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N. Duan

C. Lin

R. Y. Gao

Y. Wang

J. H. Wang

See next page for additional authors

Presenter/Author Information
N. Duan, C. Lin, R. Y. Gao, Y. Wang, J. H. Wang, and J. Hou

Ecological and economic analysis of planting greenhouse cucumbers with anaerobic fermentation residues

N. Duan[a], C. Lin[a,*],R.Y. Gao[a], Y. Wang[a], J.H. Wang[a], J.Hou[a],

a. College of Water Conservancy and Civil Engineering, China Agricultural University, Beijing 10083, China

Abstract: In this study, the effect of different fertilizers on the nutritional quality, sanitary quality and the yield of greenhouse cucumbers were analyzed by comparative experiments with chemical fertilizer and anaerobic fermentation residues (biogas fertilizer). Particularly the properties of bio-fertilizer and diseases and pests inhibition of biogas fertilizer were demonstrated and its comprehensive benefits were evaluated. The results show that compared with chemical fertilizer, biogas fertilizer increased the dry matter, solids, reductive sugar, Vc, soluble protein of cucumbers by 4.62%, 4.08%, 29.05%, 20.83%, 10.85% respectively; the chlorophyll of leaf was 9.18% higher and the incidence of aphids and mildew 20% and 25% lower respectively. After calculation, the yield was raised by 1323.4 kg/mu, an increase of 15.90%. The income was increased by 22839.8 Yuan/mu and the output/input ratio reached 63.75:1, which is 3.77 times than that of chemical fertilization. Results indicated that biogas fertilizer can effectively reduce diseases and pests, bring good economic, social, and environmental benefits, and promote the low-carbon circular development of crop farming.

Keywords: anaerobic fermentation residues, ecology, cucumber

1 Introduction

As an application technology to address energy and environmental issues, the biogas technology is widely used in China. As one transformed form of biomass energy, biogas is one kind of clean energy in the rural area, and its anaerobic fermentation residue (biogas slurry and residue) has two main functions: bio-fertilizer and diseases/pests control. Recent study has revealed that anaerobic fermentation residue has been widely applied to agricultural production, there's no longer environmental problems caused by chemical fertilizer or pesticide; moreover, it is able to reduce nitrate accumulation in crops [1], being praised as a broad-spectrum anaerobic processing agent [2].

Biogas residue is a more comprehensive organic fertilizer combining quick-acting nutrients with slow-acting nutrients, compared with common organic fertilizers. As for the utilization of nitrogen, phosphor and potassium, straw biogas fertilizer is 20.2%, 16.4% and 20.6% respectively higher than those of compost; animal manure biogas fertilizer is 22.1%, 17.5% and 20.1% respectively higher than those of compost. When the biogas residue is

* Corresponding author. Tel.: +86 10 62737608.
E-mail addresses: lincong@cau.edu.cn (C. Lin).

speeded directly on farmland as fertilizer, it can greatly increase the cropping yields; while applied constantly, it can ensure sustained increasing because of a large amount of humic acid contained in it. Biogas slurry is a multiple available compound fertilizer adopted widely in agriculture production to realize pollution-free cultivation. Biogas slurry can be used as fertilizer for irrigation, or foliar application, and nutrient fluid for soil-less culture. Meanwhile, its bio-pesticide property has been revealed and proven gradually. Studies suggest that biogas slurry can control nearly 30 diseases and pests and inhibit 17 agricultural pathogenic bacteria in various degrees [3].

The properties of anaerobic fermentation residues with swine manure as raw material of Xinke Garden in Xushui County, Hebei, China was analyzed. Anaerobic fermentation residues were applied to planting greenhouse cucumbers, with basal fertilization, topdressing fertilization and foliar fertilization by biogas fertilizer and chemical fertilizer separately. Then through the contrast analysis of applying biogas fertilizer and chemical fertilizer, the nutritional quality, sanitary quality and the yield of greenhouse cucumbers were analyzed and the ecological and economic benefits of biogas fertilizer were demonstrated in order to explore the effective way to promote low-carbon circular and sustainable development model in crop farming.

2. Materials and Methods

2.1 Experimental materials

The anaerobic fermentation residue was taken from a normal, mesophilic fermentation digester in Xinke Garden and its physicochemical properties can be seen in Table 1. The raw material for anaerobic fermentation was swine manure. The cucumber variety in the experiment was Jinlv No. 3, which was grafted with blackie pumpkin as the rootstock and field planted after seedling for 30 days in nutrition pot.

