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Biomass energy utilization in rural areas may contribute to alleviating energy crisis and global warming: A case study in a typical agro-village of Shandong, China

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ABSTRACT

A biomass energy exploration experiment was conducted in Jiangjiazhuang, a typical agro-village in Shandong, China from 2005 to 2009. The route of this study was designed as an agricultural circulation as: crops → crop residues → "Bread" forage → cattle → cattle dung → biogas digester → biogas/digester residues → green fertilizers → crops. About 738.8 tons of crop residues are produced in this village each year. In 2005, only two cattle were fed in this village and 1.1% of the crop residues were used as forage. About 38.5% crop residues were used for livelihood energy, 24.5% were discarded and 29.7% were directly burned in the field. Not more than three biogas digesters were built and merely 2250 m^3 biogas was produced a year relative to saving 1.6 tons standard coal and equivalent to reducing 4.3 tons CO_2 emission. A total of US$ 4491 profits were obtained from cattle benefit, reducing fossil energies/chemical fertilizer application and increasing crop yield. After 5 years experiment, cattle capita had raised gradually up to 146 and some 62.3% crop residues were used as forage. The percentages used as livelihood energy, discarded and burned in the field decreased to 16.3%, 9.2% and 9.8%, respectively. Biogas digesters increased to 123 and 92,250 m^3 biogas was fermented equal to saving 65.9 tons standard coal and reducing 177.9 tons CO_2 emission. In total US$ 60,710 profits were obtained in 2009. In addition, about 989.9 tons green fertilizers were produced from biogas digesters and applied in croplands. The results suggested that livestock and biogas projects were promising strategies to consume the redundant agricultural residues, offer livelihood energy and increase the villagers' incomes. Biogas production and utilization could effectively alleviate energy crisis and CO_2 emission, which might be a great contribution to reach the affirmatory carbon emission goal of the Chinese government on Climate Conference in Copenhagen in 2009.

Contents

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1. Introduction

Energy crisis and global warming are considered as two severe problems worldwide [29,6]. Scientists have been in search of renewable and sustainable energies, at least in part, substituting fossil energies for a long time [12,22,2]. Some reports indicate that biomass energy remains the primary source of energy for more than half the world's population, and accounts for 14% of the total energy consumption in the world [11,4,14]. By 2050 the contribution of biomass to global energy will fluctuate from 100 to 400 EJ y^{-1} which is about 15% of the global primary energy supplication [35,12,3]. Biomass energy utilization has already been ranked in national energy strategies in China [7].

1.1. Energy status in rural China

China, as the biggest developing country in the world, has about 1.3 billion people, and more than 70% of the nation's population lives in rural areas, meeting most of their energy requirements (for domestic needs) from traditional biomass fuels over the past decades [22,24]. The major sources of traditional biomass are crop residues and firewood and their share in energy supply is approximately 46% [28]. In the past, villagers' per capita energy consumption was very low, mostly for cooking and water heating. Annually primary energy consumption in 2000 was 13,246 Mtce and the percentage of biogas energy in total energy consumption was around 1.2% [10]. However, in the recent years, biomass fuels were used less and less year after year in rural China. Instead, coal, natural gas and electricity consumptions are significantly and rapidly increased in their energy supply with the improvements of their life levels. Total primary energy consumption in 2006 reached 235,156 Mtce but only 0.2% was biogas energy [42]. Energy competition has been existing between rural and urban areas of China. Energy crisis and greenhouse gas emissions will become more serious in the near future [26].

1.2. Energy policy of the Chinese government

Energy development is a major constraint for a sustainable development in developing countries including China [19,15]. Fossil energy (coal, natural gas, etc.) utilization maintains low energy use efficiency and emits huge amount of greenhouse gases. Clean energy (water energy, wind energy, solar energy, etc.) production is considered by the policy makers, for instance by "China Renewable Energy Law" [8], "China Saving Energy Law" [9]. However, clean energy projects move very slowly in the past years. The major stumbling block is lack in terms of capital investment since clean energy development programs are highly capital intensive. Traditionally these programs have been implemented with support or cooperation with the abroad companies. Even then the achievements made in this sector have not been able to cope with the growing demand for energy services, in terms of both quality and quantity. In response to offer renewable and sustainable energies and reach the goal of alleviating greenhouse gases emission, biomass energy production and utilization (biogas production, bioelectricity generation, etc.) in rural areas has been highly taken into account by the Chinese government.

