Effects of Mixed Cropping of Different Rice Varieties with Duck Farming on Soil Nutrient Dynamics: Postprint

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Date: 2017-11-08T00:00:00+00:00

Abstract

Both rice-duck co-cultivation and rice variety mixing can produce favorable ecological effects; however, whether these two techniques can be combined—through the superposition of different rice variety mixing and paddy field duck farming—to generate "1+1>2" ecological effects and production benefits is a subject worthy of practical investigation and exploration. To ascertain the application feasibility of this compound biodiversity utilization model of multi-variety rice mixing with duck farming, this experiment established seven planting patterns for field trials: rice monoculture conventional planting (with pesticide and fertilizer application), rice monoculture with duck farming, rice monoculture blank control (no duck farming, no fertilizer or pesticide), rice variety mixing conventional planting (with pesticide and fertilizer), rice variety mixing with duck farming, and rice variety mixing blank control (no duck farming, no fertilizer or pesticide), to investigate the effects of different rice variety mixing with duck farming on soil nutrient dynamics and v

Full Text

Preamble

Effect of Rice Varieties Mixed-Cropping with Duck Raising on Nutrient Dynamics in Paddy Soils

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Abstract: Both rice-duck farming and rice variety mixed-cropping can produce excellent ecological effects. However, it remains largely unclear whether the synergy of these two farming systems could achieve a "1+1>2" effect on ecological conditions and production efficiency when implemented concurrently. To explore the feasibility of this compound biodiversity utilization model, we conducted field experiments with six planting patterns: conventional monoculture with chemical inputs (SC), monoculture with duck raising (SD), monoculture control without chemicals or ducks (CK1), mixed-cropping with conventional farming (MC), mixed-cropping with duck raising (MD), and mixed-cropping control (CK2). Results showed that after double rice cropping, soil organic matter content under MD was significantly higher than other treatments. During both early and late rice seasons, soil total nitrogen under MD was lower than MC but significantly higher than other treatments, while alkali-hydrolyzable nitrogen was significantly increased. After late rice harvest, total phosphorus under mixed-cropping with ducks was significantly higher than conventional systems, with mixed-cropping showing higher average available phosphorus than monoculture. Total and available potassium contents were also highest under MD. MD treatment yielded higher brown rice rate, milled rice rate, amylose content, and gel consistency, with lower chalky rice rate. The integrated system of mixed rice varieties with duck raising thus improves soil nutrient status and rice quality, providing a new approach for producing healthy, high-quality rice.

Keywords: Integrated rice-duck farming; Rice varieties mixed-cropping; Soil nutrient dynamics; Rice grain quality

Introduction

Rice (*Oryza sativa* L.) is a staple food crop in China. Utilizing diversity cultivation and integrated farming systems to improve rice yield, grain quality, and pest resistance has been a major research focus. However, long-term monoculture of high-yield varieties with intensive chemical inputs has reduced agricultural biodiversity, disrupted ecosystem balance, and increased pest outbreaks. Heavy pesticide use has further exacerbated environmental pollution and food safety concerns. Consequently, intercropping and integrated farming systems have gained attention as strategies to enhance biodiversity, control pests, and reduce chemical inputs.

Over the past decade, rice-duck farming has been widely adopted in China, Japan, and Southeast Asia. Research demonstrates significant benefits in nutrient cycling, pest and weed control, water environment regulation, rice physiology, greenhouse gas mitigation, and grain quality improvement. Meanwhile, mixed-cropping (or intercropping) of multiple rice varieties—planting varieties with similar growth periods and agronomic traits but different resistance genes in specific ratios—has shown promise. Studies indicate that variety mixing enhances compensatory growth, improves light interception, optimizes resource utilization, and increases yield. The biodiversity and complementary mechanisms also help control pests and diseases, reducing pesticide use. For instance, mixing weed-tolerant varieties with allelopathic varieties can improve weed suppression.

Given the ecological benefits of both systems, combining them—through the 叠加 (stacking) of variety diversity and species diversity (mixed rice varieties + duck raising)—could potentially generate synergistic "1+1>2" effects. This study investigates whether this integrated approach can improve soil nutrient conditions and rice quality, aiming to validate the feasibility of this compound biodiversity model for producing healthy, safe rice.

