Postprint: Innovating the Research Paradigm of Agricultural Eco-economics from the Perspective of Symbiosis Theory

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Abstract

Symbiosis theory posits that heterogeneous symbiotic organisms exhibit interdependent relationships throughout their survival processes. This study attempts to transplant this argument into agricultural ecological economics research to address the conflict between ecological and economic benefits in agricultural production. To this end, the agricultural ecological economy is conceptualized as a heterogeneous symbiont composed of ecological and economic units. The structure and symbiotic patterns of this symbiont are analyzed, and Logistic equations combined with numerical simulation methods are employed to investigate the symbiotic mechanisms of agricultural ecological-economic symbionts, revealing the evolutionary laws and growth characteristics among symbiotic units. The research demonstrates that the primary objective of innovatively applying symbiotic patterns in agricultural practice is to transform the symbiont from a parasitic symbiosis pattern to a mutualistic symbiosis pattern, with incentive strategies for positive transformation being proposed. The selection of symbiotic units must ensure compatibility, and a clear symbiotic interface between units should facilitate the exchange of matter, energy, and information to increase the free energy within the symbiont. The positive development of symbiotic relationships must adhere to symbiotic evolution laws, with the commensalistic symbiosis pattern serving as an essential intermediate stage in the evolution toward mutualistic symbiosis. Cultivating a symbiotic environment conducive to mutualistic symbiosis is crucial for promoting symbiont evolution. These findings provide a new paradigm for agricultural ecological economics research and pioneer novel approaches and methodologies.

Full Text

Preamble

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Innovative Research Paradigm of Agricultural Eco-Economy from the Perspective of Symbiosis Theory

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Abstract

Symbiosis theory posits that heterogeneous symbiotic organisms exhibit interdependent relationships during their survival processes. This study attempts to transplant this argument into agricultural eco-economic research to address the contradiction between ecological and economic benefits in agricultural production. The agricultural eco-economy is regarded as a heterogeneous symbiont composed of ecological and economic units. Using Logistic equations and numerical simulation methods, this paper analyzes the structure and symbiotic patterns of this symbiont, explores its symbiotic mechanisms, and reveals the evolution rules and growth characteristics of the symbiotic units. The primary objective of innovative application of symbiotic patterns in agricultural practice is to transform the symbiont from a parasitic mode to a mutualistic mode, with incentive strategies proposed for this positive transition. The selection of symbiotic units must be compatible to increase free energy within the symbiont, and the forward development of symbiotic relationships must follow symbiotic evolution laws. Commensalism mode is an inevitable stage in the evolution toward mutualism mode. Cultivating a symbiotic environment suitable for mutualism is crucial for promoting symbiont evolution. These research findings provide a new paradigm, new ideas, and methods for agricultural eco-economic research.

Keywords: agricultural eco-economy; symbiosis theory; symbiotic mechanisms; innovative research paradigm

Introduction

The integration of ecology and economy has always been a central theme in research on global environmental change and ecological crises. Economic benefits primarily concern current and local interests, while ecological and environmental benefits involve long-term and macroscopic interests, creating obvious conflicts between economic and ecological value criteria. As economic scale continues to expand, ecological and environmental degradation becomes increasingly severe. Coordinating these contradictions represents a thorny problem for current research. However, some regions overemphasize ecological restoration while neglecting human economic needs, resulting in a lack of motivation for ecological restoration. In reality, ecological restoration is not only an ecological process but also a process of enhancing economic value. Only through the fusion of both can ecological restoration be sustained and stabilized. This issue has attracted the attention of many scholars.

Current literature shows that research hotspots focus mainly on system coupling concepts, including system coupling patterns [1], coupling situations [2-3], coupling effects [4], and system coupling process models [5]. However, research in this area lacks a convincing integration theory. Symbiosis theory provides a theoretical foundation for solving this problem. Originating from biology, symbiosis theory describes interspecies relationships in population ecology, representing a state where physiological interdependence reaches equilibrium [6]. Scott proposed that symbiosis is a state where two or more organisms are physiologically interdependent to a balanced degree. Subsequently, many scholars have widely applied this methodology to numerous fields [7-8], including industry [9], finance [10-11], urban management [12], business management [13-14], and agriculture [15-16].

