Effects of Intercropping Different Rice Varieties with Duck Farming on Soil Nutrient Dynamics (Postprint)

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Abstract

Both integrated duck-rice farming and rice variety mixture cultivation can produce favorable ecological effects. However, whether these two techniques can be combined—through the superposition of different rice variety mixtures and duck farming in paddy fields—to generate an ecological effect and production benefit of "1+1>2" is a topic worthy of practical exploration and investigation. To ascertain the application feasibility of this composite biodiversity utilization pattern of multi-variety rice mixture with duck farming, this experiment established six planting patterns for field trials: conventional monoculture rice (with pesticide and fertilizer application), monoculture rice with duck farming, monoculture rice blank control (no duck farming, no fertilizer or pesticide), rice variety mixture conventional planting (with pesticide and fertilizer), rice variety mixture with duck farming, and rice variety mixture blank control (no duck farming, no fertilizer or pesticide), to investigate the effects of different rice variety mixtures with duck farming on soil nutrient dynamics and rice quality. The results demonstrated that after double-season rice cultivation, soil organic matter content under the rice variety mixture with duck farming treatment was significantly higher than that under other planting patterns. During the growth periods of early and late season rice, soil total nitrogen content under the rice variety mixture with duck farming treatment was lower than that under the rice variety mixture conventional planting treatment, but both were significantly higher than other treatments; soil alkaline-hydrolyzable nitrogen content under the rice variety mixture with duck farming treatment was significantly higher than other treatments. After late rice harvest, soil total phosphorus content under the rice mixture with duck farming planting pattern was significantly higher than that under conventional planting patterns, and mixture treatments exhibited higher average soil available phosphorus content than monoculture treatments. Following double-season rice cultivation, soil total potassium content and available potassium content under the rice variety mixture with duck farming planting pattern were both higher than other treatments. The rice variety mixture with duck farming treatment exhibited higher brown rice rate, milled rice rate, amylose content, and gel consistency than other treatments, and lower chalky grain rate than other treatments. In summary, the rice variety mixture with duck farming pattern is more conducive to improving field soil nutrient status and enhancing rice quality, thus this pattern can provide a novel approach for high-quality healthy rice production.

Full Text

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 when concurrently implemented. To explore the feasibility of this compound biodiversity utilization model, we conducted field experiments with six treatments: conventional monoculture (with pesticides and fertilizers), monoculture with duck raising, monoculture blank control (no ducks or inputs), mixed-cropping of rice varieties with conventional practice, mixed-cropping with duck raising, and mixed-cropping blank control. Results showed that after double rice cropping, soil organic matter content under the mixed-cropping with duck raising treatment was significantly higher than other treatments. During both early and late rice seasons, soil total nitrogen under mixed-cropping with ducks was lower than conventional mixed-cropping 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 monoculture, and average available phosphorus was higher under mixed-cropping than monoculture. Total and available potassium contents were also highest under the mixed-cropping with duck raising treatment. This treatment produced higher brown rice rate, milled rice rate, amylose content, and gel consistency, with lower chalky rice rate. Overall, the integrated system of rice variety mixed-cropping with duck raising improved 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

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Rice (*Oryza sativa* L.) is a major food crop in China. Using diverse cultivation methods and integrated farming systems to increase rice yield, improve grain quality, and enhance resistance has been a research hotspot [1-2]. However, long-term pursuit of high yields and economic benefits has led to large-scale monoculture and intensification, where only a few high-yield or high-value varieties are widely cultivated. This has diminished rice variety diversity and farmland biodiversity, disrupting ecosystem balance and causing frequent pest and disease outbreaks [3-4]. Meanwhile, heavy pesticide use for pest control has increased insect resistance and caused environmental pollution and pesticide residues in agricultural products [5]. Consequently, using intercropping or integrated farming to increase farmland biodiversity for pest control and reduce chemical inputs has become a major research focus worldwide [6].