1.1 Study Site Overview

The experiment was conducted at the Zengcheng Teaching and Research Base of South China Agricultural University in Zengcheng District, Guangzhou, Guangdong Province. Located in a low hilly area with a south subtropical monsoon climate, the site features abundant sunlight, mild temperatures, ample rainfall, and rich heat resources. The annual average temperature is 21.8°C, frost-free period extends 335-360 days, annual precipitation averages 2,137 mm, and relative humidity is 78%. The experimental field consisted of paddy soil developed from latosolic red earth.

1.2 Experimental Materials

Two rice varieties were selected: (1) 'Shengbasimiao' (certification No.: Yueshendao 2005002), a high-quality indica rice suitable for both early and late seasons, with a growth period of approximately 125 days for early rice and 109-115 days for late rice. This variety has relatively tall plants (106.7-109.8 cm), lower yield, high resistance to rice blast, susceptibility to bacterial leaf blight, and good overall quality except for slightly low amylose content. (2) 'Huajingxian 74' (certification No.: Yueshendao 200002), a high-yield variety with a growth period of about 130 days for early rice and 115 days for late rice, plant height around 100 cm, high resistance to both rice blast and bacterial leaf blight, and relatively high amylose content.

1.3.1 Mixed Variety Combinations and Experimental Plots

The field experiment employed a randomized block design with three production methods: blank control, conventional cultivation, and rice-duck farming. Each method included two treatments: 'Shengbasimiao' monoculture, and mixed-cropping of 'Shengbasimiao' and 'Huajingxian 74' (mixed 1:1 by weight before sowing, hereafter "rice mixed-cropping"). These combinations formed six treatments, each with three replications, totaling 18 plots of 80 m^2 each. 'Shengbasimiao' was planted as border rows. The design allowed comparison between monoculture vs. mixed-cropping, and duck vs. non-duck systems.

1.3.2 Field Management

Rice was transplanted at a spacing of 28 cm × 22 cm. All plots received chicken manure (approximately 50 kg per plot) before transplanting. Early and late rice seeds were soaked on March 15 and July 30, respectively, and seedlings were raised for about 20 days. Fields were plowed on April 1 and August 15, with basal fertilizer application and transplanting on April 5 and August 19. Blank control and duck treatments received no chemical fertilizers, pesticides, or herbicides throughout the rice growth period. Conventional treatments received herbicide (50% butachlor emulsifiable concentrate) on April 12 and August 28, pesticide (50% dimethoate emulsifiable concentrate) on April 20, May 20, September 15, and October 8, and compound fertilizer (Batian 1+1, 18-8-15) at 4.0 kg per plot during the first pesticide application.

For duck treatments, ducklings (3 per plot) were released approximately one week after transplanting, with 50 cm-high nylon nets preventing escape. Ducks were removed at full heading stage (June 10 for early rice, October 18 for late rice). During the co-culture period, water depth was maintained at 6–8 cm; after duck removal, fields were drained. All treatments were drained three weeks before harvest, with 3–5 cm water depth maintained at other times. After each rice season, straw was returned to the field and the soil was harrowed.

1.4.1 Soil Physicochemical Property Measurement

Soil samples were collected four times: one week after transplanting (recovery stage) and one week after duck removal (full heading stage) for both early and late rice, on April 20, June 17, September 1, and October 25. Parameters included soil organic matter, total nitrogen, alkali-hydrolyzable nitrogen, total phosphorus, available phosphorus, total potassium, and available potassium. Samples were collected using a soil auger at five points per plot in a quincunx pattern, from the 0–15 cm layer (approximately 0.25 kg per point). Samples were mixed, air-dried, and plant residues and stones removed. The quartering method was used to obtain representative subsamples, which were passed through 18-mesh (for available nutrients) or 100-mesh (for total nutrients) sieves. Analytical methods followed Bao Shidan' s *Soil and Agricultural Chemistry Analysis*. Organic matter was determined by potassium dichromate volumetry (dilution-heat method), total nitrogen by Kjeldahl digestion, total phosphorus by $HClO_4$-H_2SO_4 digestion, total potassium by NaOH fusion-flame photometry, alkali-hydrolyzable nitrogen by alkaline hydrolysis diffusion, available phosphorus by 0.5 $mol \cdot L^{-1}$ $NaHCO_3$ extraction, and available potassium by NH_4OAc extraction-flame photometry.