This study opens a new path by introducing symbiosis theory into agricultural eco-economic research, treating economic and ecological units as two independent yet heterogeneous symbiotic units coexisting within the agricultural eco-economic symbiont. Precisely because of this heterogeneity, multiple symbiotic units can establish more interdependent relationships [17] and exhibit stronger complementarity during their survival processes, with each unit strengthening the survival capabilities of others. The existence and development of one symbiotic unit is premised on the existence of other units. This complementarity forms the basis for co-evolution and structural renewal of the symbiont. A search of domestic and international literature, including a scientific novelty search report from the Institute of Scientific and Technical Information of China (20141100100613), reveals that while symbiosis theory has been widely applied in many fields, no research reports have been found on its application to the integration of ecology and economy.

1. Composition of the Symbiont

The agricultural eco-economic symbiont is composed of agricultural ecological symbiotic units and agricultural economic symbiotic units. The agricultural ecological symbiotic unit consists of two major elements: agricultural ecological environment and agricultural biological populations. The agricultural ecological environment includes climate, soil, and water resources that crop growth depends on, while agricultural biological populations include animals, plants, and microorganisms involved in crop cultivation, animal husbandry, and fisheries. The agricultural economic symbiotic unit is primarily composed of agricultural inputs and outputs. Agricultural inputs include labor, capital, and technology, while agricultural outputs include the yield and output value of various agricultural products and their processed goods. The collective within the boundaries of the agricultural economic symbiotic unit aims to fulfill its economic functions, whereas the collective within the agricultural ecological symbiotic unit aims to fulfill its ecological functions. The symbiotic interface provides smooth channels for energy flow, information flow, and value flow between symbiotic units, promoting the evolution and development of the symbiont. The ecological symbiotic unit provides suitable natural conditions for the development of the economic symbiotic unit, while the economic symbiotic unit ensures the development of the ecological symbiotic unit and simultaneously digests and processes waste generated by the economic symbiotic unit. The two units are intertwined and interact to constitute the symbiont.

2. Formation of Symbiotic Patterns

Symbiotic units are the basic energy production and exchange units that constitute the symbiont. Relationships between symbiotic units occur through the conduction of energy via the symbiotic interface. After two symbiotic units come into contact through the interface, they generate symbiotic energy and distribute it, thereby forming symbiotic patterns. The external conditions for the formation and evolutionary development of symbiotic patterns constitute the symbiotic environment, which reflects the essence of inter-unit relationships.

Symbiotic patterns include parasitic symbiosis, commensalism, and mutualistic symbiosis. Parasitic symbiosis manifests as unidirectional material or energy transfer between symbiotic units, benefiting one unit' s development while harming the other' s. In some regions, exploitative land management practices cause energy to transfer unidirectionally from the ecological symbiotic unit to the economic symbiotic unit, affecting the vitality of the ecological unit and damaging the symbiotic environment, thus forming a parasitic symbiosis pattern.

Commensalism pattern manifests as energy distribution concentrating on one side between symbiotic units, while the other side experiences no net loss. When developing agricultural eco-economy within the carrying capacity of resources and environmental capacity, the development of the economic symbiotic unit does not affect the ecological symbiotic unit, constituting an economic commensalism pattern. Although the ecological symbiotic unit has not reached a certain standard, energy is bidirectionally distributed between units without affecting the economic symbiotic unit, representing an ecological commensalism pattern.

Mutualistic symbiosis manifests as both economic and ecological units benefiting, with new energy continuously generated to promote the evolution and development of the symbiotic relationship, forming a mutualistic symbiosis pattern. This is the optimal model for developing agricultural eco-economy. During the transition from parasitic to mutualistic symbiosis, a transitional commensalism pattern often emerges.

3. Evolution Laws and Growth Characteristics of Symbiotic Relationships

Understanding the evolution laws and growth characteristics of symbiotic relationships is a prerequisite for applying symbiosis theory to agricultural eco-economic research. The energy output from agricultural ecological symbiotic units should follow the law of input-output appropriateness. There exists a non-negative feedback evolution relationship between its input and output volumes and the corresponding input volumes of economic symbiotic units. The Logistic equation can precisely describe the nonlinear S-shaped growth caused by the combined effects of positive and negative feedback forces under environmental capacity constraints.

