

Comparison of Comprehensive Agricultural Resource Utilization Efficiency Between Organic and Conventional Farming Across Different Time Periods: A Case Study of Rice Cultivation in Hubei Province (Postprint)

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Abstract

To conduct an in-depth analysis of the advantages and characteristics of organic agriculture in resource utilization compared with conventional agriculture, this study established an evaluation index system for agricultural resource utilization efficiency applicable to organic and conventional rice cultivation, based on a comprehensive analysis of existing evaluation index systems, combined with analysis of the rice cultivation production process and the characteristics of organic agriculture. Taking rice cultivation in Hubei Province as a case study, an evaluation survey was conducted on agricultural resource utilization under organic cultivation of different durations and conventional cultivation. The index system employed climate resources, water resources, land resources, biological resources, labor input, and resource sustainability as evaluation elements, encompassing a total of 18 evaluation indicators. The evaluation results revealed that organic cultivation generally scored lower than conventional cultivation in climate resources and land resources due to lower biological yield. However, organic cultivation scored significantly higher than conventional cultivation in the evaluation elements of water resources, biological resources, labor input, and resource sustainability. Overall, the resource utilization evaluation score for organic rice cultivation samples of less than 3 years was 0.867, comparable to that of conventional cultivation (0.857); however, as the duration of organic cultivation increased, the evaluation score gradually improved (the evaluation score for organic cultivation samples of 3–6 years was 0.927). When organic cultivation exceeded 6 years, the evaluation score reached 0.976, representing a 14% improvement over conventional cultivation. The study indicates that organic agriculture is superior to conventional agriculture in terms of resource utilization efficiency, but this difference is not pronounced in the early stage of

organic cultivation; as the cultivation years continue to extend, the advantages of the organic model in resource utilization gradually become manifest.

Full Text

Efficiency Analysis of Comprehensive Utilization of Agricultural Resources Under Organic and Conventional Agricultures—A Case Study of Rice Cultivation Systems in Hubei Province

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Abstract

Conventional agriculture, formed during agricultural modernization, is characterized by open systems, high resource inputs, and high production efficiency. While this high-input, high-energy consumption model has delivered highly developed labor productivity and diverse agricultural products, it has also caused tremendous waste of limited agricultural resources [1-2]. Built upon massive resource consumption and environmental degradation, with cost accounting based on input-output ratios, the “efficiency” of conventional agriculture becomes meaningless and is consequently suspected of being unsustainable [3].

Organic agriculture follows sustainable development principles and basic organic standards, completely eliminating synthetic fertilizers, pesticides, growth regulators, and livestock feed additives while rejecting genetic engineering and its products. Instead, it follows natural laws and ecological principles, balances crop cultivation and animal husbandry, and employs sustainable agricultural technologies to maintain stable agricultural production processes [4]. Compared with conventional agriculture, organic systems aim to maintain and improve soil fertility and protect ecological environments, emphasizing internal material cycling and relying primarily on natural laws to enhance ecological cycle efficiency while minimizing external inputs [4-5]. Theoretically, organic agriculture should be superior to conventional agriculture in efficient resource utilization. Although numerous studies on organic agriculture exist, most focus on ecological environmental impacts [5-7], development strategies [4,8], and organic certification [9-10], with few deeply analyzing the advantages and characteristics of organic agriculture in resource utilization compared to conventional agriculture.

The index system evaluation method is fundamental and commonly used in agricultural resource utilization efficiency research. It quantitatively reflects and measures the effectiveness of agricultural resource utilization by establishing appropriate metrics and forming an orderly, comprehensive evaluation system

based on inter-indicator relationships. This approach identifies and diagnoses limiting factors and their constraints in agricultural production and reproduction processes across different regions, types, and models, thereby outlining the basic contours of resource utilization in agricultural development [11]. Domestic scholars have established various agricultural resource utilization efficiency evaluation index systems and conducted empirical studies. For example, Li Daoliang et al. [12] proposed a comprehensive agricultural resource utilization efficiency evaluation index system and auxiliary indicator system based on the connotation of efficient agricultural resource utilization and data availability. Xu Yong [11] divided agricultural production processes into economic and natural production processes, establishing evaluation systems from the perspectives of natural resource endowment, potential, and efficiency, as well as socioeconomic input and utilization efficiency. Xie Gaodi et al. [13] constructed an evaluation index system covering resource utilization efficiency, social satisfaction, economy, environment, and sustainability.