Table 1 Physicochemical properties of anaerobic fermentation residue

Item	Total N%	Total P% (P_2O_5)	Total K% (K_2O)	Available N (mg/L)	Available P(P_2O_5) (mg/L)	Available K(K_2O) (mg/L)	Organic matter (%)	Humic acid (%)
Biogas slurry	0.257	0.055	0.137	2047.50	54.24	1160.00	3.23	0.187
Biogas residue	3.874	2.389	1.106	16714.29	13904.29	7536.29	30.43	20.325

2.2 Experimental Design

Two same-sized experimental plots were designated in a greenhouse, and two

fertilization treatments: biogas fertilizer and chemical fertilizer were designed. The cultivation method and soil fertility of these two plots were the same. After planting watering, plastic mulching was applied. The average amounts of fertilizer applied were the same for those two treatments: 1/3 nutrient was from basal fertilizer, and the rest was provided by topdressing and foliar application. Topdressing was started two months after field planting. Biogas slurry and water were blended 1:1 for coupled irrigation; and for chemical fertilizer treatment, an equal quantity of diammonium phosphate, carbamide, potassium chloride and potassium sulphate compound fertilizer was applied with irrigation water. The amounts of fertilizer used in those two treatments were shown in Table 2. The tending and prevention of diseases and pests were the same. Experimental cucumbers were sampled randomly from the experimental plots.

Table 2 Different fertilization schemes of cucumber production

		Fertilization ingredient quantity						
Fertilization process	Treatment	Biogas residue (kg)	Biogas slurry (kg)	Water (kg)	Diammonium phosphate (kg)	Carbamide (kg)	Potassium chloride (kg)	Potassium sulphate compound fertilizer (kg)
Basal fertilization	1	20.00	0	0	0	0	0	0
	2	0	0	0	0.9	0.15	0.60	0
Topdressing	1	0	40	40	0	0	0	0
	2	0	0	79.69	0.18	0.03	0.10	0
Foliar application	1	0	5	5	0	0	0	0
	2	0	0	9.95	0	0	0	0.05

2.3 Measurement Methods

The characteristic of anaerobic fermentation residue, the nutritional and sanitary quality and the yield of greenhouse cucumber was measured in the study. Total nitrogen was measured by potassium persulfate oxidation-UV spectro-photo metric method, total phosphorus by Mo-Sb anti-spetrophotometry method, available phosphorus by $NaHCO_3$ extraction Mo-Sb anti-spetrophotometry method, available potassium by sodium tetraphenylboron turbidimetry, humic acid by sodium pyrophosphate extraction- potassium dichromate oxidation colorimetry, chlorophyll by acetone–ethanol colorimetry, reductive sugar by iodometric method, solvable protein by Coomassie Brilliant Blue G-250 method,

and Vc by 2, 6-dichloraphenol indophenol method. Others were determined by standard methods. Sanitary indicators were determined by Agricultural Environment Quality Supervision and Inspection Center of the Ministry of Agriculture (Beijing), and cucumber growth, diseases, pests and yield were measured by observation and statistical method.

3. Results and Discussion

3.1 Analysis of the bio-fertilizer property of anaerobic fermentation residue

3.1.1 The effects of anaerobic fermentation residue on nutritional quality of cucumbers

Observations showed that cucumbers applied biogas fertilizer had the following features: strong stem, dark green leaves, and better growth. The nutritional indicators of cucumber with two different fertilizers are shown in Figure 1. The results revealed that after applying biogas fertilizer, the content of dry matter, solids, reductive sugar, Vc, soluble protein was 4.62%, 4.08%, 29.05%, 20.83%, and 10.85% higher than those treated with chemical fertilizer. It means biogas fertilizer could effectively improve the nutritional quality, especially the reductive sugar and Vc, which are important indicators of evaluation the fruit quality. Thus, we can come to the conclusion that biogas fertilizer can improve the mouthfeel and commercial quality of cucumbers.

