EFFECTS OF BIOGAS SLURRY AS THE REPLACEMENT FOR CHEMICAL FERTILIZERS ON CHINESE CABBAGE YIELD AND SOIL QUALITY

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(Received 3rd Jan 2024; accepted 25th Mar 2024)

Abstract. To clarify the impact of biogas slurry replacing chemical fertilizers on Chinese cabbage yield and soil quality, we conducted two consecutive years of field experiment. The purified chemical fertilizer treatment was set as the control, while an equivalent nitrogen amount was added to the biogas slurry treatment (453 kg $N\cdot hm^{-2}\cdot a^{-1}$) to investigate its influence on soil nutrient indicators, heavy metals, and Chinese cabbage yield. The results indicated that compared to the chemical fertilizer treatment, the biogas slurry treatment increased soil organic matter, total nitrogen, and organic nitrogen contents by 16.4%, 35.0%, and 26.3%, respectively. The biogas slurry treatment led to decreases of Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg content by 12.6%, 14.6%, 9.25%, 32.2%, 30.1%, 12.1%, 24.0%, and 61.5%, respectively. Additionally, the Chinese cabbage yield increased by 10.0% in the biogas slurry treatment group. The study suggests that biogas slurry replacing chemical fertilizers can not only increase soil fertility and Chinese cabbage yield but also contribute to the improvement of the environmental quality of soils. However, more experiments aiming to provide references for the application of the optimal dosage of biogas slurry for optimal Chinese cabbage production are needed.

Keywords: *organic fertilizer, vegetable, recycling agriculture, heavy metals, environmental quality*

Introduction

Biogas slurry, the residue from biogas production, is a by-product of the anaerobic fermentation of livestock farming, rich in nutrients essential for plant growth, such as nitrogen, phosphorus, potassium, calcium, and manganese, as well as various active substances, including organic matter, amino acids, vitamins, and hydrolytic enzymes. It serves as an eco-friendly and efficient organic liquid fertilizer (Hu et al., 2022; Wang et al., 2019). Studies have demonstrated that biogas slurry not only promotes crop growth and agricultural product quality (Hou et al., 2019; Wang et al., 2018) but also contributes to the improvement of the physicochemical properties of the arable soil (Feng et al., 2014). With the continuous development of the livestock industry, China’s biogas slurry production is also increasing significantly (Lu et al., 2021), and it surpassed 1.6 billion tons in 2022 (Wei et al., 2023). Large amounts of biogas slurry can be efficiently utilized in fields, and it serves as the simplest and most effective method for resource utilization, thereby promoting the development of modern livestock farming. Presently, biogas slurry is primarily used for the cultivation of staple crops such as rice, wheat, and corn, with a limited application in vegetable farming (Xie et al., 2018; Huang et al., 2013). Expanding the related research can pave the way for new

DOI: http://dx.doi.org/10.15666/aeer/2203_23592366

avenues for the resource utilization of biogas slurry, aiding in the development of integrated farming systems and low-carbon agriculture.

Chinese cabbage (*Brassica juncea* (L.) Czern. et Coss. var. *multiceps* Tsen et Lee), known as “Xue Li Hong” in Chinese, belongs to the Brassicaceae family and is alternatively referred to as the leafy mustard (Zhang et al., 2019). Chinese cabbage is a distinctive agricultural product in Zhejiang Province, with a history of local cultivation over 1000 years (Ren et al., 2013). Yangmiao Town in Jiashan County is renowned as the “hometown of Chinese Cabbage in China”, where rotational planting patterns of rice and Chinese cabbage are adopted, which effectively enhances land use. This is the first study that focuses on Chinese cabbage by conducting two consecutive years of field experiment to investigate the effects of biogas slurry as a substitute for chemical fertilizers on Chinese cabbage yield and soil quality. The study aims to offer insights into the application of biogas slurry in Chinese cabbage production and to introduce new pathways for the resource utilization of biogas slurry.

