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Soilless cultivation for high-quality vegetables with biogas manure in China: Feasibility and benefit analysis

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Abstract

Vegetables, the indispensable staple produce providing humans with many beneficial substances, are readily contaminated by nitrate, heavy metals and pesticides during conventional cultivation. In particular, off-season vegetables grown in protected systems with low light intensity do tend to accumulate more nitrate in tissues due to excess N fertilization driven by farmers' desire for high yields. Over-the-limit accumulation of the harmful substances in vegetables constitutes a serious hazard to human health globally. Soilless cultivation, currently a fraction of vegetable cultivation in China, is a promising cultivation method to decrease the accumulation of harmful substances through nutrient solution regulation and environmental factor control. However, conventional inorganic nutrient solutions present few quality benefits besides plant nutrition for the widely acknowledged formulations. Currently, high-quality vegetables are urgently desired by humans globally, but they are difficult to grow for lack of an effective and practical cultivation method to lower the accumulation of harmful substances and to improve nutritional quality simultaneously. Although some attempts have been made, few commercial formulations have been applied in practice. Biogas manure (biogas slurry and biogas dregs) is a by-product of biogas production. It has been shown to be a good fertilizer with abundant nutrients, amino acids and bioactive substances. In China, as a product of the recycling process of agricultural wastes, biogas manure is an ever-growing resource due to the rapid development of biogas projects. Therefore, the need to utilize biogas manure is an urgent issue that relates both to environment protection and nutrient resources utilization. In this paper, the updated research results on yield and the quality effects of vegetables cultivated with biogas dregs and the solutions modified from biogas slurry in China are summarized, highlighting the feasibility and benefits of biogas manure in high-quality vegetable production. It is concluded that biogas manure is an effective nutrient source for high-quality vegetable production based on its synergistic effects and effectiveness in yield and quality improvement (particularly depression effects on nitrate accumulation), and stress resistance. However, deliberate component regulations need to be developed for better yield and quality of vegetables under soilless cultivation due to the large variability of components of biogas manure caused by various combinations of fermentative materials.

Key words: high-quality vegetables, biogas manure, nitrate, quality, feasibility

Introduction

Vegetables, as the basal source of essential substances such as vitamins, beneficial active ingredients, cellulose, amino acids and mineral elements, are always required to contain as much of these essential nutrients to meet dietary requirements of humans, without over-the-limit of contaminants such as nitrate, nitrite, heavy metals and pesticide residues. However, vegetables are readily contaminated by nitrate and heavy metals during conventional cultivation with mass input of manure and fertilizer. In particular, off-season vegetables cultivated in protected systems with low light intensity do tend to accumulate more nitrates in tissues due to excess N fertilization driven by farmers' desire for high yields[1]. Over-the-limit accumulation of the harmful substances in vegetables constitutes a serious global hazard to human health. Moreover, since vegetables are usually harvested at vegetative growth stages, and the edible parts

(young stems and leaves) can accumulate relatively large amounts of nitrate, vegetables have been found to be the major source of nitrate intake by humans, accounting for more than 80% of the total[2]. In addition, frequent application of pesticides easily leads to accumulation of residues during the short growth period and lack of time for them to be fully degraded. For soil cultivation, together with the inputs of large amounts of nitrogen, phosphates and organic fertilizer, substantial amounts of nitrate and heavy metals are accumulated in soil and are subsequently absorbed and accumulated in vegetables[3–5]. Currently, in China and the whole world, over-the-limit levels of nitrate, heavy metals and pesticide residues in vegetables are posing a serious threat to human health[3–7]. Globally, a serious situation was found in nitrate and heavy metal pollution in vegetables in terms of the limits issued by the different countries. In addition, apart from hygienic quality, nutritional quality of vegetables is another important issue that is of wide concern to humans. Nowadays, the quality of both the hygiene and nutrition of vegetables should be considered in the assessment of the quality of vegetables grown by various methods with respect to human health.