1.4.2 Rice Quality Measurement

The experiment was conducted during the 2009 early and late rice seasons. After harvest, rice grains were air-dried and stored for three months before quality analysis. Brown rice rate, milled rice rate, head rice rate, length-width ratio, and chalky rice rate were measured according to the Ministry Standard NY147—88 (with minor modifications). Amylose content and gel consistency were determined using a FOSS-TECATOR Infratec 1241 near-infrared grain analyzer.

1.5 Data Analysis

All data were analyzed using SPSS 17.0 software. One-way ANOVA was used to test for significant differences in soil chemical properties and rice quality among treatments, with means separated by LSD test at $P < 0.05$.

2.1.1 Effects on Soil Organic Matter Content

As shown in [Figure 1: see original paper], soil organic matter content across treatments followed a consistent trend: initial increase, then decrease, followed by another increase, with overall accumulation after double rice cropping. Before early rice harvest (June 20), organic matter under duck treatments (both monoculture and mixed-cropping) was significantly higher than other treatments, exceeding conventional monoculture, conventional mixed-cropping, and blank controls by 13.93%, 7.45%, and 17.35%, 15.59%, respectively. During late rice growth (September 1–October 22), mixed-cropping with ducks remained significantly higher than all other patterns, indicating that combining mixed-cropping with duck farming enhances soil organic matter accumulation.

2.1.2 Effects on Soil Total Nitrogen and Alkali-Hydrolyzable Nitrogen

Soil total nitrogen showed a general decline followed by an increase across treatments [Figure 2: see original paper]. Before early rice harvest, the ranking was: conventional mixed-cropping > duck monoculture > conventional monoculture > mixed-cropping with ducks > mixed-cropping control > monoculture control. After double rice cropping, total nitrogen under mixed-cropping (both conventional and with ducks) was not significantly different between these two treatments but was significantly higher than others. Mixed-cropping controls also exceeded monoculture controls, suggesting that variety mixing and duck farming help stabilize soil total nitrogen.

Alkali-hydrolyzable nitrogen [Figure 2: see original paper] in conventional and duck monoculture treatments showed continuous increase, while blank controls fluctuated. After two seasons, mixed-cropping with ducks achieved the highest alkali-hydrolyzable nitrogen content, significantly exceeding duck monoculture by 5.72%. Mixed-cropping conventional exceeded monoculture conventional by 1.20%, and mixed-cropping control exceeded monoculture control by 16.00%.

These results indicate that mixed-cropping enhances soil available nitrogen, with synergistic effects when combined with duck farming.

2.1.3 Effects on Soil Total Phosphorus and Available Phosphorus

Soil total phosphorus [Figure 3A: see original paper] declined initially then increased gradually across treatments. Before early rice harvest, monoculture control showed the highest content, while after early rice harvest, mixed-cropping control was highest. After late rice harvest, conventional systems had significantly lower total phosphorus than other treatments. Available phosphorus [Figure 3B: see original paper] first increased then decreased. After early rice harvest, mixed-cropping control had the highest available phosphorus. After late rice harvest, both mixed-cropping and monoculture controls exceeded other treatments significantly, though the average available phosphorus under mixed-cropping was slightly higher than monoculture, indicating that mixed-cropping helps maintain higher soil phosphorus availability.

2.1.4 Effects on Soil Total Potassium and Available Potassium

Total potassium [Figure 4A: see original paper] showed similar trends across treatments: initial increase, decrease, then stabilization. After early rice harvest, mixed-cropping with ducks had the highest total potassium. After late rice harvest, the ranking was: mixed-cropping with ducks > mixed-cropping control > monoculture control and duck monoculture > conventional systems (both monoculture and mixed-cropping). This demonstrates that mixed-cropping enhances soil total potassium, promoting potassium absorption and providing a foundation for lodging resistance and yield improvement.

Available potassium [Figure 4B: see original paper] decreased initially, then increased, then decreased again across treatments. During early rice, monoculture control had significantly higher available potassium than others (except mixed-cropping with ducks). After early rice harvest, duck monoculture was highest. After late rice harvest, mixed-cropping with ducks significantly exceeded all other treatments, followed by duck monoculture and mixed-cropping conventional. Mixed-cropping systems consistently outperformed monoculture systems across all production methods, indicating that mixed-cropping can more rapidly and sustainably increase available potassium, providing continuous potassium nutrition for rice growth, with enhanced effects when combined with duck farming.

