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RESEARCH ARTICLE

Non-leguminous winter cover crop and nitrogen rate in relation to double rice grain yield and nitrogen uptake in Dongting Lake Plain, Hunan Province, China

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Abstract

Annual ryegrass (*Lolium multiflorum* Lam.), a non-leguminous winter cover crop, has been adopted to absorb soil native N to minimize N loss from an intensive double rice cropping system in southern China, but a little is known about its effects on rice grain yield and rice N use efficiency. In this study, effects of ryegrass on double rice yield, N uptake and use efficiency were measured under different fertilizer N rates. A 3-year (2009–2011) field experiment arranged in a split-plot design was undertaken. Main plots were ryegrass (RG) as a winter cover crop and winter fallow (WF) without weed. Subplots were three N treatments for each rice season: 0 (N_0), 100 (N_{100}) and 200 kg N ha^{-1} (N_{200}). In the 3-year experiment, RG reduced grain yield and plant N uptake for early rice (0.4–1.7 t ha^{-1} for grain yield and 4.6–20.3 kg ha^{-1} for N uptake) and double rice (0.6–2.0 t ha^{-1} for grain yield and 6.3–27.0 kg ha^{-1} for N uptake) when compared with WF among different N rates. Yield and N uptake decrease due to RG was smaller in N_{100} and N_{200} plots than in N_0 plots. The reduction in early rice grain yield in RG plots was associated with decrease number of panicles. Agronomic N use efficiency and fertilizer N recovery efficiency were higher in RG plots than winter fallow for early rice and double rice among different N rates and experimental years. RG tended to have little effect on grain yield, N uptake, agronomic N use efficiency, and fertilizer N recovery efficiency in the late rice season. These results suggest that ryegrass may reduce grain yield while it improves rice N use efficiency in a double rice cropping system.

Keywords: double rice, grain yield, N uptake, N use efficiency, winter cover crop

1. Introduction

In most rice producing countries in Asia, double cropped early and late rice (double rice) plays an important role in guaranteeing national food security (Cassman and Pingali 1995). This intensive cropping system is usually featured with high chemical fertilizer N input but relative low N use efficiency. In double rice cropping system in China, farmers generally applied N fertilizer as much as 200 kg N ha^{-1} per planting season (Peng *et al*. 2002), with less than 36% of

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the applied N absorbed by the rice plant within the year (Zhu 2008; Zhu *et al*. 2012a). The excessive applied fertilizer N not only increased cost of production, but also resulted in many unintended environmental consequences such as eutrophication in rivers and lakes (Ju *et al*. 2009), greenhouse gas emissions (Xing and Yan 1999; Liu *et al*. 2016) and atmospheric deposition (Liu *et al*. 2013). Thus, extensive efforts have been devoted to improve N use efficiency and minimize N loss into the environment by scientists, environmental groups and governments worldwide.

Replacing bare fallow with cover crops has been mainly used as an effective tool to increase retention of post-harvest surplus soil N in intensive cropping systems and consequently reduce the risk of N introduced into the environment (Hooker *et al*. 2008; Zhu *et al*. 2012b; Ramírez-García *et al*. 2015). In many countries and regions such as USA, Germany and Mediterranean areas, cover crops have been successfully established to intercept residual soil N otherwise be lost into rivers and into groundwater (Möller and Reents 2009; Campiglia *et al*. 2011; Gabriel and Quemada 2011). However, the choice of a cover crop depends largely on its effects on yields and N dynamics of the following main crops. An ideal cover crop in a sustainable agricultural practice should prevent reactive N running into the environment from intensive agriculture systems and maintain the main crop yields (Tonitto *et al*. 2006; Singer *et al*. 2007). Studies concerning the effects of cover crops on main crop yields have got inconsistent results. Some reported increased yields favored by several factors such as weed suppression (Samarajeewa *et al*. 2005; Bernstein *et al*. 2014) and additional N supply from the decomposition of the cover crop residue (Baijukya *et al*. 2006). Some reported yield declines after cover crop planting (Zhu *et al*. 2012c; Nascente *et al*. 2013) or no difference between cover crop management and bare fallow systems (Tonitto *et al*. 2006).

In double rice cropping systems in southern China, winter fallow duration is nearly six months, lasting from late rice harvest in October to early rice transplanting in April in the following year. This allows farmers to establish such cover crops. Annual ryegrass (*Lolium multiflorum* Lam.), a fast growing grass which is usually broadcasted into paddy fields approximately a half month before late rice harvest when used as a winter cover crop, had been demonstrated as an effective tool for accumulating soil residual N and reducing soil inorganic N contents in our previous studies (Zhu *et al*. 2012b). Ryegrass decreased double rice grain yields and N uptakes in the case of zero N application during double rice seasons, possibly due to the lower soil N availability compared with bare fallow. Thus, planting ryegrass as a cover crop in the double rice cropping system may alter the rate of N fertilization for an optimal supply of N to rice. However, few studies have examined the combined effects of cover crop and N application rate on main crop yields and N dynamics.

In the present study, we measured double rice grain yields and N dynamics for continuous three years in a field experiment. There were two main objectives of this study: (1) to evaluate the combined effects of annual ryegrass as a winter cover crop and N application rate on grain yields and N use efficiencies of the succeeding double rice crops; (2) to measure the impact of different N application rates on annal ryegrass winter cover crop, as compared with bare fallow.

2. Materials and methods

2.1. Experimental site

A field experiment was conducted from 2009 to 2011 at the experimental station of Soil and Fertilizer Institute located in Huarong County in Dongting Lake Plain (29°52´N, 12°55´E), Hunan Province, China. The climate in this region is subtropical, monsoonal and humid, with a long hot period in the summer and a short cold period in the winter. Monthly mean temperatures and precipitations from 2009 to 2011 in Huarong County is shown in Fig. 1. Double rice production is mostly widely practiced cropping system in this region. Soil properties from the upper 20 cm layer were sand 24.5%, silt 62.1%, clay 13.4%, pH 6.0, soil organic matter 2.55%, total N 0.18%, Olsen extractable phosphorus 12.4 mg kg^{-1}, and available potassium 117.5 mg kg^{-1}.

2.2. Treatments and crop management

Treatments were arranged in a split-plot design. Main plots were ryegrass (RG) as a winter cover crop and winter fallow (WF) without weed. Subplots were three N treatments: 0 (N_0), 100 (N_{100}, 70 kg N ha^{-1} urea as basal fertilizer to early and late rice, 30 kg N ha^{-1} urea as top dressing at tillering stage for early and late rice) and 200 kg N ha^{-1} (N_{200}, 140 kg N ha^{-1} urea as basal fertilizer to early and late rice, 60 kg N ha^{-1} urea as top dressing at tillering stage for early and late rice). The size of subplot was 5 m×6 m. The experiments were replicated three times. The treatments were assigned in the same experimental plots in the continuous three studying years.

Before the experiment, the field was planted with continuous double rice for at least five years. Before the initiation of the field experiment, subplots were separated by 0.5 m wide ridges and plots were separated by 1 m wide irrigation ditches. The ridges were covered with plastic film to prevent runoff of nutrients from one plot to another. In RG plots, ryegrass seeds were hand broadcast in late rice field approximately 10 d before late rice harvest. Details of ryegrass variety, seeding rates, sowing dates, and harvest