With the rapid development of livestock production in China, the amount of livestock wastes being generated is increasing, which gives rise to serious agricultural non-point source pollution when the waste is improperly disposed[8]. In China, biogas production is a good method for processing agricultural wastes[9,10]. This process can maximize the utilization of biomass energy, minimize the emission of greenhouse gases and loss of N and P compounds through anaerobic fermentation. Biogas is a very important renewable energy that is used for cooking and lighting in China[11]. Therefore, the Chinese government has encouraged the establishment of biogas projects to process the biological wastes. However, besides biogas, a great deal of by-products including biogas slurry and biogas dregs is also produced during the fermentation process. Thus, a new environmental issue has arisen. The discharge of biogas manure directly into the environment may result in serious problems, like eutrophication of surface water, over-the-limit levels of nitrate in groundwater, soil salinization, etc. Currently, improper application or disposal of biogas manure is severe in China since there are no acceptable methods for its use in agriculture with high economic benefits. However, the so-called pollutants in biogas manure, N and P, in turn, are the leading nutrients for crop production. Currently, in China, biogas manure is being explored for a win–win safe use as fertilizer for crop cultivation, particular high-quality off-season vegetable production in protected systems. Based on the constituent characteristic of biogas manure, many attempts have been made to investigate the feasibility and benefits of biogas manure on vegetables, crops and fruit trees. It is obvious that recycling of biogas manure in agriculture is multi-beneficial for both agricultural production and environmental protection. The research on biogas manure application in soilless vegetable production is reviewed here, highlighting the feasibility and benefits of biogas manure in high-quality vegetable production.

Application Methods of Biogas Manure in Agriculture in China

It has been well documented that biogas manure can be applied to agriculture as a fertilizer, protector, regulator and feed additive for pigs, functioning based on its diverse constitutes including abundant nutrients, amino acids, bioactive substances, etc. It has been proven that biogas manure could be generally applied in three ways. First, biogas slurry, as fertilizer, can support crop growth[9,12]. In general, biogas manure provides almost all mineral nutrients for crop growth and development in quantities close to the crop requirements[13]. Second, biogas slurry can protect crops from stress. In biogas manure, bioactive substances, such as hormones, nucleic acids, monosaccharides, free amino acids, vitamins, unsaturated fatty acids, proline, linoleic acid and fulvic acid, and so on, play important roles in protecting crops from biotic and abiotic stress[14]. It has been widely acknowledged that, for instance, gibberellins stimulate seed germination and plant growth[15], and vitamins promote disease resistance[16]. Third, biogas slurry makes a good animal feed, providing important nutritional substances, such as carbohydrates, amino acids, microelements, hormones and crude proteins[17,18]. In brief, biogas manure contains considerable amounts of plant nutrients and its use as a nutrient source may offer a promising win–win opportunity to improve crop production and, at the same time, to prevent adverse environmental impacts of biogas manure disposal. However, some urgent issues in the utilization of biogas slurry in crop production in China should be solved. First, there are no effective and practical methods to utilize biogas manure. Therefore, novel methods with acceptable economic benefits need to be developed. Second, the application of excessive amounts in agro-ecosystems often leads to adverse effects on soil quality, including the lack of holding capacity in different kinds of soils. Thus, investigations are needed to optimize these crucial parameters. Third, there are still some puzzles on how biogas slurry affects the growth and physiological status of crops, which need further investigations. In comparison with biogas slurry, biogas dregs are even less utilized in agriculture. Taking the feasibility, benefits and significance of the possible utilization methods in China into consideration, soilless cultivation of vegetables is a good way to use biogas manure with the advantage of optimally utilizing the functional constituents of biogas slurry. Most important, many functional substances such as amino acids can improve the nutritional and hygiene quality of vegetables to some extent, which must be controlled within the limits of the issued standards[19].