1.3. Biomass resource in rural China

Biomass resources include various natural and derived materials mainly categorized as agricultural residues, wood and wood wastes, animal dung, municipal solid wastes [5,33]. In this study, we mainly focused on agricultural residues. Approximate land use for agriculture is 54.5% of the total land area of the country [44]. Agricultural residues contribute significantly to the biomass sector. About 46% of traditional biomass energy is supplied from major crop residues such as maize and wheat stalks. Large amount of residues are produced by soybean, peanut, cotton, etc. Liu et al. [26] reported that China produces about 630 million tons of crop residues each year. Half of the crop residues come from east and central south of China, including Shandong Province. Among those crop residues, corn, wheat and rice account for nearly 80% of the total crop residues. Unfortunately, only small parts of crop residues (23%) are used for forage, the large parts (75%) are used by farmers as livelihood energy or discarded or directly burnt in the field. A huge amount of biomass is wasted or used with pretty low efficiency. Therefore, a study on high-efficiency utilization of crop residues in rural China is very urgent.

1.4. Livestock development

Traditionally, cattle are important animals to meet humans' requirements of meat and milk which were mostly pastured in the north steppe of China, such as Inner Mongolia. Some reported that the livestock (cattle and sheep) capita have exceeded the high-points of grassland capacity in those areas, as a result the grasslands have been seriously degraded [36,39]. It is not a sustainable and ecological grassland management if the cattle and sheep livestock is being continuously increased in those pasture areas. By contrast, there is a plenty of nutrient forage (crop residues) being wasted in agricultural areas [13]. The development potential of livestock will be much larger in agricultural areas than in pasture areas of China [18].

1.5. Biogas production and utilization

1.5.1. Improved biogas digester and biogas production

Biogas production has been established for three decades in rural China. There have been about 550 million household digesters and 2360 biogas stations installed until the end of 2006 [42]. However, in the past, biogas digester output was very low due to improper construction and lack of producing technologies [40,37]. Most of the biogas digesters were built aboveground which was to cool for fermentation when the atmospheric temperature was low. Some of them could not produce enough biogas for cooking in late fall and winter time. In addition, biogas production was low also due to the fact that agricultural residues have being directly filled in biogas digesters without livestock pre-digestion.

Improved technologies in building biogas digesters and livestock development were involved in this study. Biogas digesters were built underground (dome type), they could effectively maintain high temperature when the atmospheric temperature was low. On the other hand, biogas digesters located behind farmers' houses and connected with their cattle sheds was another way to keep the digesters warm in winter time. Biogas production materials were changed to cattle dung. Crop residues were first fed to cattle and cattle dung was used as substrate for biogas production.

1.5.2. Biogas cooking stoves and illuminating lights

Biogas cooking stoves have been noted as the key role to efficiently utilize biomass energy. The programs have been undertaken in China and India for almost 10 years [40,34]. The traditional cooking stoves in rural China are usually mud-built cylinder with boilers being set on and used to burn biomass energies (crop residues, firewood, animal dung, etc). The energy efficiency of those type stoves for biomass fuels is between 5% and 10%, emitting smoke, including the risk of firing, creating health hazard in kitchen [16]. Improved household biogas stoves are produced on the base of natural gas stoves by some gas-fired companies of China (Fig. 1). New stoves have biogas purifying systems and automatic fire systems that are convenient and safe. Biogas lamps (Fig. 2), which illuminate by burning biogas, are also used in cattle sheds, corridors, storages, and other places in the villager's houses.

The objective of this study is to investigate how to efficiently utilize abundant biomass energy in rural China, improving the rural environment and the villagers' incomes by high-efficiency biomass energy utilization, contributing to an alleviation of energy crisis and global warming.

Fig. 1. Improved biogas stove used in villagers' kitchen.

Fig. 2. Biogas light used in farmers' household corridor.

