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Application Status and Prospects of Biogas Fertilizer in Modern Agricultural Production

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Abstract On the basis of introducing the nutrient composition and biogas fertilizer, the effects of biogas fertilizer on soil, crops and environment are summarized. Biogas fertilizer can improve soil structure, increase soil organic matter, available nutrient contents and enzyme activity, increase crop yield, quality and resistance, and relieve the non-point source pollution effectively. The harmlessness, application technology and risk are analyzed. Some suggestions are put forward to control the source pollution, strengthen the research of fermentation technology, define the standard of biogas fertilizer, and carry out large and medium-sized biogas engineering.

Key words Biogas fertilizer, Agricultural production, Fertilization techniques, Application status, Prospects

1 Introduction

With the rapid development of intensive agriculture in China, the output of agricultural and rural wastes is increasing by 5% to 10% per year, and it is estimated that it will exceed 5 billion t by 2020. At present, the recycling of agricultural waste in China is extensive, and the resource-based treatment rate of a lot of crop stalks, livestock manure and other wastes is low. However, a large number of chemical fertilizers are applied in the farming industry, the utilization rate of organic fertilizer is low, and the unreasonable disposal and utilization of agricultural wastes lead to the separation of the breeding and farming industry, resulting in serious agricultural non-point source pollution. Biogas engineering is an effective measure to solve the problem of agricultural waste resource utilization, and it has been paid more and more attention. In 2016, six ministries and commissions, including the Ministry of Agriculture, jointly issued the *Project on Promoting the Pilot Resource-based Utilization of Agricultural Wastes*, which clearly pointed out that the utilization of agricultural wastes is an effective way to improve environmental pollution, develop circular economy and realize the sustainable development of agriculture. *The Action Plan for the Utilization of Livestock and Poultry Waste Resources* (2017 - 2020), issued by the Ministry of Agriculture, emphasizes that the utilization of livestock and poultry waste should be promoted in an all-round way, with agricultural organic fertilizer and rural energy as the main utilization direction, to comprehensively promote the utilization of livestock and poultry waste resources.

Anaerobic fermentation technology is widely used in the treatment of organic substances such as crop straw, animal manure and organic waste[2]. It not only provides clean and convenient energy and biogas, but also produces some fermentation residues, and these fermentation residues include biogas liquid and biogas residue. Nutrient elements such as nitrogen, phosphorus and potassium in fermentation process are mostly reserved in biogas liquid and residue[3], which can be used as organic fertilizer in agricultural production, collectively called biogas fertilizer. With the popularization of biogas in rural areas, more and more scholars begin to study the comprehensive utilization of biogas residue and biogas liquid, such as applying biogas residue and biogas liquid to maize production[4], non-pollution vegetable production[5], and crop seedling raising[6]. There are many kinds of raw materials for biogas fertilizer production and the properties are different. In this paper, the characteristics of biogas fertilizer, its effect on agricultural production, application technology and risk control are summarized, which will provide the direction for the utilization of biogas fertilizer resources, and ensure the sustainability of biogas engineering by using agricultural waste safely, rationally and effectively. It is of great significance to alleviating the crisis of agro-ecological environment in China.

2 Composition and characteristics of biogas fertilizer

The nutrient elements such as protein, hemicellulose, auxin, microbial mass and nitrogen, phosphorus and potassium in raw materials are retained in biogas residue and biogas liquid during anaerobic fermentation[7]. Therefore, the biogas residue and biogas liquid have high nutrient content and unique properties. Biogas residue is a kind of solid material which is not decomposed or decomposed completely in the process of anaerobic fermentation and other impurities deposited in the bottom of the reactor after drying. It contains not only nitrogen phosphorus potassium and other nutrients but also organic matter, humic acid, crude protein and so on. Biogas liquid is the residue of anaerobic fermentation,

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which contains humic acid, lignin, gibberellin, linoleic acid, beneficial bacterial mass and so on[8]. Table 1 shows the content of organic matter and nutrient elements in biogas residue and biogas liquid of different fermentation materials determined by Xu Yanxi *et al.* [9].