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High-quality Vegetable Cultivation in China: Current Problems

Vegetables are high-value produce in China, particular during the out-of-season period. High economic benefits of vegetable cultivation under protected conditions has encouraged more and more farmers to establish solar greenhouses to produce vegetables in winter and spring. Currently, China ranks first in the world in the cultivation of protected vegetables, with up to 3.0 million hm^2 under cover in 2007[20]. However, vegetable quality (nutritional quality and hygienic quality) has declined in the past decade due to the increased fertilization level[3–5]. In 2007, the total input of fertilizers reached 51 million tons in China, and average nitrogen, particularly high in protected vegetables, has climbed up to 450 kg/hm^2[21]. High levels of nitrogen (urea and NH_4^+-N included) in soil will transform into nitrate, which is unavoidably absorbed and is substantially accumulated in vegetables to a harmful level for human health. In soilless cultivation, nitrate accumulation in vegetables is also unavoidable since nitrate/nitrogen has to be added into the nutrient solution or substrate to avoid ammonia toxicity and to balance medium pH. Moreover, low light intensity in protected systems could substantially increase nitrate accumulation in vegetables[22]. Previous data indicated that nitrate as well as heavy metals in vegetables had reached a serious level according to some international or domestic standards[3–5]. In China, improving the quality of vegetables is urgently needed.

The definition of high-quality vegetables is: vegetables that do not contain over-the-limit harmful substances (nitrate, nitrite, heavy metals and pesticides) and which do not have negative effects on human health after ingestion. For soil culture, at present, it is hard to produce high-quality vegetables in the field with the high-level nitrate, heavy metal and pesticide accumulation in soils combined with continued annual heavy input. Therefore, an alternative method to produce high-quality vegetables is urgently needed. To sum up, in high-quality vegetable production, inputs of fertilizers and pesticides should be lowered in order to ensure no over-the-limit accumulation of harmful substances in vegetables. Along with yield, hygienic quality assurance and the nutritional quality of vegetables should be improved as much as possible. In modern horticulture the trend is increasingly toward more soilless cultivation, which has advantages over soil-based production (e.g. decreasing succession cropping obstacles, avoiding ground water pollution and less soilborne diseases). Currently, excessive accumulation in vegetables of nitrate, heavy metals and pesticides are the major problems existing in high-quality vegetable production in soilless cultivation.

Nitrate is naturally present in all vegetables. Green, leafy vegetables, e.g. lettuce and spinach, contain relatively high concentrations. Nitrate and nitrite contamination in vegetables is produced mainly by overuse of chemical fertilizers besides low light intensity in protected systems. High intake of nitrate can transform into nitrite and then react with various proteins in the digestive system. The product, nitrosamine, is mutagenic and carcinogenic[23]. In order to eliminate the above hazards, obligatory standards have been released by many countries and international organizations. For example, the World Health Organization (WHO) and Food and Agriculture Organization (FAO) established the acceptable daily intakes (ADI) for nitrate and nitrite in 1973, 3.65 and 0.13 mg/kg (body weight), respectively. That is, for a 60 kg person, he/she is allowed to eat less than 0.5 kg fresh vegetables in which nitrate concentration is over 438 mg/kg. The European Commission has set maximum limits for levels of nitrate in lettuce and spinach[24]. In China, the content of heavy metals, nitrite and nitrate in the tissues of high-quality vegetables' is assessed under the limits of the GB-18406-2001 standard. For example, nitrite content in vegetables is less than or equal to 4.0 mg/kg (fresh weight), while the limits for nitrate content are 600 mg/kg for fruit vegetables, 1200 mg/kg (fresh weight) for stem and root vegetables and 3000 mg/kg (fresh weight) for leafy vegetables. In the newer standard, GB-19338-2003, the above limits are changed to 440, 1200 and 2500 mg/kg (fresh weight), respectively. The contents of five heavy metals and more than 40 pesticides were limited in the above standard. According to these tolerance limits, nitrate contamination in vegetables in most regions of China is a serious problem[3]. In general, nitrate content is the principal harmful substance that is difficult to control due to the large quantity of vegetables needed and their biological characteristics for easy accumulation of nitrates. Therefore, to develop effective methods to control nitrate accumulation in vegetables is an urgent issue in China and the whole world.

