Study on Main Modes and Supporting processes of Facility Ecological Agriculture Under New Situation

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Abstract. With the acceleration of agricultural modernization, traditional farming faces challenges such as high resource consumption and environmental pollution. Facility-based ecological agriculture, serving as a crucial approach that balances efficient production with ecological conservation, has become the core direction for industry development. This paper focuses on the main models and supporting technologies of facility-based ecological agriculture under new circumstances, conducting an in-depth analysis of the structural characteristics, operational mechanisms, and practical outcomes of the "four-in-one" integrated ecological model combining crop cultivation and biogas utilization, as well as the regional-level "breeding-biogas-cultivation" linkage model. Taking COFCO Meat Dongtai Branch Company as a case study, this research quantifies data on resource recycling, ecological improvement, and economic benefits for both models, while also elaborating technical key points regarding supporting processes such as pest control and fertilizer-water management.

Keywords: facility ecological agriculture; four-in-one model; pest control

1 Introduction

Facility ecological agriculture integrates cultivation, energy conversion, and waste utilization technologies to establish a "resources → production → waste → renewable resources" circular system. This approach not only enhances agricultural productivity but also reduces environmental pressure. China has developed diverse models in this field, ranging from courtyard-level "four-in-one" greenhouses to regional industrial linkages. However, systematic analysis of the applicable scenarios, operational mechanisms, and efficiency differences across these models remains lacking[1]. To address this gap, this study examines typical models by analyzing their structural layouts, resource conversion efficiency, and supporting technologies. The findings aim to provide theoretical and practical references for scaling up facility ecological agriculture, thereby advancing green and sustainable agricultural development.

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2 Main Modes OF Facility Ecological Agriculture

2.1 Facility Clean Cultivation Mode

(1) Protected ecological soil cultivation. By using organic fertilizer (solid fertilizer, decomposed fertilizer, biogas slurry, etc.) to replace chemical fertilizer in whole or in part, and using drip irrigation technology under film, the chemical fertilizer and water resources in the whole growth process of crops can be effectively controlled, and the recoverable production of soil ecology can be realized. (2) Organic ecotype soilless culture. By using organic solid fertilizer (organic nutrient solution) to replace chemical fertilizer in whole or in part, and using crop straw, jade core, peanut shell, waste mushroom residue, slag, coarse sand and other substrates as soilless cultivation substrates to replace peat, vermiculite, perlite and rock wool, at the same time, using drip irrigation technology, the harmless production of agricultural products and the sustainable utilization of resources can be realized. (3) Integrated pest control mode of ecological and environmental protection facilities. Through biological control based on natural enemy insects and the development and application of a number of new low toxicity and non-toxic pesticides, pesticide residues are reduced; Through the application of physical means such as environmental regulation, insect prevention net, Silver Ash film insect avoidance and yellow plate insect trapping plasma technology, the pesticide dosage was reduced, and the quality of vegetable varieties was significantly improved.

2.2 Ecological Mode of Combination of Facility Planting and Breeding

Through the greenhouse project, vegetable planting and livestock (FISH) breeding are organically combined to form a quality energy complementary and virtuous cycle ecosystem. At present, this mode has two main forms: (l) Greenhouse "livestock vegetable" symbiotic complementary ecological agriculture model. It mainly uses CO2 released by livestock and poultry respiration. Vegetables are supplied as gas fertilizer, and livestock manure is treated as the source of organic fertilizer for vegetable cultivation. At the same time, beneficial gases such as O2 generated in the assimilation process of vegetables are supplied to livestock and poultry to improve the breeding ecological environment and realize symbiosis and complementarity. (2) Greenhouse "fish Lai" symbiotic complementary ecological agriculture model. The nutrient water of fish is used as part of the fertilizer source of vegetables, and the root purification function of vegetables is used to clean and purify the water of fish pond.

2.3 Three Dimensional Ecological Cultivation Mode of Facilities

There are three main forms of this mode: (l) Greenhouse "fruit Lai" three-dimensional ecological cultivation mode. The suitable vegetable varieties were selected for intercropping and interplanting by using the idle stage of the ground space in the dormancy period and non fruit bearing period of greenhouse fruit trees. (2) The "mushroom Lai" three-dimensional ecological cultivation mode in greenhouse is to carry out the "mushroom vegetable" three-dimensional ecological cultivation by placing edible mushroom sticks in the corridor of greenhouse and the gap between rows. The CO2 produced by edible fungi can be used as a source of gas fertilizer for vegetables, and the high temperature and humidity environment in greenhouse is conducive to the growth of edible fungi. (3) Greenhouse "Lai Cai" three-dimensional ecological cultivation mode. Taking advantage of the spatial differences between rattan vegetables and leafy vegetables, three-dimensional cultivation can be carried out. In summer, rattan vegetables can also be used as shade for shade loving vegetables, which can be used for each other.