The Logistic equation has been innovatively applied in agricultural eco-economic research, describing the internal growth laws of symbiotic units and the interaction relationships between units during the evolution of agricultural eco-economic symbionts. This study attempts to utilize the Logistic equation to examine the transformation relationships between symbiotic patterns to obtain the optimal model.

3.1 Evolution Laws of Symbiotic Relationships

Assuming that when economic and ecological symbiotic units exist independently in the agricultural eco-economic symbiont, their development and evolution both follow Logistic growth. Let x represent the energy scale of the economic symbiotic unit in the agricultural eco-economic symbiont, r_1 its inherent growth rate, and N_1 the maximum environmental capacity for the economic unit' s independent growth. The term $\frac{x}{N_1}$ represents the proportion of resources consumed by the economic unit, and $r_1\frac{x}{N_1}$ represents the inhibition of its own scale growth due to resource consumption during development.

Similarly, let y represent the energy scale of the ecological symbiotic unit, r_2 its inherent growth rate, and N_2 the maximum environmental capacity for the ecological unit' s independent growth. When economic and ecological symbiotic units coexist in the same agricultural eco-economic symbiont, their symbiotic relationship may be mutualistic, commensalistic, or parasitic, with different patterns producing different effects. Mutualistic symbiosis allows one unit to benefit from the existence of the other, while commensalism benefits one unit without affecting the other. Parasitic symbiosis causes one unit' s growth to negatively affect the other.

By introducing symbiotic coefficients α and β for the symbiotic units, we can derive the dynamic evolution equations. For the economic symbiotic unit x under symbiotic conditions, the evolution dynamics equation is:

$$\frac{dx}{dt} = r_1 x \left(1 - \frac{x}{N_1} + \alpha \frac{y}{N_2}\right)$$

Similarly, the evolution dynamics equation for the ecological symbiotic unit y is:

$$\frac{dy}{dt} = r_2 y \left(1 - \frac{y}{N_2} + \beta \frac{x}{N_1}\right)$$

Here, α represents the symbiotic coefficient of the ecological unit on the economic unit, and β represents the symbiotic coefficient of the economic unit on the ecological unit. Different combinations of these coefficients can determine the symbiotic relationship of the agricultural eco-economic symbiont.

shows the symbiotic relationships based on different value combinations of the coefficients. When both coefficients are positive and equal, it represents a typical mutualistic symbiosis pattern. When both are positive but unequal, the two units have different degrees of mutual benefit. When coefficients are negative and equal, it represents a competitive pattern; if unequal, it represents a vicious competition pattern. When one coefficient is positive and the other negative, it represents a parasitic symbiosis pattern where the unit with the negative coefficient benefits. When one coefficient is zero, it represents a commensalism pattern where the unit with the positive coefficient is unaffected while the other benefits. When both coefficients are zero, it represents independent coexistence where units do not affect each other.

3.2 Growth Characteristics of Symbiotic Patterns

Since the evolution of symbiotic relationships between economic and ecological units in agricultural eco-economic symbionts requires considerable time, traditional methods struggle to depict this evolution. Computer simulation can better reflect the dynamic changes of agricultural eco-economic symbionts under specific circumstances and reveal the growth characteristics of symbiotic patterns.

To illustrate the impact of symbiotic coefficients on system evolution, this study assumes that the inherent growth rates of economic and ecological symbiotic units are $r_1 = 0.8$ and $r_2 = 0.5$, respectively, and the maximum environmental capacity supporting their independent growth is $N_1 = N_2 = 1600$. Using Matlab 2008, we explore the evolution process under different combinations of α and β values, with an evolution period of 1500. Sensitivity analysis was conducted on other parameter values, and simulation results are shown in Figures 2-7.

The results show that although numerical values differ slightly, the trends and patterns are consistent with our analysis. Under mutualistic symbiosis, both units evolve toward scales larger than their maximum independent growth limits, eventually reaching stable states at different upper limits. The upper limit increase is related to the symbiotic coefficients—the larger the absolute value, the greater the increase in the scale upper limit.