High-quality Vegetable Cultivation with Biogas Manure: Feasibility Analysis

As a staple food worldwide, vegetables need special assurances on quality (nutritional quality and hygienic quality). Excessive nitrate, heavy metal and pesticide contents in vegetables are basic problems. Application of biogas manure in vegetable production could specifically help solve these tough problems. It has been verified that the application of biogas manure improves yield, nutritional quality and stress resistance. Furthermore, biogas manure has a particular role in decreasing nitrate and heavy metal contents in vegetables. Based on the above functions of biogas manure, vegetables cultivated with biogas manure using appropriate management measures (e.g. quality control and composition regulation of biogas manure) will not exceed the tolerance limits for nitrate, heavy metals and pesticide residues.

The raw materials for biogas production, animal wastes, are mainly transformed from feeds, which are mostly plant-derived. Biogas slurry therefore consists of similar kinds and ratios of mineral elements as the physiological requirements of crops since few elements are lost during

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anaerobic fermentation. Biogas slurry contains abundant N (0.03–0.08%), P (0.02–0.07%), K (0.05–1.4%), as well as Mg (97 mg/l), S (14.3 mg/l), Cu (36.8 μg/l), Fe (1.4 μg/l), Mo (4.2 μg/l), etc. In addition, the beneficial elements Ca, Cl, Na, Si, Co, Sr, Li, F and Ba are also contained in biogas slurry[13]. Biogas slurry has a higher nutrient content than compost, and recovery rates for N, P and K exceed 90% after digestion[25]. Therefore, biogas slurry is a complete nutrient solution that basically meets the needs of vegetable growth. Similarly, dry dregs also contain abundant nutrient substances including organic matter (36–50%), humic substance (10.1–24.6%), nitrogen (0.78–1.61%), P (0.39–0.71%, P_2O_5) and potassium (0.61–1.3, K_2O)[13].

Partial replacement of nitrate in nutrient solution with amino acids at 20 and 30% could significantly decrease nitrate accumulation in vegetables[26–30]. However, this is hard to apply in practice due to the high cost of amino acids. More than 15 acid amides and amino acids can be found in biogas slurry in amounts of 500 mg/l.[13,31] Therefore, biogas slurry is a suitable alternative to solve this issue. Moreover, in biogas slurry, mixed amino acids are presented. Some authors have proven that mixed amino acids are more efficient in lowering nitrate content in vegetables[27,30,31]. Of course, based on the complex components of biogas slurry, the effects of biogas slurry on nitrate accumulation in vegetables cannot be attributed only to the presence of amino acids; there are still some unknown mechanisms to be revealed. Shi et al.[32] suggested that biogas slurry had dual functions as a bio-fertilizer and bio-pesticide, without resistance evolution and environmental pollution. Furthermore, over 20 compounds of 120 substances in biogas slurry have the functions of anti-disease and insect prevention[33]. As mentioned above, some constituents of biogas slurry could increase the resistance to abiotic stress, such as drought, chilling and so on. All the above functions are helpful in vegetable cultivation to ensure that the contents of nitrate and pesticides are under the limit. As to heavy metal content, there is a lack of sufficient data to draw a conclusion; however, the proper selection of fermentative materials could easily help control the content of heavy metals in biogas manure. In addition, biogas manure is pathogen- and vermin egg-free after the long-term fermentation process[13]. Based on the above-mentioned ingredient analysis, it is concluded that biogas slurry is a feasible nutrient solution for soilless cultivation of high-quality vegetables.