Table 1 The content of organic matter and nutrient elements in biogas residue and biogas liquid of different fermented raw materials

	Fermented raw materials	Organic matter//%	Total N//g/kg	Total P//g/kg	Total K//g/kg	Available N//g/kg	Available P//g/kg	Available K//g/kg
Biogas residue	Cow dung	9.05	16.78	10.50	8.46	0.49	0.630	0.88
	Pig manure	16.50	17.41	15.22	9.07	0.32	1.310	0.82
	Chicken manure	17.40	13.12	8.83	12.75	0.45	0.880	1.23
	Corn stalk	42.90	20.98	2.37	16.04	0.72	0.230	1.55
	Wheat straw	35.67	19.16	2.09	14.53	0.53	0.200	1.41
Biogas liquid	Cow dung	0.42	1.28	0.21	0.52	0.48	0.059	0.35
	Pig manure	0.25	1.02	0.17	0.44	0.43	0.037	0.25
	Chicken manure	0.23	0.61	0.50	0.29	0.35	0.104	0.20
	Corn stalk	0.22	0.56	0.19	0.74	0.21	0.086	0.32
	Wheat straw	0.34	0.63	0.16	0.77	0.24	0.073	0.33

Yao Yan[10] studied the production technology of anaerobic fermentation broth using animal manure as raw material, and it was found that the factors affecting the fermentation efficiency of biogas fertilizer were the concentration of raw material, fermentation time and fermentation temperature. The content of ammonium nitrogen and available phosphorus in biogas liquid was the highest when the concentration of raw material was 3.7%, the fermentation time was 4 days and the temperature was 55 degrees celsius. The anaerobic fermentation process can eliminate the odor and kill most of the pathogenic bacteria and insect eggs. The fully fermented biogas liquid should be dark brown and non-odorous with pH of 7.5 to 8.0[7]. The studies of CÔté *et al.* [11] showed that the *Escherichia coli* in pig feces could be reduced by 99.67% to 100% after anaerobic fermentation for 20 days. Álvarez *et al.* [12] found that chlortetracycline could be removed by 53.2% to 67.7% after anaerobic fermentation for 31 days.

Biogas fertilizer is a kind of quick-acting compound fertilizer with comprehensive nutrition, high nutrient utilization ratio and multiple elements. It contains humic acid, gibberellin, indoleacetic acid and other functional substances. It has the characteristics of improving soil, sterilizing and resisting disease and insect, and improving crop resistance. It has the dual functions of "biological fertilizer" and "biological pesticide"[13]. Wei Quanyuan *et al.* [6] found that the content of ammonium nitrogen in biogas fertilizer was 25% higher than that in untreated organic fertilizer, which was more favorable for crop uptake. Ding Jingtao[14] found that the biogas fertilizer also contains calcium, magnesium, iron, zinc, boron, manganese and other mineral elements; fulvic acid, linoleic acid and other cold-resistant substances; auxin, gibberellic acid and other growth-promoting hormones and some antibiotics. Therefore, biogas fertilizer can not only increase crop yield as fertilizer, but also inhibit plant disease, induce microbial resistance and prevent soil-borne diseases of crops.

3 Effects of biogas fertilizer on modern agricultural production

3.1 Effects of biogas fertilizer on soil Humus contained in biogas manure is the main part of soil organic matter, which can improve the soil water and fertilizer retention ability, and humic acid and fulvic acid and other weak acidic organic substances and a variety of microorganisms[7], have a strong ability to buffer the changes of acid and base. It can improve the saline-alkaline soil, increase the total number of soil aggregates and the exchange capacity of soil, increase the soil porosity and improve the soil structure. Xiao Yang *et al.* [15] found that chemical fertilizer combined with biogas residue and biogas liquid could reduce soil bulk density, increase soil organic matter content, effectively prevent soil acidification and significantly improve soil physical properties. Cordovil *et al.* [16] found that the application of biogas liquid fermented in swine manure could increase the content of ammonium nitrogen and nitrate nitrogen in the soil, improve and remedy the post-fire soil in forest area. Huang Jichuan *et al.* [17] found that the content of organic matter and available nutrients in paddy soil could be significantly increased with the increase of the amount of biogas liquid, and the activity of urease, invertase and acid phosphatase in paddy soil could be significantly increased compared with the treatment without biogas liquid. Wan Haiwen *et al.* [18] found that application of biogas liquid increased the activity of catalase and urease in wheat soil. Zhang Cuili *et al.* [19] applied biogas fertilizer to improve soil with different salinization levels, and it was found that biogas fertilizer could significantly reduce soil pH and bulk density, which proved the feasibility of improving saline-alkali soil with biogas fertilizer.

3.2 Effects of biogas fertilizer on crops Biogas fertilizer contains nutrient components which are needed by many crops. It has strong nutrient capacity and high nutrient utilization ratio. The application of biogas fertilizer in field can not only improve the yield and quality of crops, but also play a role in disease prevention and resistance. The field experiment of Wan Haiwen[20] showed that the application of biogas fertilizer could increase the photosynthetic rate and water use efficiency of wheat and maize, increase the relative content of chlorophyll in leaves, promote the growth of wheat, increase the percentage of spike and grain weight of wheat and increase the yield of wheat. Ai Junguo[21] found that suitable

