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Responses of rice production, milled rice quality and soil properties to various nitrogen inputs and rice straw incorporation under continuous plastic film mulching cultivation

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ABSTRACT

Yield decline from continuous cropping of aerobic rice is a constraint to the widespread adoption of plastic film mulching cultivation (PFMC); rice straw incorporation has been proposed to counter this negative effect of long term PFMC. Shifts in water management from flooded to aerobic conditions are known to influence the availability of N and might have an influence on rice quality. A long-term (2001–2010) field experiment was conducted to examine the effects of five fertilizer nitrogen (N) application rates (0, 45, 90, 135, 180 kg N ha^{-1}) and rice straw incorporation on rice grain yield, milled rice quality and soil quality under PFMC in non-flooded conditions. There were significant responses in grain yield to various N fertilizer rates and rice straw incorporation during 2008 to 2010. Total amino acids and protein concentrations in polished rice increased with increasing N rates. Split-plot factor significantly affected soil fertility and rice plant N uptake in our study. With rice straw incorporation, total annual and mean amount of soil organic matter was improved by 6.4%, 7.6% and 12.2%; NH_4OAC-extractable K amount was improved by 28.2%, 64.0% and 52.9%; N uptake was improved by 20.4%, 23.9% and 23.6%, respectively, from the year of 2008 to 2010. Dynamics of rice grain yield, soil organic matter, alkali-hydrolyzable N and NH_4OAC-extractable K from 2001 to 2010 proved that rice straw incorporation obviously improved rice grain yield and soil quality under continuous PFMC. Our results suggest that there is a possibility of reversing yield decline observed in the continuous PFMC system by using rice straw incorporation.

1. Introduction

Rice (*Oryza sativa* L.) is a staple food grain for two thirds of the world's population (Zhou et al., 2002). Demand for rice is expected to increase as population grows in China and other countries of the world. Rice is customarily grown under continuously flooded conditions, especially in China and other Asian countries. Nearly three-quarters of the global rice production occurs in irrigated lowlands (Maclean et al., 2002). As fresh water is becoming increasingly scarce water-saving in rice cultivation must be sought to allow the development of sustainable agriculture (Lu et al., 2001).

Plastic film mulching cultivation (PFMC), a new non-flooded mulching cultivation was introduced in China in the late 1980s (Fan et al., 2005). Lowland rice fields are irrigated and a shallow water layer is maintained on top of the soil prior to transplanting. The soil surface is then covered with plastic film or crop straw and the soil is maintained at 70–90% of water holding capacity or rain fed. Compared with conventional flooded rice cultivation, PFMC under non-flooded conditions seemed to have a striking capacity to maintain soil moisture, increase soil temperature in the early season and improve nutrient availability. Studies also showed that PFMC led to stable or increased yield (Wu et al., 1999; Fan et al., 2002).

However, long-term cultivation under non-flooded mulching conditions altered the environment of growing rice through changes in soil water conditions, leading to a prolonged aerobic phase. This makes the conservation of soil organic matter and soil N in the cropping system difficult (Fan et al., 2005). Furthermore,

Abbreviations: PFMC, plastic film mulching cultivation; CFC, conventional flooding cultivation; N, nitrogen; PC, protein content; TAAC, total amino acids concentration; AC, amylose content; GC, gel consistency; ASV, alkali spreading value; M1, treatment without rice straw incorporation; M2, treatment with rice straw incorporation.

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a change from traditional flooded to non-flooded cultivation with mulching will modify soil temperature. These effects are likely to have a big influence on N availability and N cycling. A positive correlation has previously been reported between N inputs and rice production as well as rice quality (Fan et al., 2005; Ning et al., 2010). However, little is known regarding long term effect of PFMC on rice grain yield and quality, and soil fertility among contrasting N treatments under prolonged aerobic phase. There is therefore a need so to clarify the effects of various N inputs on rice production and nutritional quality as well as soil fertility under long-term PFMC in non-flooded conditions.

Incorporation of the post-harvest straw into the soil returns most of the nutrients and helps to conserve soil fertility in the long term. Soil quality enhancement could have positive influence on rice production and quality improvement. To examine the effect of rice straw incorporation on rice grain yield and nutritional quality as well as soil quality will help to overcome soil fertility decline under continuous PFMC system.

The objective of this paper was to investigate the long-term effects of varying N inputs and rice straw incorporation on productivity, and quality of rice and soil fertility under un-flooded plastic mulched conditions.

2. Materials and methods

2.1. Field experiment

The experimental site was located in a field in Duntou town (29° 19′ N, 119° 43′ E and 72.8 m elevation) of Lanxi, located in Eastern China. The experimental site is typical of that region. The cropping system in our study was single cropping system of late rice. The gritty red soil at the start of the experiment in 2001 contained 30.2 g kg^{-1} organic matter, 2.1 g kg^{-1} total N, 62 mg kg^{-1} Olsen-P and 69 mg kg^{-1} NH_4OAc-exchangeable K. The soil is classified as Stagnic Anthrosol and has a pH of 5.1 (H_2O, 20 °C).