High-quality Vegetable Cultivation with Biogas Manure: Benefit Analysis

In China, the studies on effects of biogas slurry on vegetable nitrate content, yield and quality have been conducted for more than two decades. To date, more than ten vegetable species, including lettuce, Chinese cabbage, rape, Malabar spinach, tomato, cucumber, garlic, green pepper, *Ipmoea aquatica* Forsk., bitter gourd and *Gynura bicoloar*, etc., have been tested and successfully grown in soil and soilless conditions supplied with biogas manure showing substantial benefits. Among the tested vegetable species, lettuce is the most common species studied. In terms of yield and quality, it is well reported that biogas manure was efficient in promoting yield and quality of vegetables. However, no comprehensive review had been published to summarize the current status of this issue in China. In this paper, studies have been integrated to provide a reference for researchers worldwide.

Yield

As early as 1985, Zhu[34] found that the application of biogas slurry could increase the yield of Chinese cabbage. In the 2000s, more than 20 studies have been conducted focusing on the application effectiveness of biogas manure in the cultivation of vegetables. Among the previous investigations, the majority of results were obtained in pot experiments and field experiments by the soil cultivation method. The majority of results showed that biogas manure application will enhance the yield of vegetables, such as celery[35], Chinese cabbage[34], pakchoi[36], lettuce[19,37,38], green pepper[39], mustard[40], *Ipmoea aquatica* Forsk.[41] and mushroom[42]. Recently, some studies have been conducted successfully under soilless conditions. These have confirmed that lettuce[19,43,44], Malabar spinach[45], *Gynura*, *Gynura divaricata* and Purple leaf lettuce[12], cucumber[46,47], pepper[39] and *Ipmoea aquatica* Forsk.[41] can be cultivated successfully with a modified biogas slurry solution.

Nutritional quality

The content of soluble sugar, vitamin C, acidity and amino acids of vegetables are the main indices that have been examined in previous studies. In summary, there are inconsistent effects of biogas slurry on vitamin C and the soluble sugar content of vegetables. Some reports showed that vitamin C and soluble sugar in pakchoi[36], lettuce[43] and cucumber[46] were increased. However, in contrast, Xu et al.[37,38] found that soluble sugar and vitamin C of lettuce cultivated with biogas slurry were decreased. Similar results were presented in mustard[40]. In addition, Zhou et al.[39] found no influence of biogas slurry on vitamin C and soluble sugar content in pepper, but the ratio of sugar to acid was increased. To sum up, current data about the effects of biogas manure on nutritional quality are confused, which may be caused by discrepancies in experimental materials and various experimental conditions. More investigations should therefore be conducted to clarify the effects on quality and their mechanisms.

The nitrate content is an important index used in almost all related studies to determine the nutrient quality of vegetables. Almost all results showed consistently that the nitrate content of vegetables was decreased significantly after cultivation with biogas manure, in both soil and soilless cultivation. The vegetable species reported include Malabar spinach[43], lettuce[19,37,38,42], rape[18,31], cucumber[29]

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Table 1. Results of previous studies on the effects of biogas manure on yield and quality of vegetables grown soilless.

Vegetable species	Yield effects or feasibility	Nitrate content	Nutritional indices	References
Malabar spinach	Decreased	481 mg/kg, decreased by 67.4%	Soluble sugar and Vc were reduced	Li et al.[45]
Gynura, *Gynura divaricata* and Purple leaf lettuce	Feasible	–	–	Ning et al.[12]
Lettuce	Increased	–	–	Yang[44]
Cucumber	Feasible	–	–	Yuan[53]
Pepper	Increased	16 mg/kg, decreased by 72%	Reduced fruit acidity but did not affect V_C content	Zhou et al.[39]
Lettuce	Increased	59 mg/kg, decreased by 88%	Reduced sugar, total sugar and Vc increased by 74, 73 and 106% respectively	Su et al.[43]
Lettuce	Increased	209 mg/kg, decreased by 77%	–	Liu et al.[19]
Bailin mushroom	Increased	–	–	Ji et al.[42]
Tomato	Increased	–	Enhanced the content of soluble sugar and protein in fruit	Lu et al.[54]
Ipmoea aquatica Forsk.	Decreased	244 mg/kg, decreased by 75%	Vc increased by 38%	Lin et al.[41]

Vc, vitamin C.