combination of biogas fertilizer and chemical fertilizer could promote the growth and development of spring maize, enhance the dry matter and photosynthetic characteristics of spring maize, improve the root structure, and improve the yield and grain quality of spring maize. Tani *et al.* [22] applied biogas fertilizer with animal ashes, and found that corn yield increased by 4.32% compared with chemical fertilizer alone, indicating that biogas fertilizer instead of chemical fertilizer would not result in crop yield reduction. Niuwei *et al.* [23] found that the quality of apples was significantly improved under the long-term implementation of "pig-marsh-fruit" management. Qi Cuiling *et al.* [24] irrigated cherry with biogas liquid and found that it could significantly improve the shape of trees and improve the nutritional status of fruit trees. Compared with water treatment, the yield per plant increased by 21.76% and the weight per fruit increased by 28.89%. Hu Min *et al.* [25] found that spraying biogas liquid on leaves could promote the growth of pepper and increase the content of chlorophyll in leaves. The application of biogas fertilizer could significantly increase the yield of pepper. Yong Shanyu *et al.* [26] found that the reasonable combination of biogas fertilizer and chemical fertilizer could obviously increase the yield of maize, and the application of biogas fertilizer could effectively control the root rot of maize. Zhang Xiaokang *et al.* [27] found that compared with chemical fertilizer, biogas fertilizer could improve the yield and quality of watermelon, and reduce the incidence of disease and insect pests in watermelon seedling stage. Dong Zhaofeng *et al.* [28] studied the effect of biogas fertilizer on the growth of *Salvia miltiorrhiza* by the way of biogas residue base application and biogas liquid spraying. It was found that biogas fertilizer could increase the yield of *Salvia miltiorrhiza* and control the root rot of *Salvia miltiorrhiza* effectively. Yongabi *et al.* [29] found that biogas liquid could inhibit the growth of *Escherichia coli*, *Staphylococcus* and *Pseudomonas aeruginosa* and improve the antibacterial activity of medicinal plants.

3.3 Effects of biogas fertilizer on the environment Taking some kind of integrated ecological circulation agricultural park as an example, Shi Pengfei *et al.* [30] found that biogas fermentation and returning organic fertilizer to field were the core of material circulation and energy flow, which could achieve annual saving of chemical fertilizer and electricity cost of 17 968 000 yuan, solve the problems of non-point source pollution and resource depletion, and have obvious eco-economic benefit. Zheng Miaozhuang *et al.* [31] found that under the soil-lawn system, the nitrate nitrogen and total nitrogen concentrations of soil leachate below 1 m were lower than those of chemical fertilizers with the same amount of nitrogen, and there was no pollution to the groundwater environment when the amount of biogas fertilizer was 600 kg/ha in the whole year. Through comparative experimental study, Li Yi *et al.* [32] found that the application of biogas fertilizer could reduce the available content of heavy metal Cr in soil and stem and leaf of rapeseed in sewage irrigation area. However, when applying biogas fertilizer in agricultural production, there are no standard and reasonable technical guidelines. Once the amount of biogas fertilizer exceeds the carrying capacity of soil and crops, it will cause secondary pollution to the environment. By biogas residue composition detection and hazard analysis, Liu Yanping *et al.* [33] found that it was basically in line with the Chinese standard, but the content of Cu and Zn was higher than that of agricultural heavy metals in developed countries. The risk assessment of heavy metals shows that the potential hazards of Cd, Hg and Cu in biogas residues are the strongest. It is necessary to study the safe application technology of biogas residues.

4 Application technology and risk control of biogas fertilizer

At present, the raw materials of biogas fermentation in China are mainly crop straw and poultry manure, and the biogas residue and biogas liquid produced by fermentation are more effective than the raw materials[34]. However, the fertilizer efficiency of biogas residue and biogas liquid is also restricted by anaerobic fermentation technology, fermentation raw materials and application technology. There are some problems such as pathogen, insect eggs, nutrient difference, heavy metals and antibiotic residues. Therefore, attention should be paid to the selection of biogas fertilizer in agricultural production and application, so as to ensure the rational utilization of agricultural wastes while avoiding the secondary pollution to soil, crop and environment.