3 "Four-in-one" Ecological Model Combining Planting, Breeding and Marsh

The "Four-in-One" Ecological Model, also known as the "Four-in-One" Ecological Greenhouse Model, is a solar-powered system that integrates four key technologies: greenhouse vegetable cultivation, livestock breeding, biogas fermentation, and manure composting. This innovative approach combines planting, breeding, and biogas production into an optimized integrated system, creating a high-yield, high-quality, efficient, and low-consumption ecological agricultural framework. First documented by Wang Baiyi et al. in 1992 during their study of Wang Jingping's courtyard-style ecological greenhouse at Qingshui Farm in Dawo County, Panjin City, Liaoning Province, the model features a central biogas digester with hardened roof housing livestock pens. The digester processes organic waste (including animal manure, human waste, and crop residues) to produce biogas year-round. A connected toilet system channels waste into the digester, where it undergoes high-temperature fermentation to generate biogas and organic fertilizer for crop use. The greenhouse's opposite side cultivates vegetables and fruits (Figure 1). In 1994-1995, Guo Huiqing et al. analyzed the development of a solar-powered livestock-vegetable complementary ecosystem combining animals, crops, and biogas digesters, identifying challenges for future implementation. Their findings provided crucial guidance for establishing and managing this ecological greenhouse model[2].

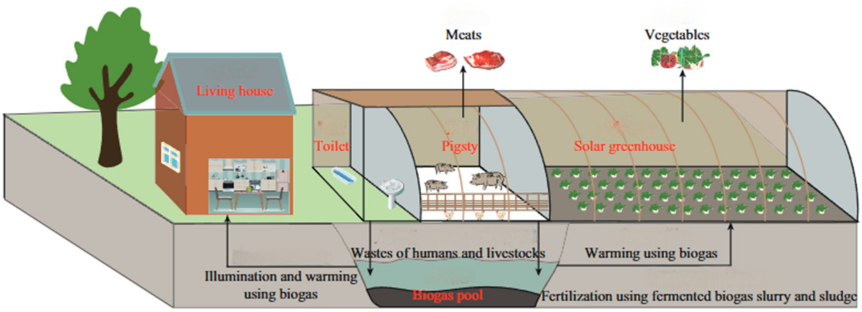

Fig. 1. Schematic diagram of structure and function of "four-in-one" ecological solar greenhouse

4 Practice of "Breeding-Biogas-Planting" Linkage Mode in Regional Ecological Agriculture Facilities

4.1 Core Facilities and Processing Capacity

Zhongliang Meat (Jiangsu) Co., Ltd. Dongtai Branch has established a regional "breeding-biogas-cultivation" integrated model. Its three large-scale biogas projects process manure from three livestock farms housing 600,000 pigs, with a daily processing capacity of 1,284 tons and an annual biogas output of 5.95 million m³. The power generated through Asia's largest single-unit Jindongtai Biogas Power Plant is connected to the grid, producing 11.76 million kWh annually[3]. The facility also generates 460,000 tons of digestate and residue each year. Researchers from Nanjing Forestry University have determined optimal crop application rates for these byproducts, which improve soil quality (reducing pH levels, enhancing conductivity, and increasing organic matter) while boosting crop yields. The digestate is distributed via a 6-kilometer pipeline to vegetable fields as fertilizer, with surplus transported to fish ponds as feed. This integrated approach not only resolves waste disposal issues but also enables synchronized development across multiple industries within the region (Figure 2). And shown in Table 3.