Materials and methods

Field experiment

The experimental base is located in Guangming Village, Yangmiao Town, Jiashan County, Zhejiang Province, China, at 120.8022° E, 30.8396° N. The experiment was conducted between March 2021 and February 2023. Before the experiment, 20 cultivated layer soil samples (0–20 cm) were collected from the experimental base, and the nutrient and heavy metal contents in the soil were analyzed as background values, which were shown in *Tables 1* and *2*. At each sample site, 5 soil subsamples were gathered and were mixed into a composite sample. The biogas slurry used originated from the Jiashan breeding base of Zhejiang Huateng Livestock Co., Ltd. Analysis of the nutrient composition of biogas slurry revealed that it contained 0.24% total nitrogen, 0.01% total phosphorus, 0.19% total potassium, and 1.61% organic matter. Of the total nitrogen, 70% was in the ionic form, equivalent to 1.68 kg of nitrogen per tonne of biogas slurry. In addition, no heavy metal content was detected in the biogas slurry.

Table 1. *Nutrient contents ($g\cdot kg^{-1}$) in the soil before the experiment*

Nutrients	pH	Organic matter ($g\cdot kg^{-1}$)	Total nitrogen ($g\cdot kg^{-1}$)	Total phosphorus ($g\cdot kg^{-1}$)	Total potassium ($g\cdot kg^{-1}$)	Organic nitrogen ($g\cdot kg^{-1}$)
Contents	4.70 ± 0.11	37.8 ± 0.72	1.87 ± 0.04	0.21 ± 0.01	11.6 ± 0.10	2.84 ± 0.02

Table 2. *The contents of heavy metals ($mg\cdot kg^{-1}$) in the soil before the experiment*

Heavy metals	Cr	Ni	Cu	Zn	As	Cd	Pb	Hg
Contents	105 ± 4.45	46.4 ± 2.48	55.5 ± 1.84	204 ± 5.21	4.37 ± 0.60	0.33 ± 0.02	68.4 ± 1.26	0.29 ± 0.02

The control group received only chemical fertilizers without biogas slurry. The basal chemical fertilizer treatments included 150 $kg\cdot hm^{-2}\cdot a^{-1}$ of 46% urea (equivalent to 69 kg nitrogen (N)$\cdot hm^{-2}\cdot a^{-1}$), 300 $kg\cdot hm^{-2}\cdot a^{-1}$ of the N18-P8-K18 compound fertilizer (equivalent to 54 kg $N\cdot hm^{-2}\cdot a^{-1}$), and an additional topdressing of 600 $kg\cdot hm^{-2}\cdot a^{-1}$ of 46% urea (equivalent to 276 kg $N\cdot hm^{-2}\cdot a^{-1}$) and 300 $kg\cdot hm^{-2}\cdot a^{-1}$ of the N18-P8-K18 compound fertilizer (equivalent to 54 kg $N \cdot hm^{-2} \cdot a^{-1}$), totaling 453 kg $N \cdot hm^{-2} \cdot a^{-1}$. The experimental group, however, included 270 $t \cdot hm^{-2} \cdot a^{-1}$ of biogas slurry, equivalent to 453 kg $N \cdot hm^{-2} \cdot a^{-1}$, applied as the basal fertilizer before Chinese cabbage planting. Chinese cabbage was planted once a year, sown in August and harvested in December. During the experiment, the planting density of Chinese cabbage was 8.66 plants per square meter, equivalent to 86,625 plants per hectare. Except for the fertilization mode, the planting methods of the experimental group and the control group remained consistent.

The Chinese cabbage plants of both the control and experimental groups were harvested in December 2021 and 2022. The average yields of Chinese cabbages for all treatment groups were calculated. Additionally, after the experiment was completed, 40 cultivated layer soil samples were collected from the experimental fields (20 samples from the control group and 20 samples from the experimental group) for the analysis of nutrient indicators and heavy metal contents.

The detection and analysis of nutrients and heavy metals in soils

Soil organic matter content was determined using the method specified in “Soil testing part 6: Determination of soil organic matter (NY/T 1121.6–2006)”. Total phosphorus content was measured using the “Determination of total phosphorus in soil by alkali fusion-molybdenum antimony absorption spectrophotometry (HJ 632–2011)” method. Total nitrogen was measured using the “Determination of total nitrogen in soil by Kjeldahl (HJ 717–2014)” method. Total potassium was determined using the “Determination of potassium in forest soil (LY/T 1234–2015)” method. Additionally, organic nitrogen in the soil was detected using acid hydrolysis-distillation method.

