to increase the mobility and plant nutrient availability in soil was not entirely confirmed. On the other hand, to save labor and input cost, solid organic fertilizer was recommended for use because they were applied only once before the sowing time. Moreover, also because the liquid fertilizer was applied 4 times in total during the experimental time. Therefore, it can be concluded that solid organic fertilizer from biogas effluents helps to reduce or replace chemical fertilizers up to 25% of total recommended NPK formula to maintain sustainable agricultural production.

These results in this current study are compatible with those obtained by Kandil et al. (2020) who reported that the application of compost (as organic manure) and the potassium forms significantly affected the plant height, ear length, grains number/rows, grains number/ear, 100-grain weight, straw and biological yields, protein in grain and K contents in both two maize crops. Beside, increasing the application doses from 5 to 10 ton/ha of organic fertilizer made an increase of the yield of maize, its components, protein content in grain and K contents as well. This meaned that LOF consistently increased the growth, yield and quality of sweet corn. Similarly, Jjagwe et al. (2020) investigated how organic fertilizers could be used to replace the conventional fertilizers and they found that all forms of organic waste management (storage, composting, and anaerobic digestion) helped to increase number of leaves, plant height, cob, and grain yields of maize and concluded that organic fertilizer from anaerobic digestion can replace partly inorganic fertilizers (Jjagwe et al.

2020). In the past, the study of Ross et al. (1989) also illustrated that dry yield biomass of maize were not consistently influenced by any of the treatments, apparently because of high soil-nutrient reserves. The study by Linh and Guong (2013) showed that biogas sewage discharged was used as liquid organic fertilizer and when irrigating this kind of organic fertilizer for maize could replace chemical fertilizers and it also helped to increase ear length and ear diameter of maize, resulting in increased ear weight and ear yield comparable to chemical fertilizer application treatments. Similarly, Thao et al. (2017) showed that using 35 L/m^2 of biogas sewage containing 75% nitrogen content helped to maintain maize yield equivalent to the chemical fertilizer application treatment and as well the input costs for farmers reduced.

The results of this study is also consistent with previous study to evaluate the influence of biogas liquid waste as utilized as fertilizer on vegetables and indicated that this kind of fertilizer had a very good efficacy on increasing vegetable yield. Typically, the study of Duyen et al. (2012) on lettuce plants showed that utilization of used coal slag to absorb biogas effluents to mix with manure as organic fertilizer for lettuce under the greenhouse conditions stimulated significantly the growth and fresh biomass of lettuce at harvest time as compared to the control treatment applied only chemical fertilizers. Especially, the addition of coal slag to absorb biogas sewage discharged helped to increase leaf length, leaf width and fresh biomass of lettuce, leading to an increase in lettuce yield by 47.38-155.38% compared to the control treatment with only chemical fertilizer application (Nga et al., 2016). This result proved that the coal slag used for absorbing biogas wastewater can be reused as a source of fertilizer for plants and soil while still minimizing environmental pollution.

Furthermore, on other crops, previous studies showed that using biogas effluents as organic fertilizer helped to increase crop yield, to reduce chemical fertilizer dose of application and to improve some soil properties. For others crops like watermelon, alfalfa, soybean and other cereal crops, studies in other countries also showed that using liquid or solid fertilizers from biogas digesters can replace or reduce effectively chemical fertilizers while the yield of crops was equivalent or even higher than recommended chemical fertilizer application treatments (Alburquerque et al., 2012; Koszel and Lorencowicz, 2015; Ortenblad et al., 2002; Rodhe et al., 2006; Smith et al., 2007; Moller and Stinner, 2009; Pertiwiningrum et al., 2017; Sigurnjak et al., 2017; Nu et al., 2015).

Based on these results, the use of digestates can be compared to the use of animal manure or mineral fertilizers with respect to trace metal accumulation in soil and grain uptake. Thus, the achieved results of this study continue to confirm the effectiveness of utilization of biogas digester wastewater in combination with coal slag, sugarcane sludge, and beneficial bacterial strains to make solid organic fertilizer products on plant growth and yield. This is the basis for continuing to conduct more studies in near future to evaluate the effectiveness of solid organic fertilizer on the growth and yield of other crops under the field conditions and as well in reducing NPK fertilizer doses, contributing to reducing input costs and increasing profits for farmers.

4 Conclusion

In summary, biogas effluent was a real source of nutrients that can be utilized for plants and soil to reduce the environmental pollution. Because biogas liquid waste contained a diverse source of nutrients including nitrogen, phosphorus, potassium, it was suitable for reuse as a nutrient source to make organic fertilizer. The combination of biogas effluents together with fish emulsion, coal slag and sugarcane filter to make liquid or solid organic fertilizer met national standard for the organic matter production. Organic fertilizers from biogas effluents could replace up to 25% of the recommended NPK, especially, solid organic fertilizer with 1 ton/ha as an application dose was recommended to use so that farmers can get the highest net profit under the study conditions. However, other additional studies are needed to investigate in future to evaluate the effect of different application doses of solid organic fertilizer on growth and yield of other crops and its effects on soil properties. This practice will contribute to the reuse of waste sources from the biogas digester system, as well as coal slag, sugarcane sludge to minimize the environmental pollution and to practice sustainable agricultural development.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data.

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