This study takes rice cultivation in Hubei Province as its research object, combining analysis of rice production processes to construct a comprehensive agricultural resource utilization efficiency evaluation index system applicable to both organic and conventional rice cultivation based on previous research. Through empirical research, we explore the advantages and characteristics of organic rice cultivation across different time periods (less than 3 years, 3-6 years, and over 6 years) in sustainable agricultural resource utilization.

1. Study Area and Data Sources

Hubei Province is a major rice-producing region in China, with rice accounting for over 50% of cultivated area, 70% of grain output, and 80% of commodity grain, making it the third-largest rice province after Hunan and Jiangxi [14]. Located in a north-south transitional zone with abundant light, temperature, and water resources, diverse rice varieties, and varied farming systems, Hubei has developed a comprehensive rice cultivation pattern featuring early, medium, and late maturation periods with coexisting indica, japonica, and glutinous rice varieties.

To reduce data variation from different survey regions, this study selected the concentrated double-cropping rice area in eastern Hubei hilly land as the survey object. This area includes 11 counties: Tuanfeng, Xishui, Qichun, Wuxue, Huangmei, Xinzhou, Huangpi, Daye, Ezhou, Xiaonan, and Xiaochang, with 470,000 hectares of cultivated land, including 330,000 hectares of paddy fields (70% of cultivated area). Rice total output accounts for 85% of annual grain output. The average annual temperature is 16.2-17.0°C, annual active accumulated temperature exceeds 5,200°C, and average annual rainfall is over 1,100 mm.

The study analyzed data from 2013-2014. Organic rice cultivation enterprises with existing organic certification in the study area were randomly selected. Re-

source utilization data during organic rice cultivation were obtained through analysis of cultivation operation procedures and farming records, field observations, and interviews with enterprise internal organic inspectors. Conventional rice fields surrounding the surveyed enterprises were randomly selected, with resource utilization data obtained through household questionnaires and field observations. Soil and water physicochemical properties of conventional and organic rice fields were obtained through field sampling and laboratory analysis. Meteorological data were sourced from the China Meteorological Data Sharing Service System and China Meteorological Data Network. A total of 70 enterprises or households were surveyed, with 39 valid samples remaining after eliminating invalid samples. This included 8 organic rice cultivation samples (4 with organic certification less than 3 years, 3 certified for 3-6 years, and 1 certified for over 6 years) and 31 conventional rice cultivation samples.

Establishing a scientific and feasible evaluation index system is crucial for agricultural resource utilization efficiency assessment. This study comprehensively analyzed existing index systems [11-13,15-20], combined with systematic analysis of agricultural production processes in the survey area (Fig. 1 [Figure 1: see original paper]), to construct an agricultural resource utilization efficiency evaluation system framework (Fig. 2 [Figure 2: see original paper]). Through objective analysis, indicators irrelevant to this study and overlapping indicators were removed from existing systems, while characteristic rice cultivation evaluation indicators were added to initially formulate the evaluation index system. Finally, opinions from local farmers, enterprises, and agricultural experts were extensively collected, and the Delphi method and principal component analysis were used to optimize the index system, establishing a scientific, rational, and operable evaluation index system consistent with actual agricultural development conditions in the survey area.

Weight coefficients for each index system were obtained using a combination of the Delphi method and Analytic Hierarchy Process (AHP). Expert opinions were solicited through multiple questionnaires, with Saaty's method used to assign values through pairwise comparison of the importance of lower-level evaluation indicators relative to higher-level indicators, constructing judgment matrices. The geometric mean method was used to determine weights and conduct consistency tests on judgment matrices. The agricultural resource comprehensive utilization efficiency evaluation index system and its weights are shown in Table 1. This process was completed using the AHP software yaahp V7.5. Evaluation methods for each indicator combined specific numerical calculations with subjective scoring to balance evaluation result accuracy with operational feasibility.