Under competitive symbiosis, the growth of one unit inhibits the other. When reaching stable states, both units' scale upper limits are below their maximum independent growth scales. Under vicious competition mode, the economic unit is suppressed by the ecological unit and becomes extinct first. Under parasitic symbiosis, the economic unit' s scale upper limit is below its independent maximum while the ecological unit' s exceeds its independent maximum. Under commensalism, the economic unit' s growth is unaffected by the ecological unit, with its scale upper limit equal to the independent maximum while promoting the ecological unit' s growth. Under independent coexistence, both units remain unaffected, with scale upper limits equal to their independent maximums.

2. Incentive Strategies for Agricultural Applications

Heterogeneous symbiosis has two possibilities: it can manifest as mutual attraction, complementarity, and promotion among symbiotic units [23], or it can appear in opposite forms [24-25]. The fundamental law of symbiont evolution is to apply incentive strategies to promote transformation toward mutualistic symbiosis.

2.1 Selecting Mutualistic Symbiotic Objects

In practice, we must firmly grasp that mutualistic symbiosis is the general direction of symbiont evolution. Agriculture not only provides materials needed by humans but also possesses ecological service functions such as regulating atmospheric composition (CO /O), reducing atmospheric pollutants, conserving water and soil, and maintaining nutrient cycling. The interwoven nature of agricultural production functions and ecological service functions—where the latter creates value several times higher than the former [26]—provides favorable conditions for selecting symbiotic objects and establishing forward symbiotic relationships based on common interests.

Many scholars have explored this issue. Zhang Xiaofeng et al. proposed that partner selection requires an association degree between symbiotic units not lower than a critical value, and that any unit will prioritize partners with strong capabilities and good matching [27]. Zaccaro et al. [28] argued that reasonable division of labor between symbiotic units generates symbiotic energy. Fortin et al. [29] and Cote et al. [30] introduced the symbiotic network concept, suggesting that models merely 停留在 byproduct exchange lack stability guarantees. The stability of symbiotic networks means that when internal or external environments change, the industrial chain can maintain stable circulation, making symbiotic network development resilient.

The selection of forward symbiotic objects must involve definite symbiotic interfaces among units within the symbiont, with inherent compatibility enabling material, information, and energy exchange in certain ways to continuously increase free energy within the system and form a symbiont whose overall structure and function far exceed the sum of its units. To make this operational, we can simulate natural biological group symbiosis phenomena, such as ecological symbiosis mimicking food chain principles, to select highly associated symbiotic objects.

For example, Maping Town in Fujian Province, despite superior natural conditions, initially practiced a rice-dominated farming system with improper orchard development, resulting in opposite-signed symbiotic coefficients between economic and ecological units—a parasitic symbiosis pattern. In 2001, by simulating food chain principles, they selected several compatible symbiotic units: planting forage in orchards, developing animal husbandry with the forage, using animal manure to cultivate edible fungi, and using fungal residue as fruit tree fertilizer, forming a multi-unit matching chain. This increased symbiotic density and enhanced symbiotic effects through orderly input and output of energy flow, information flow, and human activity value flow among units, eventually forming a new symbiont with negative symbiotic coefficients for both units and achieving a mutualistic symbiosis pattern. Ecological and economic benefits increased by 2-3 times compared to traditional agriculture [31-32].

The key to selecting symbiotic objects lies in ensuring strong association between units. Currently, some regions implement diversified agricultural operations, but due to weak associations among symbiotic units, economic benefits remain low. For instance, although Fujian Province has the highest forest coverage in China, the lack of mature and reasonable agroforestry management methods results in weak associations among units. Maping Town also established three-dimensional spatial symbiosis based on ecological niche principles: courtyard breeding, slope orchards intercropped with forage, and lowland freshwater aquaculture, forming multi-level material and energy spatial cycles. This three-dimensional spatial symbiont not only improves soil fertility but also yields income per unit area 3-5 times higher than general field crops, with farmers' per capita net income increasing by over 30% [31-32]. Natural phenomena such as physiological symbiosis (e.g., legumes with grasses) and plant natural replacement provide diverse symbiosis patterns for simulation. Selecting appropriate symbiotic objects from natural symbiosis phenomena is currently an important topic for technological innovation, involving both the number of symbiotic units and their inter-associativity.