Over the past decade, rice-duck farming has become widely promoted as an ecological agriculture technology in China, Japan, and Southeast Asia. Chinese researchers have extensively studied its effects and mechanisms on nutrient cycling [7-8], pest and weed control [9-10], water environment [11], rice physiology and ecology [12], greenhouse gas emissions [13-14], and rice quality [15]. Simultaneously, intercropping and mixed-cropping of crops have been widely studied and practiced. Mixed-cropping involves planting multiple varieties with similar growth periods and agronomic traits but different resistance genes in specific proportions [16]. Studies show that mixed-cropping enhances compensatory effects between plant types, improves light interception, utilizes space and natural resources more efficiently, and ultimately increases population yield [17-20]. It also controls pests and diseases through biodiversity and complementary mechanisms, reducing chemical use and environmental impacts [21-22]. Han et al. [23] studied mixed planting of rice varieties with different weed tolerance potentials, finding that mixing weakly resistant varieties with strongly allelopathic varieties improved weed suppression and controlled barnyard grass (*Echinochloa crusgalli* [L.] Beauv.).

Given that both rice-duck farming and rice mixed-cropping produce positive ecological effects, combining these technologies—through 叠加 of variety diversity and species diversity (different rice varieties mixed-cropping + duck raising)—could potentially create synergistic ecological and production benefits worth investigating. This study conducted field experiments mixing two rice varieties with duck raising to determine whether this compound biodiversity model could improve environmental conditions and soil nutrient status, thereby enhancing rice quality and providing a new ecological agriculture technology for producing healthy, safe rice.

1.1 Study Site

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 humid climate, the site has abundant sunlight, mild temperatures, plentiful rainfall, and rich heat resources. The average annual temperature is 21.8°C, frost-free period lasts 335-360 days, average annual precipitation is 2,137 mm, and relative humidity is 78%. The experimental field consisted of paddy soil developed from latosolic red soil.

1.2 Experimental Materials

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

1.3 Experimental Design and Field Management

1.3.1 Variety Combinations and Experimental Plots The field experiment used a randomized complete 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' (seeds mixed 1:1 before sowing, hereafter "rice mixed-cropping"), forming six total treatments with three replications each (18 plots total). Each plot was 80 m^2, arranged in randomized blocks with 'Shengbasimiao' planted as border rows. The effects of monoculture with ducks, mixed-cropping, and their combination were compared across production methods.

1.3.2 Field Management Planting density was 28 cm × 22 cm. All plots received chicken manure (~50 kg per plot) before transplanting. Early and late rice seeds were soaked on March 15 and July 30, respectively, grown in nursery beds for ~20 days. Land was 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 and May 20 for early rice and September 15 and October 8 for late rice, and compound fertilizer (Batian 1+1, 18-8-15) at 4.0 kg per plot during the first pesticide application.

Ducklings were released ~1 week after transplanting in duck treatments, with 50 cm high nylon nets around each plot to prevent escape (3 ducklings per plot). 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, water was drained. All treatments stopped irrigation 3 weeks before harvest during the drying period; otherwise, a 3-5 cm water layer was maintained. The field was double-cropped annually, with rice straw returned after each harvest.

1.4 Measurements

1.4.1 Soil Physicochemical Properties Soil samples were collected four times: 1 week after transplanting (regreening stage) and 1 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 in a quincunx pattern from the 0-15 cm layer (~0.25 kg per point), mixed, air-dried, and cleaned of plant residues and stones. The quartering method was used to obtain representative samples, sieved through 18-mesh for available nutrients or 100-mesh for total nutrients. Analytical methods followed Bao [24]: organic matter by dichromate oxidation (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 Determination The experiment was conducted in 2009 for early and late rice seasons. After harvest, grains were air-dried and stored for 3 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 Infratec1241 nearinfrared grain analyzer.