Fig. 1 Systematic analysis of the agricultural production process in the investigated area [Figure 1: see original paper]

Fig. 2 Framework of evaluation system for comprehensive use efficiency of agricultural resources [Figure 2: see original paper]

Based on the evaluation index system, a multi-factor comprehensive evaluation model was used to assess agricultural resource comprehensive utilization efficiency under conventional and organic cultivation models [21], expressed as:

$$P = \sum_{i=1}^n W_i \sum_{j=1}^m W_{ij} X'_{ij}$$

where:

P is the agricultural resource comprehensive utilization efficiency evaluation score,

W_i is the weight of criterion layer factor i ,

W_{ij} is the weight of indicator layer j under criterion layer factor i ,

X'_{ij} is the standardized value of indicator layer j under criterion layer factor i .

To eliminate the influence of different indicator dimensions on evaluation results, each indicator was first processed for direction consistency before linear transformation standardization using the formula:

$$y_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$$

where y_{ij} is the standardized indicator value and x_{ij} is the original indicator value.

3. Results and Analysis

Agricultural resources encompass natural and socioeconomic resources involved in agricultural natural and economic reproduction processes. Natural resources such as land, soil, and climate directly affect plant growth and belong to agricultural natural resources [11]. Land provides growth space, soil provides nutrients and water, and climate provides light energy, heat, and precipitation. Therefore, climate resources, land resources, and water resources all carry relatively high weights in the established evaluation system (16%, 24%, and 19%, respectively) (Table 1).

3.1 Climate Resource Utilization Efficiency

Evaluation results show that organic rice cultivation climate resource evaluation factor scores gradually increase with organic cultivation duration (0.131 for <3 years, 0.143 for 3-6 years, and 0.156 for >6 years), yet all remain lower than conventional cultivation (0.160). This is reflected in three aspects: light use efficiency, heat output rate, and precipitation output rate (Table 2). Since the survey area was limited to a relatively small region with minimal climate differences, rice yield became the main factor affecting climate resource utilization efficiency. Yield has always been the primary issue facing world agriculture. Since organic agriculture's inception, whether crops can achieve high yields

under organic cultivation has attracted considerable attention. In this study, the average annual yield of organic rice samples was approximately $8.0 \text{ t} \cdot \text{hm}^{-2}$, only 87% of conventional rice yield, consistent with some existing research results [22-23]. However, other reports indicate organic cultivation yields higher than conventional [24-25]. Notably, the surveyed organic rice cultivation duration was relatively short, and the view that organic agriculture yields are low is mostly based on comparisons with conventional cultivation within the first few years after organic conversion. Organic cultivation systems represent a rapid ecosystem change process under artificial control that requires time to reach a stable state. Therefore, during the conversion period from establishment to equilibrium, yields are inevitably affected by multiple factors both within and outside the organic system [26]. Generally, crop yields fluctuate significantly and remain lower than conventional levels during the first 2-5 years of organic system establishment. After 5 years, organic cultivation yields stabilize, become less susceptible to external factors, and show stronger resistance to adverse climate and pests [26]. This perspective aligns with our findings, as rice yields gradually improved with extended organic cultivation duration. This suggests that as organic cultivation continues, evaluation scores for climate resource utilization efficiency in Hubei Province's organic rice cultivation are expected to gradually improve.

3.2 Water Resource Utilization Efficiency

For water resource evaluation factors, organic cultivation scores were 0.171 (<3 years), 0.171 (3-6 years), and 0.187 (>6 years), compared to 0.170 for conventional cultivation. Conventional rice is mostly cultivated by scattered smallholders using flooding irrigation, while organic cultivation typically follows a company-plus-farmer model. With unified planning and greater capital availability, organic rice cultivation usually incorporates water-saving irrigation facilities and enables more refined management, such as "wet irrigation" or "intermittent irrigation," directly reflected in higher irrigation indices for organic rice cultivation (Table 2). Research shows that "wet irrigation" and "intermittent irrigation" reduce rice water consumption by 32% while maintaining nearly identical yields [27]. However, water productivity in organic cultivation using these new irrigation technologies was not higher than conventional cultivation in this study, again attributable to lower organic rice yields.

