Comprehensive Evaluation of Eco-Economic Benefits of Multiple Cropping-Rotation Systems in Paddy Fields: Postprint

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Abstract

To screen for sustainable winter green efficient cyclic compound planting patterns suitable for the Poyang Lake Ecological Economic Zone, a comprehensive evaluation of the ecological and economic benefits of five paddy field multiple-cropping rotation patterns in the Poyang Lake Ecological Economic Zone (fallow-winter-rice-rice → fallow-winter-early rice-late rice, green manure-early rice-late rice → rapeseed-corn||soybean-late rice, rapeseed-corn||soybean-late rice, broad bean-early rice-sweet potato||corn → vegetable-sugarcane||soybean, vegetable-sugarcane||soybean → green manure-early rice-late rice) was conducted through continuous two-year field location experiments from 2012 to 2013 using the AHP method and comprehensive index method. The results showed that after conversion based on the price ratio of late rice, the vegetable-sugarcane||soybean planting pattern achieved the highest crop yield among all patterns during the two-year period, followed by green manure-early rice-late rice, while the broad bean-early rice-sweet potato||corn pattern had the lowest crop yield. The comprehensive evaluation of ecological and economic benefits indicated that in 2012, the ranking of comprehensive benefit indices for each system was: vegetable-sugarcane||soybean > rapeseed-corn||soybean-late rice > broad bean-early rice-sweet potato||corn > green manure-early rice-late rice > fallow-winter-early rice-late rice, demonstrating that the vegetable-sugarcane||soybean planting pattern, which involves "changing rice to cash crops," is a planting pattern that can promote high yield and high efficiency in paddy fields and is conducive to the sustainable development of agricultural production. In 2013, after paddy field multiple-cropping rotation, the comprehensive benefit indices of each system were: green manure-early rice-late rice > vegetable-sugarcane||soybean > rapeseed-corn||soybean-late rice > broad bean-early rice-sweet potato||corn > fallow-winter-early rice-late rice, indicating that the green manure-early rice-late rice planting pattern with winter Chinese milk vetch in paddy fields can balance the three major benefits and is conducive to the sustainable development of

agricultural production. From the perspective of two-year comprehensive benefit results, the vegetable-sugarcane||soybean → green manure-early rice-late rice pattern can promote high yield and high efficiency in paddy fields, balance economic, ecological, and social benefits, address social issues such as food security, agricultural structure adjustment, and farmers' income increase, and also greatly promote winter agricultural development, full utilization of natural resources, and sustainable agricultural production. In summary, the vegetable-sugarcane||soybean → green manure-early rice-late rice pattern is a paddy field winter agricultural development and multiple-cropping rotation cycle pattern suitable for large-scale promotion and application in the Poyang Lake Ecological Economic Zone of China.

Full Text

Comprehensive Evaluation of Eco-Economic Benefits of Multi-Crop Rotation in Paddy Field Systems

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Abstract

To identify sustainable, green, and efficient winter multiple-cropping rotation patterns suitable for the Poyang Lake Eco-Economic Zone, we conducted a comprehensive evaluation of the eco-economic benefits of five paddy field rotation systems through two consecutive years of field experiments (2012-2013) using the Analytic Hierarchy Process (AHP) and comprehensive index method. The five rotation patterns evaluated were: (1) winter fallow-early rice-late rice → winter fallow-early rice-late rice, (2) green manure-early rice-late rice → rapeseed-maize||soybean-late rice, (3) rapeseed-maize||soybean-late rice, (4) faba bean-early rice-sweet potato||maize → vegetables-sugarcane||soybean, and (5) vegetables-sugarcane||soybean → green manure-early rice-late rice.

When crop yields were converted to comparable units based on late rice price equivalents, the vegetables-sugarcane||soybean pattern consistently produced the highest yields across both years, followed by the green manure-early rice-late rice system, while the faba bean-early rice-sweet potato||maize pattern yielded the lowest. The comprehensive eco-economic benefit evaluation revealed that in 2012, the overall benefit index ranked as: vegetables-sugarcane||soybean > rapeseed-maize||soybean-late rice > faba bean-early rice-sweet potato||maize > green manure-early rice-late rice > winter fallow-early rice-late rice. This indicated that the vegetables-sugarcane||soybean pattern, which "transforms

rice cultivation into economic crops," represented a high-yield, high-efficiency system conducive to sustainable agricultural development.

In 2013, after implementing the rotation sequence, the ranking shifted to: green manure-early rice-late rice > vegetables-sugarcane||soybean > rapeseed-maize||soybean-late rice > faba bean-early rice-sweet potato||maize > winter fallow-early rice-late rice, demonstrating that the winter milk vetch green manure pattern could balance all three benefit dimensions. Across the two-year study period, the vegetables-sugarcane||soybean → green manure-early rice-late rice rotation system proved most effective, simultaneously enhancing economic, ecological, and social benefits while addressing food security, agricultural restructuring, and farmer income challenges. This pattern also promoted winter agricultural development, optimized natural resource utilization, and supported sustainable agricultural production, making it suitable for large-scale application in the Poyang Lake Eco-Economic Zone.