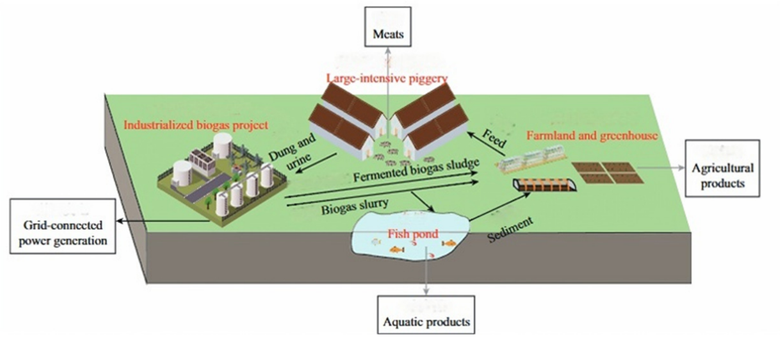

Fig. 2. Schematic diagram of regional material cycle in the integrated area of aquaculture, biogas and planting in Dongtai City, Jiangsu Province

Table 1. Aquaculture-gas-planting mode of COFCO Meat Dongtai Branch

metric	data
The scale of pig breeding	Three large-scale breeding communities with an annual output of 600,000 head
Daily disposal capacity of feces	1284 t
Annual disposal capacity of sewage	About 469,000 t
Annual biogas production	5.95 million m³
annual energy output	11.76 million kW·h
Annual output of biogas sludge	460,000 tons
Length of biogas slurry pipeline network	6 km
Increase of soil organic matter	12%-15%

Soil pH Value reduction	0.3-0.5
Vegetable production increased	8%-12%
Increase in grain crop yield	5%-8%

4.2 Material Cycle and Resource Conversion Efficiency

This model achieves the "full conversion" of aquaculture waste: the manure is converted into clean energy (biogas) and organic resources (biogas liquid and residue) through biogas project. The power generation efficiency of biogas reaches 85%, and the biogas liquid and residue are completely utilized through the "fertilizer + feed" dual path, which completely solves the problem of waste treatment in large-scale aquaculture. As shown in Table 2 Material cycle and transformation of aquaculture-biogas-planting model.

Table 2. Material cycle and transformation of aquaculture-biogas-planting model

Material type	Output	Pathways to transformation	utilization efficiency
Pig manure	469,000 t/year	Enter the biogas fermentation project	The treatment rate is 100%, no direct discharge pollution
methane	5.95 million m^3/year	It is fed into biogas power plants to generate electricity	Energy conversion rate 85%, annual power generation 11.76 million kW·h
Biogas sludge	460,000 tons/year	322,000 t applied to farmland through the pipeline network (70%), 138,000 t as fish pond feed (30%)	The utilization rate of resources is 100%
electric energy	11.76 million kW·h/year	It was incorporated into the State Grid to supply industry and civil services	It can meet the annual electricity demand of 30,000 households

4.3 Quantitative Analysis of Ecological and Economic Benefits

Through the linkage of "breeding-gas-planting", this model not only improves the ecological environment (improving soil quality and reducing pollution), but also creates significant economic benefits: the three types of income from energy generation, crop yield increase and cost saving total more than 20 million yuan annually, forming a virtuous cycle of "ecology-economy" win-win. As shown in Table 3 Ecological and economic benefit indicators of the mode.

Table 3. Ecological and economic benefit indicators of the model

Benefit type	Specific indicators	Data performance
ecological benefit	land betterment	The organic matter content increased by 12%-15%, the pH value decreased by 0.3-0.5, and the available phosphorus content increased by 8%-10%
	Pollution reduction	COD removal rate is above 85%, ammonia nitrogen removal rate is 78%, fertilizer use is reduced by 1500 t/year
economic benefits	Energy gains	The annual income of biogas power generation is 9.408 million yuan (calculated by 0.8 yuan /kW·h)
	Agricultural production increased	The average yield of vegetables increased by 8%-12%, and that of grain crops increased by 5%-8%, with an annual output value of about 8 million yuan
	cost saving	Reduce the cost of manure treatment by 2.8 million yuan/year and save the cost of fertilizer purchase by 1.5 million yuan/year

In conclusion, the regional "breeding-biogas-planting" model provides a replicable practical example for the industrialization of facility ecological agriculture through large-scale facilities support, efficient material circulation and diversified benefit output.

5 3Supporting Technology of Facility Ecological Agriculture

5.1 Pest Control Technology

Among the supporting technologies in facility ecological agriculture, pest and disease control stands out as a crucial technique. This approach effectively reduces the likelihood of crop diseases and pests occurring within greenhouses, ensuring healthy plant growth. Given the unique characteristics of facility ecological agriculture, the following pest management techniques are primarily employed[4].