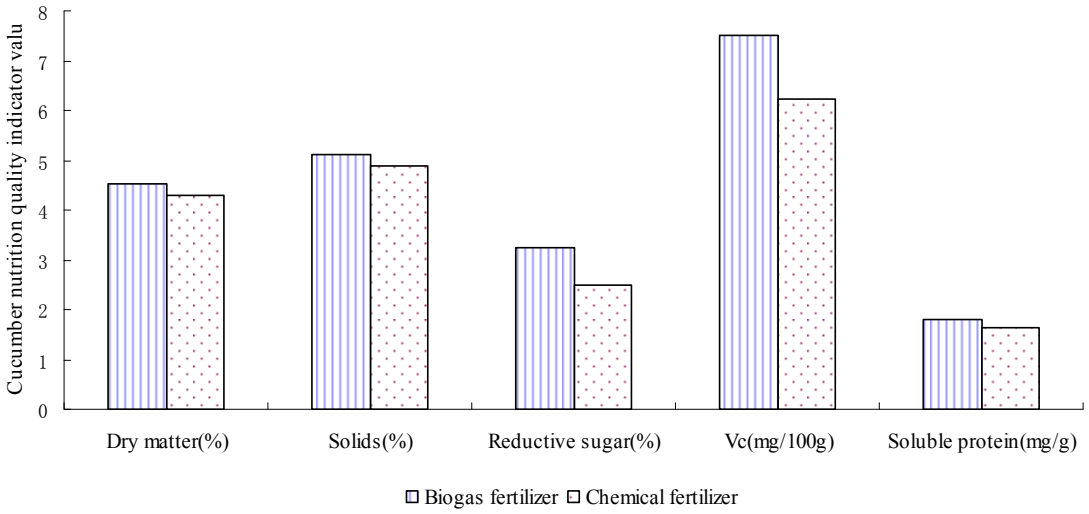

Figure 1 Nutritional quality of greenhouse cucumber

3.2.2 The effects of anaerobic fermentation residue on sanitary quality of cucumber

The sanitary quality is another important indicator of cucumber. Table 3 is the test report of sanitary indicators of cucumbers planted with biogas fertilizer from Agricultural Environment Quality Supervision and Inspection Center of the Ministry of Agriculture (Beijing). Table 4 is the test result of cucumbers with chemical fertilizer by Tianmin[4]. The results show that, either biogas fertilizer or chemical fertilizer, Pb, Cd, Hg and As are lower

than the minimal detectable limit of national standard. However, the nitrite content in cucumbers with chemical fertilizer is far beyond the standard value, 3.96 times higher than those treated with biogas fertilizer. The results suggest that chemical fertilizer will increase the nitrite content of vegetables and influence fruit quality, which is directly associated with nitrogen fertilizer. More than 70% of nitrite is absorbed into the human body from vegetables, thus, overuse of nitrogen fertilizer will increase nitrite content of soil environment and crops, and then it will greatly endanger human health. However, biogas fertilizer contains a lot of organic matters and humic acid. Functional groups of organic matters can absorb heavy metallic ions, and humic acid can form complex compound with heavy metallic ions to decrease vegetable's absorption of heavy metals and further decrease hazardous residues.

Table 3 Sanitary indicators of cucumbers for application biogas fertilizer

Item	Unit	Measured value	Indicator	Judgment	Reference
Hg	mg/kg	0.0030	≤0.01	qualified	GB/T 5009.17-1996
As	mg/kg	0.0060	≤0.5	qualified	GB/T 5009.11-1996
Pb	mg/kg	0.0392	≤0.2	qualified	GB/T 5009.12-1996
Cd	mg/kg	0.00639	≤0.05	qualified	GB/T 5009.15-1996
Nitrite	mg/kg	1.64	＜4.0	qualified	GB/T 15401
Acephatemet	mg/kg	Non-detectable	None	qualified	GB 14876-94
Karbofos	mg/kg	Non-detectable	None	qualified	GB 5009.20-1996
Parathion	mg/kg	Non-detectable	None	qualified	GB 5009.20-1996
Acetyl ethylamine phosphorus	mg/kg	Non-detectable	≤0.2	qualified	GB 14876-94
Flolimat	mg/kg	Non-detectable	None	qualified	GB 5009.20-1996
Thimet	mg/kg	Non-detectable	None	qualified	GB 5009.20-1996

Table 4 Sanitary indicator of cucumbers for application of chemical fertilizer

Item	Unit	Measured value	Indicator	Judgment	Reference
Hg	mg/kg	0.005	≤0.01	qualified	GB/T 5009.17-1996
As	mg/kg	0.025	≤0.5	qualified	GB/T 5009.11-1996
Pb	mg/kg	0.05	≤0.2	qualified	GB/T 5009.12-1996
Cd	mg/kg	0.0025	≤0.05	qualified	GB/T 5009.15-1996
Nitrite	mg/kg	8.13±0.78	＜4.0	unqualified	GB/T 15401

3.2.3 The effect of anaerobic fermentation residue on yield property of cucumbers

Compared with applying chemical fertilizer, the cucumber with biogas fertilizer has significant advantages as follows: more unit plant yields, longer cucumbers with a low

curvature and better commercial property. As an important photosynthetic pigment, chlorophyll has great influence on photosynthetic product accumulation. Table 5 suggests that chlorophyll of leaves of biogas fertilizer treatment is 9.18% higher than that of chemical fertilizer treatment, proving that biogas fertilizer can increase chlorophyll content of leaves, improve photosynthesis rates of plants, accelerate the growth of carbohydrate, and then increase the cucumber yield. Results indicated that, compared with chemical fertilizer, biogas fertilizer has increased total yields by 22.5kg, equivalent to a increase of 1323.4 kg/mu, raising by 15.90%. Thus, application of biogas residue and slurry on greenhouse cucumbers can significantly increases the yield.