2. Materials and methods

2.1. Natural and socio-economic backgrounds of study area

Jiangjiazhuang, which is located in Eastern Shandong of China, is a typical agronomy village in agricultural areas of China (Fig. 3). It holds 248 households, total population is 923, total arable land 68 hm^2 and croplands 33.3 hm^2. About 738.8 tons fresh crop residues (mainly wheat and corn stalks) are produced each year. Farmers conventionally use parts of the crop residues as their livelihood energy, such as cooking, water heating, etc. In 2005, only two cattle were fed and three biogas digesters were built in this village. The rest of the parts of the crop residues were discarded or directly combusted in the field because of no proper ways for consuming them. The situation became more serious in the recent years, large parts of crop residues were discarded or directly combusted in the field because of more and more fossil energies (coal, natural gas, electricity, etc.) had been devoted in peoples' life

Fig. 3. Location of study area—Jiangjiazhuang.

with the improvement of living standard. Moreover, energy-hungry appliances such as air-conditioners, refrigerators and microwave ovens had gradually entered their homes. If this situation continues, the total energy and fossil energy consumption will boost in the near future and aggravate the energy crisis and global warming.

2.2. "Bread" forage processing

"Bread" forage is in fact made by crop residues following a micro-deposited fresh crop residues (MDFCR) technology. The name of "bread" forage comes from its shape like bread, and high nutrition contents and digestion efficiency. The technique of processing "bread" forages is pretty simple: crop residues are immediately reaped after the crop grains being harvested at crop mature stage. The crushed and kneaded crop residues were pressed and framed in cylinder shape with 52 cm diameter and 52 cm height. Then cylinders were wrapped with plastic and stored in open air for natural fermentation (Fig. 4). The relative water content of the "bread" forages is around 70%. After at least 15 days, the fermented crop residues can be used to feed the cattle. "Bread" forages have a special smell (faint scent smell), and the cattle like to eat them. According to Feng et al. (co-author, *unpublished data*), the cattle fed with "bread" forages grew faster than with traditionally processed crop residues.

2.3. Experimental design

The biomass energy utilization experiment was designed on the objective of wisely reusing biomass energy (crop residues) to inhibit the increment of fossil energies consumption and reduce greenhouse gas emission in rural areas. Crop residues were processed into "bread" forage to feed cattle. Cattle dung was filled in biogas digesters and the produced biogas for meeting the villagers' livelihood energy demand. Residues produced from biogas digesters were used as green fertilizers to enrich soils. The route of the project was designed as: crops → crop residues → "Bread" forage → cattle → cattle dung → biogas digester → biogas/digester residues → green fertilizers → crops (Fig. 5).

2.4. Data collection and recalculation

Data of total crop grain yields, cattle capita and biogas digesters were collected from the statistic data of the local government. Crop residues were recalculated on the base of original crop grain yields data. The crop yields were transformed into crop residue values and recalculated, with the mean universal values being gained. The

Fig. 4. "Bread" forages were processed with crop residues through Micro-deposited Fresh Crop Residues (MDFCR) technology.

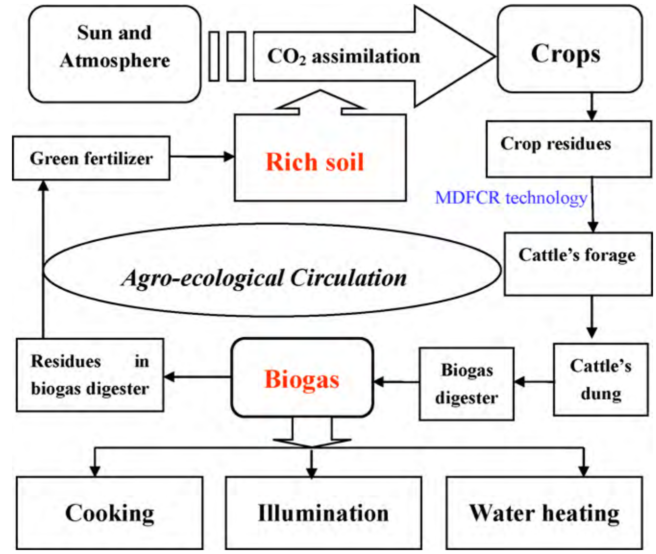

Fig. 5. Experimental route was designed in this study.

quantities of crop residue utilization were calculated following the methods described by Zeng et al. [43]. The unit of the energy was showed in forms of standard coal basing on the authoritative transform coefficients. The data of energy consumption, crop residues distribution, investments of cattle and biogas digesters and fertilizers were collected by filling in questionnaires on behalf of each household. The Microsoft Excel and Sigma Plot (Ver. 10.0, SPSS, Chicago, IL, USA) were used in data calculation and figure drawing.