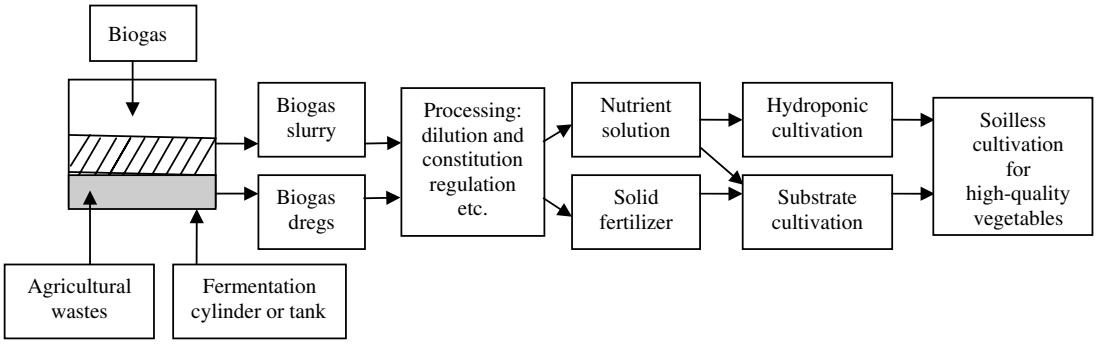

Figure 1. Process flow of soilless cultivation with modified biogas manure, and regulation measures.

and mustard[40]. Also, a study showed that the content of Hg, Cr and Cd in lettuce was decreased with increasing proportion and amount of biogas manure used in soil cultivation[48]. Light intensity has a strong influence on nitrate accumulation in vegetables[23]. Nitrate can accumulate to dangerous levels under low light conditions, when nitrate reductase is inactive[49]. China is the world's largest producer of vegetables grown in protected systems[20]; thus improving the light conditions in off-season production of vegetables is an effective method to depress nitrate accumulation. Some hydroponic lettuce producers address the problem by giving their plants N-reduced nutrient solution or supplemental light prior to harvest[50,51]. Future research should integrate these methods together, investigate the combined effects, and optimize the efficiency of lowering the nitrate level in vegetables.

Disease resistance

Many of the beneficial effects on disease resistance of biogas manures, particularly biogas slurry, have previously been demonstrated. Recently, some bio-pesticides based on biogas slurry have been investigated[33]. It is estimated that the application of biogas manure will reduce by over 20% the dosage of chemical fertilizers and pesticides, and lower by 1% the rate of pesticide residues (China National Plan on Rural Biogas Construction Projects of 2006–2010). However, the mechanisms of action of biogas manures still need to be investigated carefully. Three mechanisms of action have been revealed: (1) NH_4^+, acetic acid, butyric acid, propionic acid, gibberellin and indoleacetic acid in biogas slurry are effective anti-disease substances that can inhibit the occurrence of diseases and insects; (2) vitamins and amino acids increase the ability of crops to resist diseases; and (3) volatilization of methane and ethylene gas will help keep off pathogenic bacteria and insects. Jothi et al.[52] found that tomato plants amended with biogas slurry had more vegetative growth and tended to flower and fruit much earlier when compared with the control. The nematode population in the soil decreased, thus decreasing the severity of nematode attack.

Some authors have suggested biogas manure as a feasible nutrient resource for high-quality vegetable production under soilless conditions, with the advantages of high yield