Table 5 The effect of different treatments on greenhouse cucumber yield

Treatment	Chlorophyll (mg/g)	Cucumber number per plant	Total yield(kg)	Production calculation(kg/mu)	Production increase (%)
1	1.487	14	164.0	9646.2	15.90
2	1.362	13	141.5	8322.8	-

3.2 Analysis of diseases and pests inhibition property of anaerobic fermentation residue

During the growth process of cucumber, 50 leaves in two experimental plots were chosen randomly and observed respectively. Table 6 shows that the incidence rates of aphids and mildew on biogas fertilizer treatment were 20% and 25% lower respectively. After applying anaerobic fermentation residue, the diseases and pests situation of greenhouse cucumbers was relieved and the growth was good.

Table 6 The effect of different treatments on diseases and pests of greenhouse cucumbers

Treatment	The incidence rates of aphids (%)	The incidence rates of mildew (%)
1	8	12
2	10	16

3.3 Benefits analysis of greenhouse cucumbers with anaerobic fermentation residue

3.3.1 Economic benefit analysis

According to the inputs of material consumption and human labor, cucumber seeds were calculated as 0.8 yuan/kg, diammonium phosphate 2.8 yuan/kg, carbamide 1.8 yuan/kg, potassium chloride 2.4 yuan/kg, potassium sulphate compound fertilizer 2.8 yuan/kg, and human labor 8 yuan/h, two hours each time. The calculation results of economic benefits are shown in Table 7. Compared with chemical fertilizer treatment, cucumbers planted with biogas fertilizer saved 784 yuan per mu, income increased 4577.8 yuan per mu, and the output/input reached 63.75:1, 3.77 times than that with chemical fertilizer. Thus, biogas

fertilizer could not only save fertilizer expenditure, but also decrease the negative effect of chemical fertilizer, bringing higher economic benefits.

Table 7 the influence of different treatments on economic benefit of greenhouse cucumber

Treatment	Output		Input				Output/input	Net income (Yuan/mu)	Income increase (Yuan/mu)
	Yield (kg/mu)	Value (Yuan/mu)	Cucumber seeds (Yuan)	Fertilizer (Yuan)	Human labor (Yuan)	Total (Yuan)			
1	9646.2	23203.8	60	0	304	364	63.75：1	22839.8	4577.8
2	8322.8	19410.0	60	784	304	1148	16.91：1	18262	-

3.3.2 Analysis of social and environmental benefits

Agricultural production using biogas fertilizer is of broad and extensive social significance and environmental benefits. First, biogas fertilizer can integrate planting with breeding, promoting the formation and development of low-carbon circular economy mode. It will provide beneficial ideas for improvement of China's agricultural production, helpful for the establishment of good agricultural structure, which follows the international agricultural development trend and promotes energy saving and emission reduction. Secondly, agricultural waste like livestock manure etc. produces biogas fertilizer using anaerobic fermentation technology, which is only the first step to convert wastes into the valuable resource. In order to realize resource reusing thoroughly, the application of biogas fertilizer is the key. If biogas residue and slurry are disposed improperly, there would be a secondary pollution to the environment, which is even worse for the accumulation of ecological and environmental benefits. But if biogas fertilizer is applied in ecological and agricultural planting, there will be favorable for increasing comprehensive benefits, thus not only realizing the innocuous treatment of waste, but also promoting the development of green ecological agriculture, conducive to being carbon neutral. At last, planting vegetables with biogas fertilizer can reduce the utilization of chemical fertilizer and pesticide, improve soil fertility, change the traditionally agricultural fertilizing ways, increase agricultural yields, reduces agricultural pollution, and even more be helpful for realizing the sustainable development of green agriculture.

4、Conclusion

Anaerobic fermentation residue applied as fertilizer will bring into full play its functions of bio-fertilizer and diseases and pests inhibition, which can improve the growth and mouthfeel of cucumbers, so it is called "bioactivator" with comprehensive ecological regulating actions. It also has good economic and environmental benefits: the yield in the

cultivation season could increase significantly, an increase of 22839.8 yuan per mu, and its output/input ratio reached 63.75:1, 3.77 times than that with chemical fertilizer. Planting vegetables with anaerobic fermentation residue not only has good ecological and economic benefits for agricultural plating, but also will greatly promote the development of biogas projects in China and provide more contribution to create the optimal cycle mode of resource-environmental protection-ecology-economy benefit, realizing energy-saving and emission-reduction and low-carbon circular development of agriculture.

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