4.1 Application technology of biogas fertilizer According to different ecological types, different soil fertility, crop nutrient requirements and nutrient content of biogas fertilizer, a reasonable nutrient recommendation is made. The amount of biogas fertilizer should be based on the recommended amount of nitrogen or phosphorus, the proportion of organic fertilizer to chemical fertilizer should be considered, and the balance of nutrient should be paid attention to, so as to ensure the high yield, high quality and environmental friendliness. The carrying capacity of organic fertilizers, such as biogas fertilizer, is 30 to 45 t/ha in China[35]. The excessive application of biogas fertilizer may result in the accumulation of nitrogen and phosphorus and the secondary salinization of soil. Chen Naihe[36] suggested that applying 27 t/ha biogas fertilizer to paddy soil in Chengdu Plain could make wheat yield reach the level of yield under conventional fertilizer application. The recommended amount of biogas fertilizer for pig manure fermentation was 27 t/ha based on the analysis of soil and environmental indexes. Wan Haiwen[17] suggested that under the wheat-maize rotation model in Guanzhong Plain, the best application rate of biogas liquid with cow manure and urine as fermentation material was 22.5 to 33.75 t/ha in wheat field, and it should be applied twice at jointing stage and booting stage. Jia Liangliang *et al.* [37] found that the suitable amount of tomato biogas fertilizer in solar greenhouse was 75 t/ha, the concentration of biogas liquid should be paid attention to during spraying, and the biogas liquid with 50% volume fraction was recommended. Biogas liquid can also be used in an integrated water and fertilizer system[38], but it needs to be filtered.

4.2 Risk control risks of biogas fertilizer application Biogas fertilizer is a kind of quick-acting bio-organic compound fertilizer with strong nutrient ability, high nutrient utilization rate, bacteriostasis and enhancement of resistance. However, heavy metals of biogas fertilizer must be detected before application, and the

excess biogas fertilizer should be treated harmlessly to ensure the safe return of biogas fertilizer to field. Li Jian *et al.* found that the content of As, Cr and Cd in the biogas residues of the mixed feeding method was found to be far higher than the pollutant indexes of NY/T 5018-2001, and the content of Hg was close to the limit value of the standard, but the content of heavy metals in the biogas residues of green feeding method was not beyond the limit value of the standard except Pb. The measurement standards of heavy metals in biogas liquid were vague. The heavy metals content in biogas liquid did not exceed the standard of organic fertilizer, but far exceeded the standard of irrigation water quality. Liu Sichen *et al.* [40] found that the content of heavy metals in the biogas liquid produced by different fermentation materials was significantly different, and the content of heavy metals in the biogas liquid from pig farms was higher than that from cattle farms (Table 2). Ma Jieqiong *et al.* [41] found that the content of heavy metals in biogas liquid exceeded the national standard for comprehensive discharge of sewage and the standard for irrigation water quality. The main source of these pollutants was feed additive, and the suspended solids could be removed from biogas liquid by centrifugation, thus reducing the content of heavy metals in biogas liquid. Shi Yancai[42] found that the earthworm or earthworm with bacterial fertilizer could effectively reduce the ecological hazard of heavy metals. Chen Miao *et al.* [43] put forward that before applying biogas fertilizer, it is necessary to carry out harmless treatment and reduce the content of heavy metals in biogas fertilizer, and the concrete methods can refer to the remediation methods of heavy metals in soil, such as super-enriched plants, leachate, and fixative.

Table 2 The concentration of heavy metals in different fermented raw materials (mg/L)

Raw materials	As	Cd	Cr	Hg	Pb
Cattle dung	0.066	0.011	0.046	0.009	0.085
Pig manure	0.465	0.687	2.047	0.010	0.993

5 Prospects

Biogas manure is a kind of high-quality biological resources with high economic and ecological benefits. It is an important link in the construction of resource-saving society and environment-friendly society. However, the harmlessness and comprehensive utilization of biogas manure deserves further study. First of all, at present, China's livestock and poultry breeding is mainly based on feed, and heavy metals enter the livestock body through the feed, and then remain in the livestock excrement, therefore, we should improve the feed safety monitoring system, develop environment-friendly feed, from the source to solve the problem of heavy metals in biogas fertilizer exceeding the standard. Secondly, the fermentation technology affects the nutrient content, pathogenic bacteria and egg number of biogas fertilizer. Fermented biogas fertilizer directly used in farmland will seriously threaten environmental security, so it is necessary to improve the fermentation process and strengthen the pretreatment to ensure the resource-based and harmless biogas fertilizer. Thirdly, in order to ensure good quality, high yield and environmental friendliness of crops, we should rationally utilize biogas manure, control biogas fertilizer application rate and application mode, select the best fertilizer proportion according to different soil types and different crops, and standardize the application technology of biogas fertilizer. Fourthly, the measurement standards of heavy metals in biogas manure are not unified at present, so we should establish unified standards and technical norms as soon as possible to provide basis for the safe use of biogas manure. Finally, at the present stage, the use mode of biogas in our country is mainly based on dispersed biogas from peasant households. The equipment and technology are backward, and the facilities of biogas storage and transportation are not matched, which severely restricts the popularization and application of biogas fertilizer. We should strengthen the production, study and research, concentrate our efforts on the development of large and medium-sized biogas projects, promote the reuse of agricultural and livestock wastes, and realize the large scale, industrialization and commercialization of biogas in China.

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