Treatments were laid out in a split-plot randomized complete block design in triplicate. The main plot treatments consisted of five N fertilizer rates as urea: 0, 45, 90, 135 and 180 kg N ha^{-1} (N_0, N_1, N_2, N_3, and N_4). The two split-plot treatments were: without rice straw incorporation (M_1), with rice straw incorporation (M_2). The N, P (47.3 kg P_2O_5 ha^{-1} as triple super–phosphate) and K (67.5 kg K_2O ha^{-1} as potassium chloride) fertilizers were incorporated into the top 15 cm of the soil in all treatments prior to transplanting.

The size of each plot was 30 m^2. Plastic film, 0.007 mm thick and 1.7 m wide was used to cover the soil. Rice straw (air-dried, 3000 kg ha^{-1}) from the same field which was cut into 3–5 cm long pieces and incorporated as soon as rice grain was harvested each year in the rice straw incorporation treatment. Average N, P and K in additions from rice straw of the three years were 22.5 kg ha^{-1}, 2.9 kg ha^{-1} and 52.3 kg ha^{-1}, respectively. The rice variety used was the hybrid "IIyou 92". Rice seedlings, 37-day-old, were transplanted at a spacing of 20 × 28 cm with two seedlings per hill about June 20. Rice crop was harvested in middle November. Field was fallow during November–June. Weeds were removed several times in the field without rice straw incorporation, while nothing was done in the field with rice straw incorporation.

2.2. Rice grain yield and quality analysis

The harvested area was each whole plot. Grain weight data were adjusted to 14% moisture level.

All the rice grains were air-dried. The blighted grains were removed before rice seeds were dehusked in an electrical dehusker (model JLGJ-45, China). A part of the brown rice was polished with a sample polisher (model JB-20, China) before grinding. The polished rice was ground to flour with a Model 3010-99 cyclone grinder (Ugy, Fort Collins, CO, USA) and then passed a 0.15 mm sieve. The milled rice quality traits analyzed in this paper included protein concentration (PC, mg g^{-1}), total amino acid concentration (TAAC, mg g^{-1}), amylose content (AC, mg g^{-1}), gel consistency (GC, mm) and alkali spreading value (ASV). All of these qualities were determined by near-infrared reflectance spectroscopy (NIRS). Rice flour samples (3 g) were placed in a small ring cup of 36 mm inner diameter and scanned on an NIR System Model 5000 monochromator (NIR System, Silver Springs, MD, USA). AC, GC and nutritional quality traits were calculated by the calibration equations developed using WinISI II v.1.04 (Wu et al., 2002; Wu, 2004).

2.3. Soil quality and N uptake by rice analysis

From 2002, soil samples from 0–15 cm depths from all plots were collected in November each year after harvest. Soil samples were air-dried, and ground to pass a 2 mm sieve prior to analysis. Soil was analyzed for their basic properties with procedures described in Zhang et al. (2010).

Nitrogen uptake was calculated as the product of N concentration and yield of aboveground parts of rice on a dry matter basis. We use alkaline hydrolysis diffusion method to measure N content (Wang et al., 2010).

2.4. Statistical analysis

All statistical analyses were performed using STATISTICA software Version 5.5. Each value represented the average of three replicates. Data were subjected to analysis of variance (ANOVA) and significant differences in mean values were separated using Turkey's multiple range test ($P < 0.05$).

3. Results

As revealed by three-way ANOVA, rice grain yield and soil fertility parameters were significantly affected by year (Y), N inputs (A) and rice straw incorporation (B). The Y × A, A × B, Y × A × B interaction effect on tested soil fertility parameters were also obvious (Tables 1 and 2).

3.1. Effects of N rate and rice straw incorporation on rice grain yield

Significant grain yield responses to N fertilizer and rice straw incorporation as well as their interactions were evident during the 3-year recording period (Table 1). When N fertilizer application rate was below 135 kg ha^{-1} (N_3), rice grain yield showed an increase with each increase in N rate. Without rice straw incorporation, there was no significant difference in rice yields between N_3 and N_4 levels in year 2008 and 2009. In 2010, grain yield at the N_4 level was significantly higher than that in the N_3 level. Overall, crops responded to fertilizer N rates up to N_3, but further grain yield response to additional applied N (N_4) with increasing time of continuous rice cultivation (Table 3). With rice straw incorporation, no significant difference in rice yields was observed between N3 and N4.

At each N application rate, all plots with rice straw incorporation (M_2) gave a higher grain yield than did the corresponding plot without rice straw incorporation (M_1) over all three years, this effect extending to N4 (Fig. 1).

Dynamics of rice grain yield in different years under N rate of 135 kg ha^{-1} with and/or without rice straw incorporation was showed in Fig. 3. Though grain yields differed from 2001