1.5 Data Analysis All data were analyzed using SPSS 17.0. One-way ANOVA was used to test for significant differences in soil chemical properties and rice quality among treatments, with LSD tests for multiple comparisons at $P<0.05$.

2.1 Effects on Soil Nutrient Dynamics

2.1.1 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, then increase again, with overall increases after double rice cropping. Before early rice harvest (June 20), organic matter under mixed-cropping with ducks and monoculture with ducks was significantly higher than other treatments, being 13.93% and 7.45% higher than conventional monoculture, and 17.35% and 15.59% higher than monoculture blank control, respectively. From late rice planting to harvest (September 1-October 22), mixed-cropping with ducks remained significantly higher than other treatments, indicating that combining mixed-cropping with duck farming enhances soil organic matter content.

2.1.2 Soil Total Nitrogen and Alkali-Hydrolyzable Nitrogen Soil total nitrogen dynamics are shown in [Figure 2: see original paper]A. Total nitrogen generally decreased then increased across treatments in both seasons. Before early rice harvest, the ranking was: mixed-cropping conventional > monoculture with ducks > monoculture conventional > mixed-cropping with ducks > mixed-cropping blank > monoculture blank. After double rice cropping, no significant difference existed between mixed-cropping conventional and mixed-cropping with ducks, but both were significantly higher than other treatments. Mixed-cropping blank was also significantly higher than monoculture blank, indicating that both variety mixed-cropping and duck farming help stabilize soil total nitrogen.

Alkali-hydrolyzable nitrogen ([Figure 2: see original paper]B) showed continuous increases in conventional monoculture and monoculture with ducks, a decrease-increase-decrease pattern in blank controls, and a decrease-increase pattern in duck treatments. After two seasons, mixed-cropping with ducks had the highest alkali-hydrolyzable nitrogen content, being 5.72% higher than monoculture with ducks, while mixed-cropping conventional was 1.20% higher than monoculture conventional, and mixed-cropping blank was 16.00% higher than monoculture blank. This demonstrates that mixed-cropping increases soil alkali-hydrolyzable nitrogen, with enhanced effects when combined with duck farming.

2.1.3 Soil Total Phosphorus and Available Phosphorus Soil total phosphorus ([Figure 3: see original paper]A) decreased then gradually increased across treatments. In early rice, monoculture blank had the highest content, while after early rice harvest, mixed-cropping blank was highest. After late rice harvest, conventional treatments had significantly lower total phosphorus than other treatments. Available phosphorus ([Figure 3: see original paper]B) initially increased then decreased. After early rice harvest, mixed-cropping blank had the highest available phosphorus. After late rice harvest, both mixed-cropping and monoculture blank controls had significantly higher available phosphorus than other treatments, 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 Soil Total Potassium and Available Potassium Total potassium ([Figure 4: see original paper]A) increased, then decreased, then stabilized across treatments. 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 blank > monoculture blank > monoculture with ducks > mixed-cropping conventional > monoculture conventional, showing that mixed-cropping enhances total potassium content, promotes potassium absorption, provides a material basis for lodging resistance, and ultimately increases yield.

Available potassium ([Figure 4: see original paper]B) decreased, then increased, then decreased across treatments with similar amplitude (except late rice monoculture conventional). During early rice, monoculture blank had significantly higher available potassium than other treatments (except mixed-cropping with ducks). After early rice harvest, monoculture with ducks was highest. After late rice harvest, mixed-cropping with ducks was significantly higher than all other treatments, with the ranking: mixed-cropping with ducks > monoculture with ducks > mixed-cropping conventional > mixed-cropping blank > monoculture blank > monoculture conventional. This indicates that mixed-cropping more rapidly and sustainably increases available potassium, providing sustainable potassium nutrition for rice growth, with enhanced effects when combined with duck farming.