2.5. Nutrient parameters analysis

The nitrogen content (N) was determined following the Kjeldahl Nitrogen Determination method (AACC approved method 46-13 [1]). The crude protein content (PC) was calculated by using the formula: PC ($mg\ g^{-1}$ dm) = N × 5.7

Crude fat and crude fiber contents were measured according to the method described by Zhao et al. [46].

2.6. Biogas production and energies transforming

Biogas digesters were filled with cattle dung and pachyrhizus bine (9:1) in 2005. Cattle urine and water were simultaneously added into biogas digesters. The biogas digesters were closed and materials were fermented for about 20 d, while the produced amount of biogas might be enough for villagers' livelihood energy. Biogas production was recorded by a biogas hydrometry meter (ZG-2, Kaitai Instrument Co. Ltd., Zhejiang, China), which was installed in each household. Different species energies (biogas, natural gas, etc.) transforming to standard coal were based on the coefficients showed in Table 1.

2.7. Economic benefit

Economic benefits were calculated according to the temporal market prices of energies, cattle and fertilizers. The benefits were transformed into US$ following the current exchange rate of RMB (1 US$ = 6.83 RMB).

Cattle benefit (US$) = cattle weight × market prices − cost.

Energy saving (US$) = biogas cubage × 0.03 − cost.

Fertilizer saving (US$) = weight of reduced chemical fertilizers × market prices.

Crop yield benefit (US$) = increased grain yield × market prices.

Table 1
Coefficients of raw materials and standard coal.

Species	kJ/m^3	KC/m^3	kg standard coal/m^3
Natural gas	38,931	9310	1.330
Cattle dung	13,799	3300	0.471
Soybean/cotton stalk	15,890	3800	0.543
Wheat stalk	14,635	3500	0.500
Maize stalk	15,472	3700	0.529
Biogas	20908	5000	0.714
Electricity			0.123
Raw coal			0.714

2.8. Statistical analysis

Nutrient components, water contents and digestion rates of differently processed crop residues were separately analyzed in the lab of Shandong Agricultural University. There were three replicates for each treatment. Data were analyzed using a one-way analysis of variance (ANOVA) of SPSS package (Ver. 11, SPSS, Chicago, IL, USA). Differences between different types of crop residues were considered to be significant at $P \leq 0.05$.

3. Results and discussion

3.1. Crop residues distribution and livestock development

Crop residues produced each year in Jiangjiazhuang were around 730 tons during 2005–2009 (Fig. 6). Cattle capita increased from 2 in 2005 to 146 in 2009. Proportion of crop residues for livelihood energy/total crop residues significantly decreased, while the proportion of crop residues for forage/total crop residues considerably elevated during 2005–2009. For crop residues distribution (Fig. 7), in 2005, 38.5% were used as livelihood energy, 29.7% were directly combusted, 24.5% were discarded and only 1.1% crop residues were used as forage. In contrast, in 2009, the proportion of crop residues for forage/total crop residues increased to 62.3%, the proportion of livelihood energy/total crop residues decreased to 16.3%, 9.8% were directly combusted in the field and 9.2% were discarded.