The contents of copper, nickel, chromium, zinc, lead, cadmium, and arsenic in the soil were determined using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500c, Thermo Scientific, USA) according to the method outlined in “Determination of twelve metal elements in soil and sediment by the aqua regia extraction method-inductively coupled plasma mass spectrometry (HJ 803–2016)”. The content of mercury was measured using an atomic fluorescence spectrometer (AFS-230E) based on the “Determination of mercury, arsenic, selenium, bismuth, and antimony in soils and sediments by microwave digestion atomic fluorescence spectrometry (HJ 680–2013)” method.

Quality control and quality assurance

Quality control measures employed in this study included method blanks, process blanks, and parallel samples. For the analysis of nutrient indicators and heavy metals, batch experiments, with each involving the blank samples (2 per batch) and quality control standard samples (3 replicates per sample), were carried out. Additionally, at least 10% of the samples (2 duplicate pairs for every 10 samples) underwent repeated parallel experiments and analyses. The recovery rate of standard samples in this study ranged from 80% to 120%, and the relative standard deviation of parallel samples was less than 10%. Triplicate parallel blank samples were analyzed three times to calculate the standard deviation of the data on the detection of nutrients and heavy metals. Three times the standard deviation of the blank sample was taken as the limit of detection

(LOD), while ten times the standard deviation of the blank sample was considered as the limit of quantification (LOQ).

Results

Nutrient contents in the soil

The contents of nutrients in the soil for both the control and experimental groups are presented in *Table 3*. As indicated in the table, the organic matter, total nitrogen, and organic nitrogen contents in the soil of the experimental group were significantly higher than those of the control group, with increases of 16.4%, 35.0%, and 26.3%, respectively, indicating the positive contribution of substituting chemical fertilizers with biogas slurry. Moreover, the total phosphorus content in the soil of the experimental group showed a minor increase compared to that of the control group, while the total potassium content was slightly lower than that in the control group. This suggests that the influence of biogas slurry replacing chemical fertilizers on these two elements in the soil was relatively limited.

Table 3. *Nutrient contents (g·kg^{-1}) in the soil for both the experimental and control groups*

Group	pH	Organic matter (g·kg^{-1})	Total nitrogen (g·kg^{-1})	Total phosphorus (g·kg^{-1})	Total potassium (g·kg^{-1})	Organic nitrogen (g·kg^{-1})
Control	4.74 ± 0.06a	35.4 ± 0.95a	2.80 ± 0.04a	0.19 ± 0.03a	12.4 ± 0.33a	2.74 ± 0.02a
Experimental	4.85 ± 0.05a	41.2 ± 1.03b	3.78 ± 0.07b	0.21 ± 0.02a	11.8 ± 0.27a	3.46 ± 0.03b

Heavy metal contents in the soil

The contents of heavy metals in the soil for both the control and experimental groups are presented in *Table 4*. As observed in the table, the contents of the soil of the experimental group were significantly lower than those in the control group. Specifically, the contents of Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg decreased by 12.6%, 14.6%, 9.25%, 32.2%, 30.1%, 12.1%, 24.0%, and 61.5%, respectively. Thus, the significant reduction of the heavy metal content in the soil by substituting chemical fertilizers with biogas slurry could promote the improvement of soil environmental quality.

Table 4. *The contents of heavy metals (mg·kg^{-1}) in the soil for both the experimental and control groups*

Group	Cr	Ni	Cu	Zn	As	Cd	Pb	Hg
Control	100 ± 5.67b	47.9 ± 2.42b	56.2 ± 1.91b	208 ± 7.13b	4.05 ± 0.17b	0.33 ± 0.01b	67.8 ± 1.01b	0.39 ± 0.01b
Experimental	87.4 ± 3.44a	40.9 ± 2.09a	51.0 ± 2.77a	141 ± 6.66a	2.83 ± 0.25a	0.29 ± 0.01a	51.5 ± 1.80a	0.15 ± 0.00a

Yield of Chinese cabbage

Figure 1 depicts the yield of Chinese cabbage for the control and experimental groups, which was significantly higher in the latter (82.5 ± 1.52 t·hm^{-2}) than in the former (75.0 ± 1.21 t·hm^{-2}). These results indicate that substituting chemical fertilizers with biogas slurry could enhance the yield of Chinese cabbage, demonstrating a favorable effect on its production.