(1) Physical control technology

Physical pest control employs physical methods to eliminate pests and diseases in agricultural facilities without affecting crops. This approach proves particularly effective in controlled agricultural environments, where micro-environmental management yields optimal results. Professionals can utilize insects' phototaxis by deploying insect-killing lamps. Additionally, installing insect-proof nets on facility doors and windows creates physical barriers that effectively repel pests while maintaining crop health.

(2) Biological control technology

Biocontrol technology harnesses natural biological mechanisms to manage crop diseases and pests without harming crops. To implement this approach, farmers must first understand the characteristics of crops in ecological agriculture systems and identify potential pest risks. Based on these assessments, they can utilize natural insect predators to eliminate pests. Additionally, the "insect-based disease control" strategy can be employed, such as using predatory mites for pest management, provided that all practices strictly comply with China's relevant regulations and standards.

(3) Chemical control technology

Compared to the first two methods, chemical control offers more thorough pest management. However, proper dosage and timing must be carefully managed during implementation to avoid adverse effects on crops. When applying chemical control techniques, professionals should provide guidance. By selecting appropriate pesticides and application methods tailored to specific crop needs, optimal pest control results can be achieved.

5.2 Monthly Fertilizer and Water Management and Supply Technology

In ecological agriculture within greenhouses, the management of fertilizer and water supply is crucial. Excessive fertilizer or water application in these facilities can negatively impact crops. Therefore, strategic planning and efficient delivery techniques have become essential supporting technologies. Proper implementation of these techniques effectively prevents nutrient imbalances and environmental pollution in crops, while meeting actual water supply demands. The primary strategies for fertilizer and water management in greenhouse ecological agriculture include the following approaches[5].

(1) Integrated water and fertilizer technology

The integrated water-fertilizer technology delivers precise irrigation and nutrient supply tailored to crop characteristics. Unlike traditional methods, this system mixes fertilizers with water into liquid solutions for drip irrigation delivery. This approach ensures uniform distribution of water and nutrients while precisely reaching plant roots. Given the compact nature of ecological agriculture facilities, this technology proves particularly suitable. It not only boosts crop yields but also achieves water and fertilizer conservation.

(2) Fertilization and water management techniques

Fertilization and irrigation management technology serves as a crucial supporting measure in ecological agriculture, enabling effective nutrient and water management to ensure healthy agricultural yields. When implementing this technology, it's essential to tailor nitrogen, phosphorus, potassium, and other nutrients according to crop requirements and soil conditions, ensuring crops receive comprehensive nutrient absorption. Selecting appropriate fertilizer types and application methods is crucial to maximize fertilizer efficiency. Irrigation schedules and water volumes should be strategically planned based on crop growth needs and local climate conditions. Adopting water-saving irrigation techniques like drip irrigation and sprinkler irrigation not only meets crop hydration demands but also prevents water wastage.

(3) Fertilizer and water management technology

Fertilization and irrigation planning technology refers to the adoption of rational fertilization and irrigation management methods in ecological agriculture facilities to ensure robust crop growth. The key aspect of this technology lies in fertilizer application timing, which can be implemented through phased approaches. Water control should prioritize irrigation periods, ensuring seasonal adaptation of irrigation methods to guarantee scientific precision and operational efficiency.

6 Conclusion

Facility-based ecological agriculture has achieved synergistic development between agricultural production and ecological conservation through innovative models and technological integration. The "Four-in-One" integrated model combining cultivation, breeding, and biogas utilization centers on solar energy, featuring a closed-loop design within greenhouses that integrates "planting-breeding-biogas-fertilizer". This system is particularly suitable for small-scale courtyard economies, with its strength lying in the seamless integration of energy self-sufficiency and organic production. At the regional level, the "Breeding-Biogas-Cultivation" linkage model (as exemplified by Dongtai's case) leverages large-scale facilities to enable cross-industry material circulation. It processes 469,000 tons of manure annually and converts 5.95 million cubic meters of biogas, resulting in a 12%-15% increase in soil organic matter content and a 5%-12% yield boost for crops, demonstrating the dual benefits of ecological and economic efficiency in scaled production. Supporting technologies include coordinated physical, biological, and chemical pest control methods, along with integrated water-fertilizer management and phased irrigation strategies, which provide critical support for efficient model operation.

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