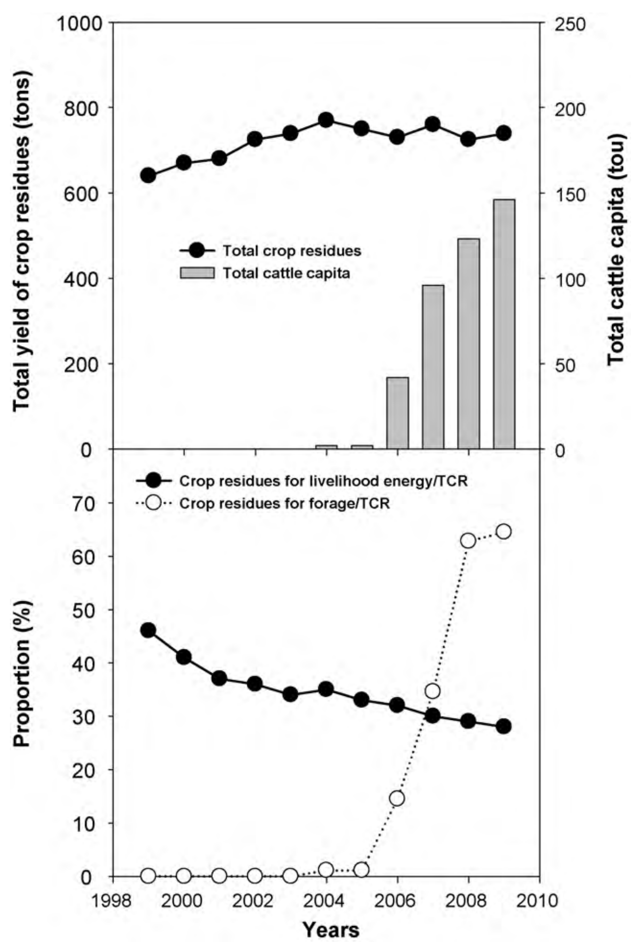

Fig. 6. Total crop residues yield, cattle capita, proportions of crop residues for livelihood energy/total crop residues (TCR) and crop residues for forage/TCR in Jiangjiazhuang from 1999 to 2009.

Traditionally, villagers treated parts of crop residues as livelihood energy and small percentage was used as animal forage, however, large parts of the crop residues were discarded or directly combusted in the field because there were no proper way of consuming the redundant crop residues [26,45,20,41]. The reason might be most of the villagers could not afford to buy a cattle depending on themselves. In addition, it was hard for the farmers to loan money from the government. Although they loaned some money, they did not want to stick their chin out on feeding cattle due to a lack of technologies, such as feeding techniques or medical treatment. As the project was running, the scientists persuaded the local government to loan some money to the farmers being able to buy cattles. And we trained a couple of animal doctors being able to offer services to cure cattle illnesses. The farmers gradually found that feeding cattle by crop residues really could generate benefits. They begun to like this business and the cattle capita in this village were up to 146 in 2009. Consequently, we concluded that the key roles to develop livestock in rural areas are: (1) train technicians for the farmers on feeding cattle; (2) financial supports from the Chinese government is urgently needed.

3.2. "Bread" forage nutrition

As shown in Table 2, no significant differences were noted between "Bread" forage and fresh maize stalks in water content, crude protein/fat/fiber content. The pH value was considerably lower but the digestion rate was drastically higher in "Bread" forage than in fresh maize stalks. Water content, crude protein/fat/fiber content and digestion rate were significantly higher in both "Bread" forage and fresh maize stalks than dry maize stalks. While the pH value of "Bread" forage and fresh maize stalks was lower (<7) than that of dry maize stalks (>7). This is in agreement with Wang [36], which reported acidic forage was easier for animal digestion. Therefore, micro-deposited fresh crop residues (MDFCR) technology ("Bread" forage processing technology) is a crucial tache in improving the livestock development in rural areas of China.

3.3. Biogas production

Biogas production was initiated three decades ago in China [44]. However, the amount of biogas was low for the reasons of improperly built biogas digesters and a lack of fermentation technologies. As a result, the biogas projects were moved very slowly in the past decades [32,30,38]. However, the total energy consumption in this village increased rapidly from 1999 to 2009 (Fig. 8). The total amount of biogas digesters were significantly increased during the experiment runs. Only two biogas digesters existed in this village and biogas yield was merely 2250 m^3 in 2005. Many families disliked to build biogas digesters because of (1) the capital costs; (2) the biogas yield was too low. Along with the experiment run, biogas digesters building technologies were improved and the substrate was changed to cattle dung. As a result the biogas yield considerably increased. The proportions of biogas