Discussion

Biogas slurry, which is rich in various nutrients essential for plant growth, can serve as an organic fertilizer for agricultural production (Huang, 2020). Presently, extensive research has focused on the impact of biogas slurry on the yield of major staple crops like rice. Studies have shown that applying biogas slurry promoted rice growth, leading to yield increases ranging from 49% to 286% (Jiang et al., 2022). Optimal rice yields obtained at biogas slurry application rates between 11.25 ~ 18.75 $t{\cdot}hm^{-2}$ exhibited an increase ranging from 6.78% to 9.93% compared to those recorded for fertilizer treatments (Tang et al., 2010), which is similar to a 10.0% increase in Chinese cabbage yield achieved by the substitution of chemical fertilizers with biogas slurry in this study. However, limited research has explored the effects of biogas slurry on the growth and yield of vegetable crops (Lin, 2012). Studies indicate that irrigating lettuce with biogas slurry increased yields within the range of 11.4% to 37.9% (Zhao et al., 2020), while drip irrigation led to an increase ranging from 3.28% to 58.5%, and spray irrigation resulted in an increase between 24.6% and 51.8% in lettuce yields (Li et al., 2014), showing better results than those obtained in this study. This suggests that substitution with biogas slurry is advantageous for lettuce yields, with drip and spray irrigation methods being more beneficial for leafy vegetable production compared to conventional irrigation methods. Research by Ye et al. (2014) revealed that compared to water treatment, fertilizer reduced lettuce yield by 12.3%, while biogas slurry increased it by 4.30% to 11.1%, similar to our findings. An investigation by Mao et al. (2017) demonstrated an increase within the range of 2.50% to 7.12% in mustard yield with biogas slurry treatment, with 116.7 $t{\cdot}hm^{-2}$ found as the most effective dosage. However, Wu et al. (2017) found an increase between 12.5% and 50.0% in mustard yield when biogas slurry treatment was applied compared to the fertilizer, demonstrating better findings than those of the present study. This difference might stem from laboratory simulations, which might have caused a more substantial increase in the production and yields of mustard compared to field experiments.