3.3 Land Resource Utilization Efficiency

Land resource evaluation factors are assessed through reclamation rate, land productivity, and multi-cropping index (Table 1). Evaluation scores ranked from highest to lowest as: >6 years organic cultivation (0.232), conventional cultivation (0.224), 3-6 years organic cultivation (0.221), and <3 years organic cultivation (0.210) (Table 2). Organic cultivation achieved higher reclamation rates due to rational planning and larger field areas, while conventional cultivation fields were more scattered and irregular. Additionally, organic cultivation

models emphasized soil fertility improvement, promptly planting green manure such as alfalfa after rice harvest, whereas conventional models mostly left fields fallow during the off-season, reflected in higher multi-cropping indices for organic cultivation. However, lower organic rice yields still reduced scores for land productivity.

3.4 Biotic Resource Utilization Efficiency

Biotic (crop) resources also belong to agricultural natural resources. This study evaluated them through biodiversity index, biological economic index, and straw return rate (Table 1). Higher farmland vegetation diversity benefits ecological regulation of insects [28], playing a role in integrated pest management. Survey results showed higher farmland vegetation diversity indices under organic cultivation (Table 2), manifested not only in more weed species in fields and ridges, larger hedgerows, and more trees, but also in greater crop variety cultivation. The biological economic coefficient reflects the economic output characteristics of biological varieties and is closely related to agricultural production benefits, thus carrying relatively high combined weight (0.0825) (Table 2). Although land productivity was lower under organic cultivation, significantly higher organic rice prices substantially improved the biological economic coefficient (Table 2). Organic cultivation generally achieved full straw return (100% straw return rate), which not only improves soil fertility and increases soil carbon pools but also reduces greenhouse gas emissions, benefiting farmland sustainable development [29]. Overall, organic cultivation scores for biotic resource utilization efficiency were 0.138 (<3 years), 0.141 (3–6 years), and 0.150 (>6 years), all significantly higher than conventional cultivation (0.099).

3.5 Labor Input Efficiency

Humans improve agricultural effective output through rational labor, science and technology, information, and management inputs to natural production processes, representing socioeconomic resources in agriculture [11]. This study evaluated labor input factors through input-output ratio, labor productivity, science and technology contribution rate, and agricultural commodity rate (Table 1). Evaluation results showed lower input-output ratios under organic cultivation, particularly evident in the initial years (Table 2). This resulted from both lower organic rice yields and higher agricultural input costs. Since pesticides and fertilizers used in organic cultivation must comply with organic agriculture standards and specifications, their actual purchase costs are higher. Furthermore, most surveyed organic enterprises only engaged in cultivation, requiring external purchase of organic fertilizers. Extending organic industry chains to include breeding and processing could reduce external input costs through internal material cycling. Organic cultivation scored higher than conventional in science and technology contribution rate (Table 2), indicating new technologies and methods are widely applied and recognized in organic agriculture. While new technologies can improve natural resource utilization efficiency, their higher

transformation costs reduce socioeconomic resource utilization efficiency. For example, some enterprises installed solar insect traps for pest control, reducing pesticide use but with installation and maintenance costs exceeding reduced pesticide expenses. Additionally, restrictions on agricultural inputs in organic cultivation increased labor input per unit area, with manual weeding required every 20 days, resulting in significantly lower labor productivity than conventional cultivation. This aligns with Huang Huiying's [30] view that organic agriculture is labor-intensive, but also suggests organic agriculture development helps alleviate local employment pressures. Survey results showed organic agricultural product commodity rates of approximately 45%, only half that of conventional cultivation (Table 2), reflecting current organic product sales conditions in China. Due to limited consumer awareness, high organic product prices, and irrational product structures [31], organic products perform poorly in general markets, mostly targeting high-end consumers or direct enterprise/institution orders. However, this situation will gradually improve as public awareness of organic food increases, organic certification systems improve, and organic product varieties diversify. Overall, organic cultivation scores for labor input evaluation factors were 0.148 (<3 years), 0.151 (3-6 years), and 0.151 (>6 years), higher than conventional cultivation (0.144), though differences among different organic cultivation durations and conventional cultivation were minimal.