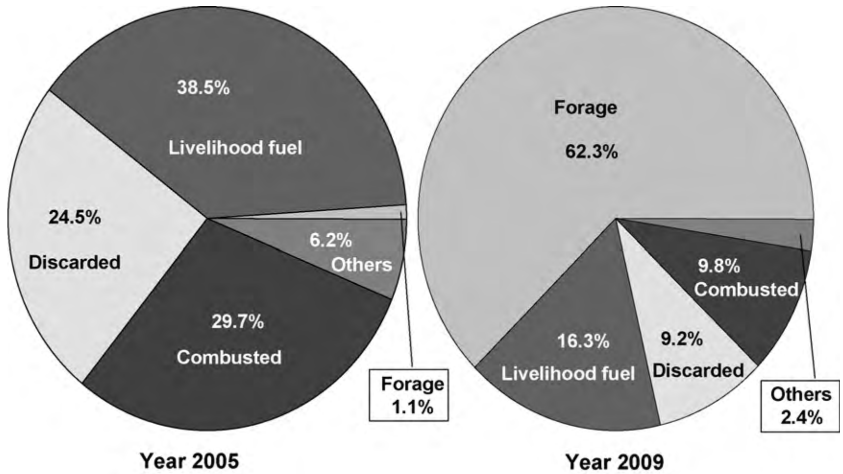

Fig. 7. Proportions of crop residues for different usage in Jiangjiazhuang in 2005 and 2009, respectively.

Table 2
Nutrient analysis on different treatments of corn stalks. Data are the mean ± SE ($n = 3$). Different letters within a column indicate significant differences ($P < 0.05$, t test).

Treatment	Water content (%)	pH value	Nutrition (%)			Digestion rate (%)
			Protein	Fate	Fibrin	
Dry maize stalks	13 ± 1.1b	8.0 ± 1.0a	5.7 ± 0.2c	1.1 ± 0.1b	40.6 ± 3.1a	42 ± 3.8c
Fresh maize stalks	73 ± 1.3a	5.4 ± 0.8b	6.1 ± 0.1b	1.8 ± 0.3a	35.6 ± 2.8b	65 ± 4.7b
"Bread" forage	70 ± 0.9a	4.2 ± 0.7c	6.4 ± 0.1a	2.1 ± 0.3a	32.3 ± 2.7b	89 ± 5.8a

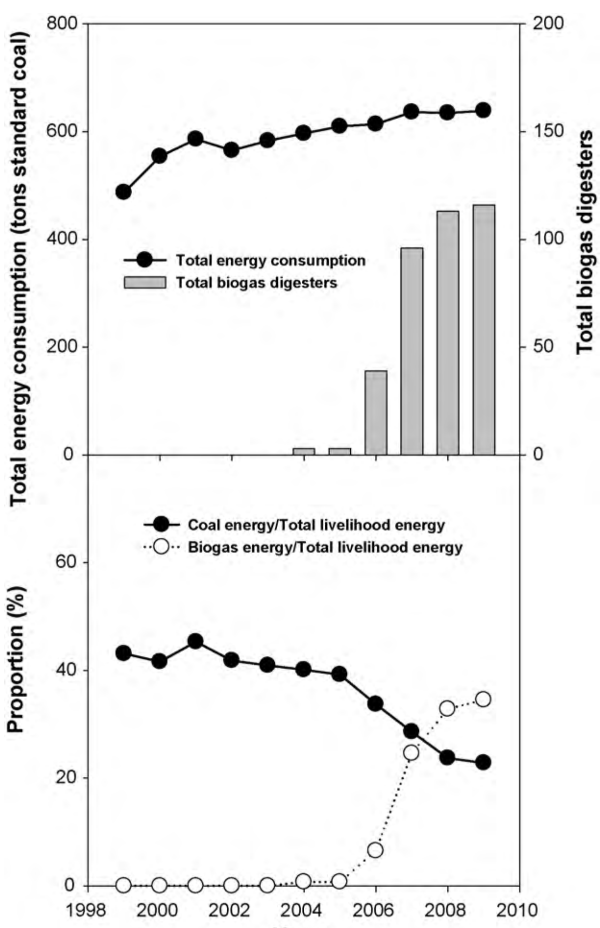

Fig. 8. Total energy consumption, biogas digesters, proportions of coal energy/total energy and biogas energy/total energy in Jiangjiazhuang during 1999–2009.