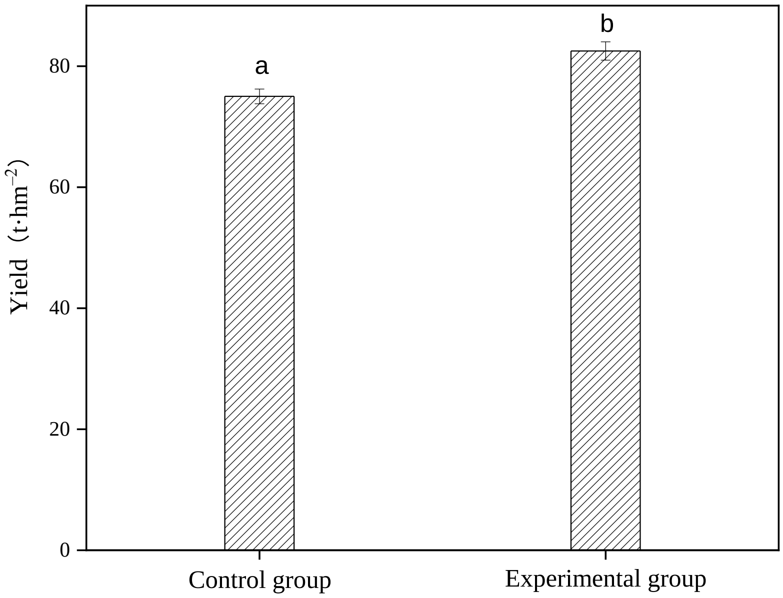

Figure 1. *Yield of Chinese cabbage in the experimental and control groups*

Substituting chemical fertilizers with biogas slurry not only increases crop yields but also enhances soil fertility, thereby contributing to the improvement of the physicochemical properties of the topsoil (Sun et al., 2013). The results of this study demonstrate that replacing chemical fertilizers with biogas slurry increased the contents of organic matter, total nitrogen, and organic nitrogen in the soil, aligning with the findings of Yang et al. (2017). Additionally, the greater increase in total nitrogen content compared to organic nitrogen and organic matter contents in the soil indicates that biogas slurry application plays a more significant role in elevating inorganic nitrogen content in the soil, which favors the growth of vegetable crops. Studies found that biogas slurry contains large amounts of readily available nutrients, which cause an increase in inorganic nitrogen contents in the soil. Furthermore, the increased organic matter content enhanced soil microbial community activity, promoting nitrogen mineralization and subsequently enhancing the absorption and utilization of nitrogen by crops (Abubaker et al., 2012; Li et al., 2011). However, using biogas slurry as a substitute for chemical fertilizers may potentially impact soil environmental quality due to the possible presence of harmful substances in biogas slurry, such as heavy metals and antibiotics, as well as antibiotic resistance genes (Ji, 2021). Research indicates that biogas slurry treatment leads to varying degrees of the accumulation of certain heavy metals (Cu, Zn, As, and Hg) in the soil, albeit below the screening values for contamination of agricultural land soil as per the “Soil Environmental Quality Risk Control Standards for Soil Contamination on Agricultural Land (Trial; GB15618–2018)” (Zhu, 2022). Research by Lv (2022) reported a significant increase in Cr, Cd, Cu, Zn, and Pb contents in the soil with biogas slurry treatment, indicating a positive correlation between heavy metals and organic matter. Chen et al. (2021) propose that the high Zn content in biogas slurry necessitates the investigation of its long-term impact on Zn levels in the soil. Moreover, some studies have found a significant positive correlation between As and Cr contents in the soil and biogas slurry, suggesting that the long-term application of biogas slurry might lead to excessive As and Cr accumulation in the soil (Huang et al., 2016). In contrast to these studies, this research demonstrated a decrease in Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg contents in the soil following biogas slurry application. The concentrations of heavy metals in biogas slurry primarily depend on the feed used in livestock and poultry farming. The use of traditional feeds, due to their higher heavy metal contents, results in an increase in concentrations of heavy metals in the generated livestock waste and biogas slurry and subsequently the increased heavy metal contents in the soil upon their application. Therefore, the type and quality of biogas slurry have a considerable influence on soil environmental quality. The biogas slurry used in this study originated from an ecological recycling pig farming enterprise, without the addition of antibiotics or heavy metals during pig breeding. Consequently, the produced biogas slurry contains minimal concentrations of residual heavy metals, thereby exerting a minimal influence on the accumulation of heavy metals in the soil. Moreover, biogas slurry is rich in organic matter and microbes and exhibits a strong ability to adsorb and chelate heavy metal ions. The application of biogas slurry can serve as an important measure for the remediation of heavy metal-contaminated soils (Lu et al., 2019). The conclusions drawn from this study can provide a reference for the use of biogas slurry to improve soil fertility and efficiency of pollution control in farmland soils.

Conclusions

The present research showed that biogas slurry treatment increased the contents of organic matter, total nitrogen, and organic nitrogen in the soil but significantly reduced the levels of Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg. In addition, this study demonstrated that substituting chemical fertilizers with biogas slurry enhanced soil fertility, increased the yield of Chinese cabbage, and promoted the improvement of soil environmental quality. However, further experiments are needed to determine precisely the optimal dosage of biogas slurry for optimal Chinese cabbage production, further providing guidelines for its use in cultivation practices.

Acknowledgements. This research was funded by the Natural Science Foundation of Zhejiang Province, China (LQ23D030002); the Scientific Research Fund of Zhejiang Provincial Education Department (Y202248575); and the Jiaxing Public Welfare Research Project of Jiaxing Science and Technology Bureau (2022AY10031, 2023AD11013).

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