Keywords: Poyang Lake Eco-Economic Zone; paddy field; multiple cropping rotation; eco-economic benefits; comprehensive evaluation

1.2.3 Planting Methods

Growing Season Crop Management: In 2012, early rice was sown on March 26, transplanted on April 15, and harvested on July 10; late rice was sown on June 10, transplanted on July 13, and harvested on November 3. In 2013, early rice was sown on March 23, transplanted on April 12, and harvested on July 13; late rice was sown on June 12, transplanted on July 14, and harvested on November 5. For secondary crops in 2012, sugarcane was sown on March 20, transplanted on April 22, and harvested on December 2; maize and soybean were sown on April 22 and harvested on June 25; sweet potato was planted on July 15 and harvested on November 5. In 2013, sugarcane was sown on March 25, transplanted on April 15, and harvested on December 6; maize and soybean were sown on April 15 and harvested on June 20; sweet potato was planted on July 18 and harvested on November 10.

Winter Crop Management: Milk vetch was broadcast-seeded in late September to early October each year, while rapeseed, faba bean, and vegetable crops were sown in mid-November after late rice harvest. All winter crops were measured for yield and incorporated into the soil 15 days before early rice transplanting in the following year, with a single application of paraquat for weed control before plowing. Seeding rates were 37.5 kg · hm ^{2} for milk vetch and 7.5 kg · hm ^{2} for rapeseed. After milk vetch seeding, fields were immediately irrigated to maintain a shallow water layer for 2 days, with other management following conventional practices. Rapeseed received calcium-magnesium phosphate fertilizer at 150 kg · hm ^{2} as basal dressing, plus potassium chloride (250 kg · hm ^{2}) and urea (80 kg · hm ^{2}) as topdressing. Faba bean received calcium-magnesium phosphate (375 kg · hm ^{2}) and potassium chloride (75 kg · hm ^{2}) and urea (75 kg · hm ^{2}) with a basal:topdressing ratio of 1:2. No fertilizer was applied to milk vetch. All winter crops (milk vetch, rapeseed, faba bean, and vegetables) were returned to the field as green manure at maturity.

Rice Fertilization: Both early and late rice received urea (N 46%), calcium-magnesium phosphate (P O 12%), and potassium chloride (K O 60%) at annual rates of N:P O :K O = 150 kg • hm ²:90 kg • hm ²:120 kg • hm ². Nitrogen application followed a basal:tillering:panicle ratio of 6:3:1 for early rice and 5:3:2 for late rice. Phosphorus was applied entirely as basal fertilizer, while potassium was split between tillering and panicle stages at a 7:3 ratio. Basal N and P fertilizers were applied one day before transplanting, tillering fertilizer at 5–7 days after transplanting, and panicle fertilizer when the main stem panicle reached 1–2 cm. Other cultivation practices followed standard local methods.

1.3.1 Crop Yield Assessment

To enable standardized comparison across different crops, economic yields were converted to late rice price equivalents based on market prices. Rice yields were measured by harvesting entire plots at maturity. Maize yields were determined using five-point sampling, collecting 20 ears per plot, shelling, drying, and weighing. Soybean yields were measured by harvesting 20 plants per plot, removing pods, drying, and weighing. Sweet potato yields were assessed by harvesting 20 tubers per plot, washing, drying, and weighing. Sugarcane yields were measured by harvesting and weighing 5 stalks per plot. Winter green manure crops (milk vetch, rapeseed, faba bean, vegetables) were sampled using five-point quadrats (1 m^2 each) at maturity to determine fresh weight.

1.3.2 Evaluation Factor Weights and Comprehensive Assessment Method

All material inputs, labor investments, and product outputs were recorded to calculate input-output balances based on prevailing agricultural prices. The Analytic Hierarchy Process (AHP) and comprehensive index method were employed to determine indicator weights and conduct integrated evaluations. The comprehensive benefit of winter multiple-cropping rotation systems in double-rice paddy fields comprises three dimensions: economic, ecological, and social benefits. To ensure scientific rigor and completeness, evaluation factors were selected through frequency statistics, theoretical analysis, and expert consultation. Preliminary factors underwent principal component analysis to merge or eliminate minor or irrelevant indicators, resulting in a concise yet comprehensive evaluation index system.

AHP was used to scientifically determine factor weights based on existing literature and researcher experience. The final screened index system with AHP-calculated weights is presented in . The comprehensive index method was applied to evaluate system benefits using the formula:

$iV = \Sigma(W \times F(X))$

where iV is the comprehensive benefit evaluation index, W is the weight of the j-th indicator, and F(X) is the evaluation function of the j-th indicator. Since indicators have different units and dimensions, direct multiplication of weights and observed values is invalid. Therefore, standardization was applied to transform all indicator observations to a common scale, eliminating dimensional effects through normalization.