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and good quality[12,43]. To sum up, biogas slurry can be used as a nutrient solution, while biogas dregs can serve dual functions as solid manure and cultivation substrate for vegetable cultivation. Yuan[53] found that the mixed substrate of rough river sand and sawdust (1 : 1) was best for soilless culture of cucumber with 50% biogas slurry (water/biogas slurry, 1 : 1). In general, the original biogas slurry with high electrical conductivity (EC) was not suitable for vegetable cultivation[44]. Some authors suggested that appropriate adjustments before use (e.g. dilution and the addition of fertilizer) will enhance the cultivation effectiveness. Liu et al.[19] found that biogas slurry could grow higher biomass lettuce after being diluted at 1 : 4 or 1 : 5 (v/v, biogas slurry/water). The yields of Malabar spinach in the treatment supplied with 50% biogas slurry were the highest[43]. Ning et al.[12] confirmed that it is feasible to utilize the biogas digested fluid as the nutrient solution in soilless plantings of Gynura (*Gynura divaricata*) and Purple leaf lettuce, with the dilution ratio of 1 : 4 of biogas digested fluid. Liu et al.[19] found that biogas slurry (1 : 5 dilution) could significantly decrease nitrate content in lettuce, and the added amino acids in biogas slurry would bestow other benefits. Biogas slurry was used as nutrient solution for soilless tomato cultivation, and it improved tomato yield and quality. Also Lu et al.[54] found that biogas slurry diluted to a ratio of 1 : 8 (v/v) was the most suitable for tomato growth in the experiment. The relevant literature dealing with the soilless cultivation of vegetables and its efficiency is summarized in Table 1.

Research Prospects

Utilization of biogas manure is a key issue for sustainable development of the biogas industry and rural eco-environment. Based on the present data, chemical fertilizer can be entirely substituted by biogas manure in soilless culture[55]. Both yield and quality of vegetables cultured by nutrient solutions modified from biogas slurry are usually improved. Furthermore, nitrate accumulation in vegetables is largely lowered, heavy metals and pesticide residues in vegetables can also be controlled. In summary, biogas slurry, after proper adjustment, is a feasible nutrient solution for high-quality vegetable production. However, ingredients of biogas manure differ with species, ratios and amount of materials for anaerobic fermentation[54]. Furthermore, they could also be modified by local agronomic measures such as fertilization, spraying pesticide, soil type and climate conditions. Although ingredients of biogas manure are variable, they can be adjusted through adding mineral elements to realize the optimal components for vegetable growth. Thus, biogas slurry can be looked on as an adjustable liquid fertilizer. Many authors have suggested that biogas slurry was an excellent organic fertilizer, which could be used in soilless cultivation of vegetables[19,12,55]. Investigations are needed to develop regulation techniques aiming at optimizing the composition of biogas manure to increase the cultivation efficacy during pre-production, production and post-production of biogas. In addition, nutrient amendment strategies for biogas manure should be designed to balance the nutrient ratio to cater for vegetable uptake requirements[12]. All in all, three kinds of regulation measures can be conducted during the production of biogas manure for vegetable soilless cultivation (Fig. 1), including material constituents, fermentative conditions and constitutive modification of biogas manure.

China currently has a large number of methane tanks run by farmers, large-scale plants of livestock production and industrial enterprises. There were 18 million methane tanks used by farmers at the end of 2005 in rural areas, and 1500 were run by large-scale plants of livestock production and industrial enterprises. As designed in The Eleventh Five-year Plan of Renewable Energy Development of China, China will possess 40 million biogas farmer–users, and 4700 biogas projects for large-scale plants of livestock breeding and 1600 biogas projects for treatment of organic wastes from industry by 2010. It appears that a large quantity of biogas manure will be produced in the future. On the basis of eco-economy, biogas slurry and biogas residues re-utilization is a substantially beneficial action. The main advantages of high-quality vegetable cultivation with the modified biogas slurry, as a feasible alternative to the traditional inorganic nutrient solution, are to reduce the negative effects of environmentally toxic substances and improve the quality of vegetables. In China, it is highly feasible to combine the two developmental tendencies of increased biogas production and the need for high-quality vegetables. When this combination is applied widely in China, it is believed that non-point pollution will be reduced, even considering the ever-growing intensive livestock farming. To sum up, it is concluded that the application of biogas slurry in vegetable cultivation is a feasible pathway to agricultural production and environmental protection. China is the world's largest producer and consumer of vegetables in protected facilities; both the government and scientists should pay more attention to soilless production of high-quality off-season vegetables because, after all, public concern about vegetable quality and health is growing.

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