3.6 Resource Sustainability

Only through sustainable utilization of agricultural development resources can agricultural sustainability be achieved, which is the goal of developing alternative agricultures such as organic agriculture. However, existing agricultural resource utilization efficiency evaluation index systems mostly consider only soil fertility changes, without treating resource sustainability as a separate evaluation factor. This study incorporated resource sustainability into the criterion layer, examining it through soil nutrient balance, water environmental quality, and resource stability (Table 1). Since soil and water environment baseline conditions varied across survey sites, potentially compromising data comparability, this study used subjective scoring for evaluation. Results showed organic cultivation improved soil to some extent, manifested in increased soil organic matter and total nutrient content. For conventional cultivation, while heavy chemical fertilizer use maintained soil nutrient content, soil organic matter remained in deficit. Similarly, heavy chemical fertilizer use in conventional cultivation also caused some groundwater/surface water pollution. No difference existed between organic and conventional cultivation in resource stability. Overall, organic cultivation scores for resource sustainability evaluation factors were significantly higher than conventional cultivation.

3.7 Comprehensive Agricultural Resource Utilization Efficiency

The comprehensive agricultural resource utilization efficiency score was 0.867 for <3 years organic cultivation, similar to conventional cultivation (0.857). How-

ever, evaluation scores gradually increased with organic cultivation duration, reaching 0.976 for >6 years organic cultivation, a 14% improvement over conventional cultivation (Table 2). This indicates organic agriculture is superior to conventional agriculture in resource utilization efficiency, though this difference is not obvious in the early stages of organic cultivation. The advantages of organic models in resource utilization gradually emerge with extended cultivation duration, which is also the process of gradually improving organic cultivation yields. Notably, standards for measuring efficient agricultural resource utilization should include: 1) resource conservation and high utilization efficiency; 2) effective resource utilization and high output rates; 3) high economic efficiency with low input and high output; 4) sustainable resource utilization without degradation or depletion; and 5) maintenance of high-quality agricultural ecological environments [32]. However, existing evaluation index systems have not sufficiently emphasized maintaining high-quality agricultural environments. Although this study separately proposed resource sustainability as an evaluation factor, its weight was not high (10%), diluting the most significant characteristic of organic agriculture—its profound environmental protection culture [7]—and somewhat affecting evaluation accuracy of organic agriculture resource utilization efficiency. How to quantitatively evaluate the environmental value generated by organic agriculture requires more extensive research.

Table 2 Evaluation results of comprehensive utilization efficiency of agricultural resources of organic cultivation for different years and conventional cultivation of rice in Hubei Province

This study established a comprehensive evaluation index system for agricultural resource utilization applicable to organic and conventional rice cultivation based on existing research, conducting empirical research in Hubei Province. Results showed organic rice cultivation resource utilization efficiency scores were comparable to conventional rice cultivation in the initial stage, but organic model advantages gradually manifested with extended cultivation duration. Overall, the main factors limiting organic rice cultivation resource utilization efficiency were lower rice yields and higher agricultural input costs. Therefore, to further improve resource utilization efficiency in organic cultivation, future development should consider: 1) gradually improving organic product yields; 2) perfecting organic market systems to increase organic product commodity rates; 3) gradually reducing science and technology transformation costs through policy support; and 4) extending organic industry chains to reduce agricultural input costs through internal material cycling. Finally, incorporating environmental value into accounting systems in future research will facilitate more comprehensive and accurate evaluation of organic agriculture's comprehensive natural resource utilization efficiency.

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