2.2 Effects on Rice Quality

As shown in , after double rice cropping with ducks and mixed-cropping, the mixed-cropping with duck treatment produced the highest brown rice and milled rice rates, significantly increasing by 2.03% and 1.98% compared to monoculture blank, and by 6.29% and 5.85% compared to monoculture conventional. Head rice rate was also higher under mixed-cropping than monoculture, with mixed-cropping with ducks significantly higher than monoculture blank. Length/width ratio was higher than all treatments except monoculture blank. Chalky rice rate was lowest under mixed-cropping with ducks. Amylose content and gel consistency were higher than other treatments and significantly higher than monoculture with ducks, indicating that mixed-cropping with ducks improves rice cooking and eating quality.

3 Discussion and Conclusion

Numerous studies have examined the separate effects of rice mixed-cropping and rice-duck farming on soil nutrients and rice quality, but few have investigated their combined effects. This study found that after double rice cropping, mixed-cropping with ducks significantly increased soil organic matter content compared to other treatments. This occurred because mixed-cropping with ducks promoted higher tillering and biomass, increasing straw return [29], while duck manure provided additional organic inputs. Fresh duck manure contains 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 100.0 g fresh manure daily [25-26]. Duck activity also promoted gas exchange between paddy water, soil, and the atmosphere, increasing soil redox potential and dissolved oxygen, which accelerated decomposition of coarse organic matter from rice straw [27-28].

For soil nitrogen, no significant difference existed between mixed-cropping conventional and mixed-cropping with ducks after double rice cropping, but both were significantly higher than other treatments. Duck excreta supplemented nitrogen requirements [30], while duck activity loosened surface soil, promoted mineralization of soil organic matter, and enhanced nutrient release [31], increasing available nitrogen accumulation. For phosphorus, mixed-cropping with ducks had the highest total phosphorus after late rice harvest, significantly higher than conventional treatments. Mixed-cropping maintained higher average available phosphorus than monoculture. During early growth, phosphorus demand was low, leaving surplus available phosphorus. As the season progressed, organic matter decomposition reduced remaining phosphorus while crop demand increased, causing available phosphorus to decline, though differences in total phosphorus were small.

For potassium, no significant differences in total potassium existed among treatments after double rice cropping, likely due to straw return. Although available potassium declined after two seasons due to crop uptake, duck activity in duck-rice systems improved soil aeration, accelerating potassium transformation [32], maintaining significantly higher available potassium. Mixed-cropping also enhanced canopy ventilation, promoting potassium availability, so mixed-cropping with ducks showed synergistic positive effects on soil potassium.

Rice quality is influenced by genetics [33-34], environmental conditions, and cultivation techniques [35], representing a comprehensive interaction between variety characteristics and ecological conditions [36]. Under fixed genetic conditions, quality depends on growth environment and management. This study showed that rice-duck farming improved processing quality (brown and milled rice rates), consistent with Wang et al. [37] who found that duck activity and manure as organic fertilizer improved rice quality. Blank controls received only initial organic fertilizer but no pest control, leading to frequent disease, insect, and weed damage that reduced quality (e.g., sheath blight and planthoppers causing unfilled grains). Mixed-cropping reduced pest and disease incidence through complementary resistance between varieties, improving quality, similar to findings by Sang et al. [38] and Zhu et al. [39]. Mixed-cropping with ducks significantly reduced chalkiness because ducks removed old leaves, sheaths, and fungal structures, improving ventilation and soil aeration, thereby enhancing rice quality [37]. Amylose content and gel consistency under mixed-cropping with ducks remained within optimal quality ranges, likely due to balanced and complementary nutrient uptake between the two varieties.

In conclusion, rice variety mixed-cropping with duck raising increased soil organic matter, total nitrogen, and alkali-hydrolyzable nitrogen, improved milling quality (brown and milled rice rates), enhanced appearance quality (reduced chalkiness), and optimized amylose content and gel consistency, thereby improving overall rice quality. This integrated system produces positive ecological effects and economic benefits through quality improvement, warranting demonstration and promotion.