2.1 Effects of Winter Multiple-Cropping Rotation Patterns on Crop Yield

Comparative crop yields under different rotation patterns are shown in . Analysis of the same crops across treatments revealed that in both 2012 and 2013, early and late rice yields in the green manure–early rice–late rice pattern (Treatment B in 2012, Treatment E in 2013) exceeded those of the continuous cropping control (winter fallow–early rice–late rice, Treatment A) by 1.6% and 4.4% for early rice, and 1.8% and 3.3% for late rice, respectively. Comparing maize yields between intercropping systems, maize intercropped with soybean (Treatment C in 2012, Treatment B in 2013) produced 12.5% and 8.6% higher yields than maize intercropped with sweet potato (Treatment D in 2012, Treatment C in 2013) in consecutive years. Similarly, soybean intercropped with maize yielded 80.6% and 69.2% more than soybean intercropped with sugarcane (Treatment E in 2012, Treatment D in 2013), indicating that sugarcane intercropping negatively affected soybean growth. These results demonstrate that the maize||soybean intercropping system achieved relatively high yields for both component crops.

For cross-crop comparison, yields of maize, soybean, sweet potato, sugarcane, and early rice were converted to late rice equivalents based on price ratios. In 2012, the ranking of converted yields was: E > B > A > C > D, with the vegetables–sugarcane||soybean pattern producing the highest yield—8.2%, 11.5%, 33.0%, and 38.1% higher than Treatments B, A, C, and D, respectively—and showing significant differences from Treatments C and D ($P < 0.05$). The faba bean–early rice–sweet potato||maize pattern yielded the lowest. In 2013, the ranking was D > E > A > B > C, again with vegetables–sugarcane||soybean showing the highest yield and significant differences from all other treatments, followed by green manure–early rice–late rice, while faba bean–early rice–sweet potato||maize remained lowest. The poor performance of the sweet potato||maize system may be attributed to sweet potato being a short-day crop requiring full sunlight; when intercropped with tall crops or under excessive rainfall with poor drainage, both yield and quality were compromised.

2.2 Comprehensive Evaluation of Winter Multiple-Cropping Rotation System Benefits

Following indicator screening and weight determination, the comprehensive index method was applied to evaluate the rotation systems. Initial values of evaluation indicators for each system are presented in . In 2012, Treatment E (vegetables–sugarcane||soybean) showed the highest values for total economic output, net output, soil organic matter content, soil fertility maintenance crop index, and grain yield. Treatment C (rapeseed-maize||soybean-late rice) performed best for material cost-benefit rate, economic output-input ratio, auxiliary energy efficiency, labor net output rate, and technological advancement contribution rate. Treatment B (green manure-early rice-late rice) achieved the highest nitrogen output-input ratio, while Treatment D (faba bean-early rice-sweet potato||maize) excelled in land equivalent ratio and solar energy utilization rate.

In 2013, Treatment B (rapeseed-maize||soybean-late rice) showed optimal performance for total economic output, net output, material cost-benefit rate, economic output-input ratio, land equivalent ratio, solar energy utilization rate, and technological advancement contribution rate. Treatment D (vegetables-sugarcane||soybean) led in organic matter content, soil fertility maintenance crop index, and grain yield. Treatment E (green manure-early rice-late rice) achieved the highest nitrogen output-input ratio and labor net output rate, while Treatment B showed maximum auxiliary energy efficiency.

Using the values from and standardized values from , comprehensive benefit indices were calculated and presented in . In 2012, individual benefit indices ranked as follows: economic benefit—E > C > D > B > A; ecological benefit—E > D > C > B > A; social benefit—E > B > C > D > A. However, single-dimension indices only reflect partial system functions and may lead to contradictory conclusions. The comprehensive benefit index better captures overall system performance by integrating all dimensions for objective scientific evaluation. The 2012 comprehensive ranking was: E > C > D > B > A, confirming that the vegetables-sugarcane||soybean pattern, which "transforms rice cultivation into economic crops," represents a high-yield, high-efficiency system supporting sustainable agriculture.

In 2013, individual benefit indices were: economic benefit—B > E > C > D > A; ecological benefit—E > D > B > C > A; social benefit—D > E > B > C > A. The comprehensive ranking was: E > D > B > C > A, demonstrating that the winter milk vetch green manure pattern (green manure-early rice-late rice) effectively balanced all three benefit dimensions. Across the two-year rotation cycle, the vegetables-sugarcane||soybean → green manure-early rice-late rice pattern showed the most significant comprehensive benefits, simultaneously addressing grain security, agricultural restructuring, and farmer income while promoting winter agricultural development, natural resource utilization, and sustainable production. This rotation system is therefore recommended for large-scale application in the Poyang Lake Eco-Economic Zone.

Recent studies have evaluated ecosystem benefits from economic, ecological, and social perspectives. However, China' s diverse regional environments and long cultivation histories have hindered development of universally applicable evaluation frameworks, limiting cross-case comparisons and theoretical standardization. This represents a limitation of the current study. Future research should apply consistent functional value assessment systems to similar paddy field rotation patterns in other regions to derive more generalizable conclusions.

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Note: Figure translations are in progress. See original paper for figures.