2.2 Following Symbiotic Evolution Laws

After selecting appropriate objects to construct the symbiont, both parties enter an adaptation phase, first adjusting in structure and function. This mutual adaptation is followed by interaction generating new energy—a self-organizing process demonstrating openness, nonlinearity, and fluctuation. Research on Fujian' s agricultural eco-economic development trends from 2007-2010 [33] revealed this phenomenon: slow economic development placed the symbiont in an ecological commensalism pattern; after stimulating the economic unit' s vitality, the ecological unit' s energy supply couldn' t match, shifting to an economic commensalism pattern; by 2010, it evolved into a higher-level mutualistic symbiosis pattern.

The general trend of agricultural eco-economic development is from commensalism to mutualism, then to a new commensalism pattern, and finally to a higher-level mutualism. This reflects that agricultural eco-economic mutualism requires passing through a commensalism process; otherwise, it can only achieve low-level mutualism. Therefore, commensalism mode is an inevitable process in the evolution toward mutualism mode. The focus of symbiotic evolution strategy is to leverage the transitional role of commensalism to guide forward symbiotic development.

Traditional ecological reconstruction emphasizes functional restoration of the natural ecological side while often neglecting the economic side, indiscriminately proposing an "ecological priority" strategy. In reality, ecological reconstruction should follow symbiotic evolution laws and adopt different strategies according to different evolution stages. When economic development places excessive pressure on the ecological environment, even causing degradation, an ecological priority strategy should be adopted. However, for economically underdeveloped regions, economic benefits serve as both goal and means—only through economic incentives can ecological-economic symbionts be formed.

2.3 Cultivating Symbiotic Environment Suitable for Mutualism

Generating symbiotic energy is the most basic requirement of mutualism, and the symbiotic interface directly constrains the formation and enhancement of symbiotic energy [34]. If symbiotic interface media can not only reduce the time and cost of symbiosis but also expand its dimensions and density, the symbiotic effect is better than direct interface exchange. This indicates that while symbiont evolution follows its own laws, appropriate measures can promote it. Humans can cultivate symbiotic environments and skillfully apply symbiotic interface media to promote symbiont evolution and development.

Effectively building smooth, continuous, and stable interfaces to enhance the driving force for bidirectional energy exchange between units and ensure effective mutualistic interface function requires matching contact mechanisms. Institutions and policies are ideal symbiotic interface media. Currently, the optimal symbiotic models for different regional requirements await research, making science and technology crucial as symbiotic interface media to build more effective symbionts adapted to local needs. Agricultural management systems also serve as symbiotic interface media for agricultural eco-economic symbionts, demonstrating advantages in adaptation, integration, and new energy generation among symbiotic units. Other factors such as ecological compensation, agricultural markets, and various agricultural layouts may also become symbiotic interface media.

However, a prerequisite must be met: the symbiotic environment must adapt to the symbiont' s evolution, fostering a forward phase transition of the symbiont —that is, cultivating a symbiotic environment suitable for mutualism.

3. Conclusion

Amid global environmental change and ecological crises, the integration of ecology and economy remains a central research theme. Current research has only 停留在 system coupling concepts, lacking a convincing integration theory. Biological heterogeneous symbiosis exhibits stronger complementarity, providing an excellent theoretical basis for ecology-economy integration. Moreover, nature offers many biological mutualism phenomena for simulation, opening broad avenues for application. Agriculture is the sector most dependent on natural resources and the environment and exhibits interwoven production functions and ecological service functions. Applying this theory to agriculture demonstrates novelty and superiority.

This paper explores the symbiotic mechanism of agricultural eco-economic symbionts, emphasizing that mutualism is the general direction of symbiont evolution and that commensalism mode is an inevitable process in forming mutualism mode. Corresponding symbiotic incentive strategies are proposed to achieve the unity of economic and ecological benefits.

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