References

[1] Cheng S H, Hu P S. Development strategy of rice science and technology in China[J]. Chinese Journal of Rice Science, 2008, 22(3): 223-226

[2] Khush G S. What it will take to feed 5.0 billion rice consumers in 2030[J]. Plant Molecular Biology, 2005, 59(1): 1-6

[3] Zhou H B, Chen J L, Cheng D F, et al. Effects of ecological regulation of biodiversity on insects in agroecosystems[J]. Plant Protection, 2012, 38(1): 6-10

[4] Strand J F. Some agrometeorological aspects of pest and disease management for the 21st century[J]. Agricultural and Forest Meteorology, 2000, 103(1/2): 73-82

[5] Shi Z H. Analysis on status and impact of agricultural pollution[J]. Modern Agricultural Science and Technology, 2011(11): 262-263

[6] Gao D, He X H, Zhu Y Y. Review of advances in mechanisms of sustainable management of pests by agro-biodiversity[J]. Chinese Journal of Plant Ecology, 2010, 34(9): 1107-1116

[7] Xi Y G, Qin P. Emergy evaluation of organic rice-duck mutualism system[J]. Ecological Engineering, 2009, 35(11): 1677-1683

[8] Zhang F, Chen Y Q, Gao W S. Phosphorus cycling in rice-duck mutual ecosystem in double cropping rice growth seasons[J]. Chinese Journal of Ecology, 2012, 31(6): 1383-1389

[9] Qin Z, Zhang J E, Zhang J, et al. Study on ecological niches of main predatory arthropods integrated rice-duck farming system[J]. Scientia Agricultura Sinica, 2012, 45(1): 67-76

[10] Shen J K, Huang H, Fu Z Q, et al. Effect of large-scale rice-duck eco-farming on the composition and diversity of weed community in paddy fields[J]. Chinese Journal of Eco-Agriculture, 2010, 18(1): 123-128

[11] Xie J L, Xiong G Y. Effects of rice-duck integrated farming on water eco-

logical environment[J]. Animal Husbandry and Feed Science, 2010, 31(3): 141-142
[12] Huang Z X, Zhang J E, Liang K M, et al. Mechanical stimulation of duck on rice phyto-morphology in rice-duck farming system[J]. Chinese Journal of Eco-Agriculture, 2012, 20(6): 717-722
[13] Zhang J E, Ouyang Y, Huang Z X. Characterization of nitrous oxide emission from a rice-duck farming ecosystem in South China[J]. Archives of Environmental Contamination and Toxicology, 2008, 54(2): 167-172
[14] Yuan W L, Cao C G, Li C F, et al. Methane and nitrous oxide emissions from rice-fish and rice-duck complex ecosystems and the evaluation of their economic significance[J]. Scientia Agricultura Sinica, 2009, 42(6): 2052-2060
[15] Quan G M, Zhang J E, Yang J, et al. Impacts of integrated rice-duck farming system on rice quality[J]. Acta Ecologica Sinica, 2008, 28(7): 3475-3483
[16] Li S F, Rao W F. Effect of mixed planting on the main agronomic traits and yield of oilseed rape[J]. Tillage and Cultivation, 2001(5): 10
[17] Daellenbach G C, Kerridge P C, Wolfe M S, et al. Plant productivity in cassava-based mixed cropping systems in Colombian hillside farms[J]. Agriculture, Ecosystems & Environment, 2005, 105(4): 595-614
[18] Liu E M, Zhu Y Y, Xiao F H, et al. Using genetic diversity of rice varieties for sustainable control of rice blast disease[J]. Scientia Agricultura Sinica, 2003, 36(2): 164-168
[19] Ma H G, Shu C, Liu K C, et al. Studies on rice variety diversity for sustainable control of rice blast[J]. Chinese Journal of Eco-Agriculture, 2007, 15(2): 114-117
[20] Pan G J, Chen S Q, Liu C X, et al. Research on mixture inter-planting of different rice varieties to control rice blast in cold region[J]. Chinese Agricultural Science Bulletin, 2010, 26(4): 274-276
[21] Zhu Y Y, Sun Y, Wang Y Y, et al. Genetic analysis of rice varietal diversity for rice blast control[J]. Acta Genetica Sinica, 2004, 31(7): 707-716
[22] Neugschwandtner R W, Kaul H P. Sowing ratio and N fertilization affect yield and yield components of oat and pea in intercrops[J]. Field Crops Research, 2014, 155: 159-163
[23] Han H H, Zhou Y J, Chen X, et al. Inhibitory effects of mixed-planting of rice varieties with different weed-tolerant potentials on *Echinochloa crus-galli*[J]. Chinese Journal of Rice Science, 2007, 21(3): 319-322
[24] Bao S D. Soil and Agricultural Chemistry Analysis[M]. 3rd ed. Beijing: Chinese Agriculture Press, 2000
[25] Ni W H. The discussion of the excreta disposal on modernism duck farm[J]. China Poultry, 2003, 25(11): 22
[26] Yang Z H, Huang H, Wang H. Paddy soil quality of a wetland rice-duck complex ecosystem[J]. Chinese Journal of Soil Science, 2004, 35(2): 117-121
[27] Wang J P, Cao C G, Jin H, et al. Effects of rice-duck farming on aquatic community in rice fields[J]. Scientia Agricultura Sinica, 2006, 39(10): 2001-2008
[28] Quan G M, Zhang J E, Chen R, et al. Effects of rice-duck farming on paddy field water environment[J]. Chinese Journal of Applied Ecology, 2008,