energy/total livelihood energy were drastically increased during the experiment run. In contrast, the proportion of coal energy/total livelihood energy significantly decreased during 2005–2009. More biogas was consumed in the villagers' daily life, more fossil energies were saved and less greenhouse gases emitted to the atmosphere. In 2009, biogas yield was up to 92,250 m^3 relative to 65.9 tons standard coal. Cattle dung, which comes from cattle body via digestion, was used as the material for generating biogas. It had a lot anaerobic bacterium and high efficiency in producing biogas. The saved standard coals by biogas utilization could produce about 177.9 tons CO_2 emission (about 2.7 tons CO_2 emission per ton standard coal combustion). As a result, about 177.9 tons CO_2 were reduced. So it is conceivable to believe that biogas utilization in rural areas might be one of the key measures to alleviate energy crisis and global warming.

3.4. Green fertilizer production

Along with the industrial development, more and more young farmers immigrate into cities to obtain higher incomes [25]. Their croplands were left to their parents or other persons who did not have opportunities to immigrate to the cities (older men or women). For a reason of saving manpower, less and less animal manures were produced and used while more and more chemical fertilizers were supplied in the croplands. As a result, the soil organic carbon content significantly decreased and the soil physical and chemical characters declined. The crops grain yields were also considerably decreased year after year because of the decline of soil quality. After this project running, the residues in biogas digesters were used as green fertilizers returning to the croplands. On the other hand, huge amount of green fertilizers application could make the soil color change to "black", and it might indicate that plenty of organic carbons were fixed in soil [18,17]. Soil carbon sequestration would contribute to reduce atmospheric carbon content. It should be a huge contribution in alleviating global warming.

Table 3
Variation of economic benefit after 5 years experiment in Jiangjiazhuang. Unit: US$.

Years	Cattle benefit	Energy saving	Fertilizer saving	Crop yield benefit	Total net benefit
2005	458.8	661.7	44.1	3326.7	4491.3
2009	25923.5	16444.6	7125.0	4941.2	54434.3

3.5. Economic benefit and future perspectives

Livestock and biogas developments in rural areas of China apparently enhanced the farmers' incomes and reduced their costs in buying energies and fertilizers (Table 3). Total net benefit in 2009 was about 12 folds of the one in 2005. Wisely biomass energy utilization in rural areas may considerably elevate villagers' incomes and their life qualities. Livestock development in this eco-agricultural circulation enhanced the biomass energy use efficiency. And it was a promising way to change the crop residues into human high nutritional food by turning biomass into animal meat. It would apparently contribute to solving the food security in China. Biogas production and utilization in rural areas also significantly alleviated the energy competition between rural and urban areas. It would be a key role to lessen the energy crisis and greenhouse gas emission.

Jiangjiazhuang is just one of the 3.2 million agro-villages in China [23]. If the biogas project could demonstrate in all those villages in the future, it would be surprising figures in saving fossil energies and reducing greenhouse gases emission. According to the results of the present study in Jiangjiazhuang (about saving 65.9 tons standard coal and reducing 177.9 tons CO_2 in 2009), 3.2 million agro-villages will save some 210.9 million standard coal and reduce 569.3 million tons CO_2 emission. On the other hand, long-term increasing green fertilizers application and decreasing chemical fertilizers supply might elevated the soil carbon content [31]. Soil carbon sequestration is another crucial measurement to reduce the atmospheric carbon concentration [21,27]. A study on soil carbon sequestration should be exposed in the future. In a word, livestock and biogas development in agricultural areas of China have been proved a promising project in improving human life quality. However, it is not so easy to demonstrate this project because the farmers are lack of money and technologies. Therefore, in order to make the project going smoothly in the future, financial and technological supports will be needed from the Chinese government.

4. Conclusions

The results of the present study indicated that proper utilization of biomass energy in rural areas of China through developing livestock and biogas production might effectively improve the biomass use efficiency and reduce fossil energy consumption. Biomass energy utilization in rural areas might be a great contribution to alleviate the energy crisis and global warming.

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