2.2 Effects of Rice Mixed-Cropping with Duck Raising on Rice Quality

As shown in , after double rice cropping with ducks and mixed varieties, mixed-cropping with ducks achieved the highest brown rice and milled rice rates, significantly exceeding monoculture control and conventional monoculture by 2.03% and 1.98%, and 6.29% and 5.85%, respectively. Head rice rates were higher under mixed-cropping than monoculture, with mixed-cropping with ducks significantly exceeding monoculture control. Length-width ratios were higher under both duck treatments compared to others (except monoculture control). Mixed-cropping with ducks produced the lowest chalky rice rate among all treatments. Amylose content and gel consistency were also highest under mixed-cropping with ducks, significantly exceeding duck monoculture. These results demonstrate that the integrated system improves milling quality (brown and milled rice rates), appearance quality (chalkiness), and maintains optimal amylose content and gel consistency, thereby enhancing overall rice quality.

3 Discussion and Conclusion

Numerous studies have examined the effects of rice mixed-cropping and rice-duck systems on soil nutrients and grain quality, but research on their combined effects remains limited. This study found that after double rice cropping, mixed-cropping with ducks significantly increased soil organic matter, total nitrogen, and alkali-hydrolyzable nitrogen, while improving milling quality (brown and milled rice rates), appearance quality (chalky rice rate), and maintaining favorable amylose content and gel consistency.

The enhanced soil organic matter can be attributed to several factors. Duck manure is a high-quality organic fertilizer containing 255.0 $g \cdot kg^{-1}$ organic matter, 16.4 $g \cdot kg^{-1}$ total nitrogen, 15.4 $g \cdot kg^{-1}$ total phosphorus, and 8.5 $g \cdot kg^{-1}$ total potassium, with each duck producing approximately 100.0 g fresh manure daily. Duck activity also promotes gas exchange between paddy water, soil, and the atmosphere, increasing soil redox potential and dissolved oxygen, which accelerates decomposition of rice straw organic matter. The mixed-cropping with ducks treatment showed significantly higher tillering and biomass, increasing straw return to the field. The combination of variety mixing and duck farming thus created 叠加 (superimposed) positive effects on soil organic matter accumulation.

For soil nitrogen, mixed-cropping (conventional and with ducks) maintained significantly higher total nitrogen than other treatments after double rice cropping. Duck excreta supplemented nitrogen requirements, while duck activity loosened surface soil and promoted mineralization of organic matter and nutrient release, enhancing available nitrogen accumulation. The combination of variety mixing and duck farming further stabilized soil nitrogen status.

Regarding soil phosphorus, mixed-cropping with ducks showed the highest total phosphorus after late rice harvest, significantly exceeding conventional systems. Mixed-cropping maintained higher average available phosphorus than monoculture. While phosphorus demand is low during early growth, it increases during yield formation, leading to decreased available phosphorus. The mixed-cropping system helped sustain higher phosphorus availability throughout the growth period.

For soil potassium, no significant differences in total potassium were observed among treatments after double rice cropping, likely due to straw return. However, available potassium decreased in all treatments after two rice seasons. Under rice-duck systems, duck activity improved soil aeration and accelerated potassium transformation, maintaining significantly higher available potassium. The mixed-cropping system enhanced this effect through improved canopy ventilation from variety differences, promoting potassium availability. The 叠加 (superimposed) effects of mixed-cropping and duck farming on soil potassium were evident.

Rice quality is influenced by both genetic factors and environmental conditions during growth. Under fixed genetic backgrounds, quality is closely related to environmental conditions and cultivation techniques. This study showed that rice-duck farming improved processing quality, consistent with previous research demonstrating that ducks provide biological organic fertilizer through activity and excreta. Blank controls, despite receiving organic manure, suffered from severe pest, disease, and weed pressure without control measures, reducing grain quality. Mixed-cropping reduced pest and disease incidence through complementary resistance mechanisms, improving quality as reported in other studies. The combination of mixed-cropping and duck farming significantly reduced chalky rice rate by removing old leaves, sheaths, and fungal structures, improving canopy ventilation and soil aeration, thereby enhancing grain quality. The maintained amylose content and gel consistency under mixed-cropping with ducks may result from balanced and complementary nutrient uptake between the two varieties.

In conclusion, the integrated system of mixed rice varieties with duck raising improves soil nutrient status and rice quality, generating both ecological benefits and economic value through quality improvement. This approach warrants demonstration and broader application for sustainable, high-quality rice production.

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