19(9): 2023–2028
[29] Zhang J E, Xu R B, Quan G M, et al. Influence of rice-duck integrated farming on rice growth and yield characteristics[J]. Resources Science, 2011, 33(6): 1053–1059
[30] Zhang J E, Lu J X, Zhang G H, et al. Study on the function and benefit of rice-duck agroecosystem[J]. Ecologic Science, 2002, 21(1): 6–10
[31] Gan D X, Huang H. Analysis the development prospect of the rotation system on "rice-grass" in Hunan Province[J]. Tillage and Cultivation, 2002(4): 15–17
[32] Zhang M M, Zong L G, Xie T Z. Effect of integrated organic duck-rice farming on the dynamics of soil nutrient and associated economic benefits[J]. Chinese Journal of Eco-Agriculture, 2010, 18(2): 256–260
[33] Wu Z M, Li H J, Shi Q H, et al. Research on the effects of environment factors and cultural methods on rice quality[J]. Journal of Agricultural Mechanization Research, 2006(7): 1–4
[34] You Q R, Huang T X, Ma H M. Advances in effects of environmental ecological factors on rice quality[J]. Acta Agriculturae Jiangxi, 2006, 18(3): 155–158
[35] Liu R M, Qian F H. The effect and control measures of cultivation technique on rice quality[J]. Yunnan Agricultural Science and Technology, 2007(4): 33–34
[36] Yang H L, Yang Z M, Lu B L. The effect of the ecology environment on rice quality[J]. Hubei Agricultural Sciences, 2001(6): 14–16
[37] Wang Q S, Huang P S, Zhen R H, et al. Effect of rice-duck mutualism on nutrition ecology of paddy field and rice quality[J]. Chinese Journal of Applied Ecology, 2004, 15(4): 639–645
[38] Sang H X, Wang J S, Liu Y, et al. The effect of rice sheath blight on yield and quality[J]. North Rice, 2013, 43(1): 10–13
[39] Zhu Y Y, Chen H R, Fan J H, et al. Using rice variety diversity for rice blast control[J]. Scientia Agricultura Sinica, 2003, 36(5): 521–527

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