Interactive effects of liming and straw retention on yield and nitrogen uptake in a double rice-cropping system of subtropical China

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Abstract
Although a large body of research has examined the effect of either liming or straw retention on rice yield in acidic soils, their interactive effects are unclear. In the present study, a two-year factorial field experiment was conducted to investigate the interactive effect of liming and straw retention on rice yield and nitrogen (N) uptake in a double rice-cropping system in subtropical China (i.e. rice is cropped twice annually, including early rice and late rice). Results showed that both liming and straw retention could significantly enhance grain yield in both early- and late-rice growing seasons. There were interactive effects of liming and straw retention on late-rice yield in both years, whereas no significant interaction was found in the early-rice growing season. Like grain yield, N uptake of both early- and late-rice was significantly increased by both liming and straw retention. Liming significantly interacted with straw retention to improve N uptake in the late-rice growing season, but not in the early-rice season. Therefore, we conclude that there are synergistic effects of liming and straw retention on late-rice yield in the double rice-cropping system, which may be ascribed to the improvement in rice N uptake.

Keywords
Lime, straw, rice, yield, nitrogen.

Introduction
Rice (*Oryza sativa* L.) is a staple food for nearly half of the world's population (Van Nguyen and Ferrero, 2006; Normile 2008). However, soil acidification has become a major yield-limiting factor for rice production in subtropical China, which is due to long-term inorganic N fertilisation and inherently low soil acidity (Xu and Coventry 2002). The application of lime is a common practice for ameliorating soil acidification (Alleoni et al. 2010; Caires et al. 2011; 2015). In addition, a number of studies have shown that long-term straw incorporation could increase crop yield and improve soil fertility (Malhi et al. 2011; Ram et al. 2013; Xu et al. 2010). However, several studies have reported that straw retention could lead to a temporary N immobilistion in soil and a reduction in the number of rice tillers, thereby resulting in no gain or even a decrease in grain yield, particularly in short-term experiments (Timsina 2005; Shan et al. 2006; Huang et al. 2013). There is evidence showing that liming could increase the decomposition of crop residues and promote soil nutrient availability (Fageria et al. 2004; Tian et al. 2009; Castro and Crusciol 2013). Therefore, we hypothesised that combined liming and straw retention could significantly enhance rice yield in subtropical China. Although a large body of research had examined the separate effect of either liming or straw retention on rice yield, their interactive effects are unclear. Therefore, in the present study, we conducted a two-year factorial field experiment to investigate the interactive effect of liming and straw retention on rice yield and N uptake in a double rice-cropping system in subtropical China.

Methods
The experiment was conducted in a field at Zengjia village, Shanggao County, Jiangxi Province, China (115°09' E, 28°31' N) in 2015 and 2016. The cropping system consists of early rice (April to July), late rice (July to November), and winter fallow (November of previous year until April of next year). The initial soil contained 18.3 g kg^{-1} organic matter, 1.1 g kg^{-1} total N, 1.5 g kg^{-1} total P, 15.5 g kg^{-1} total K, with a pH of 5.2. Four treatments were arranged in a completely randomised block design with two factors of liming (L) and rice straw retention (RS), with three replications. Each plot was 25 m^2 in size. The four treatments included: (1) control, without liming and straw retention (Control); (2) lime was spreaded on the soil suface only once and then was incorpated to a depth of 15 cm by a rotavator before transplanting the early rice in 2015 at a rate of 2.1 t ha^{-1} in the form of $CaCO_3$ (L); (3) rice straw retention (RS), which incorpated all the chopped straw (10 cm) into the soil following machine harvesting (4) combined liming and straw retention (L+RS). Two high-yielding rice varieties currently used in local production, Zhongjiazao17 (inbred) and Wuyou308

(hybrid), were used in the early rice and late rice season in both years, respectively. Other practices including inorganic fertiliser application, irrigation, plant control, etc, remained the same for the four treatments.

Results

Grain yield

Both liming and straw retention significantly increased both early- and late-rice yield in both years (Table 1 and Figure 1). There was an interactive effect of liming and straw retention on late-rice yield in both years, whereas no significant interaction was found in the early-rice growing season.

Table 1. Results (*F*-values) of ANOVAs on the effects of liming (L) and rice straw retention (RS) on grain yield in 2015 and 2016.

Source of variations	2015		2016	
	Early rice	Late rice	Early rice	Late rice
L	9.6*	221.6**	36.2**	228.4**
RS	23.0**	6.6*	54.8**	10.7*
L×RS	NS	9.2*	NS	6.6*

NS = not significant; * Significant at $P \le 0.05$; ** Significant at $P \le 0.01$.

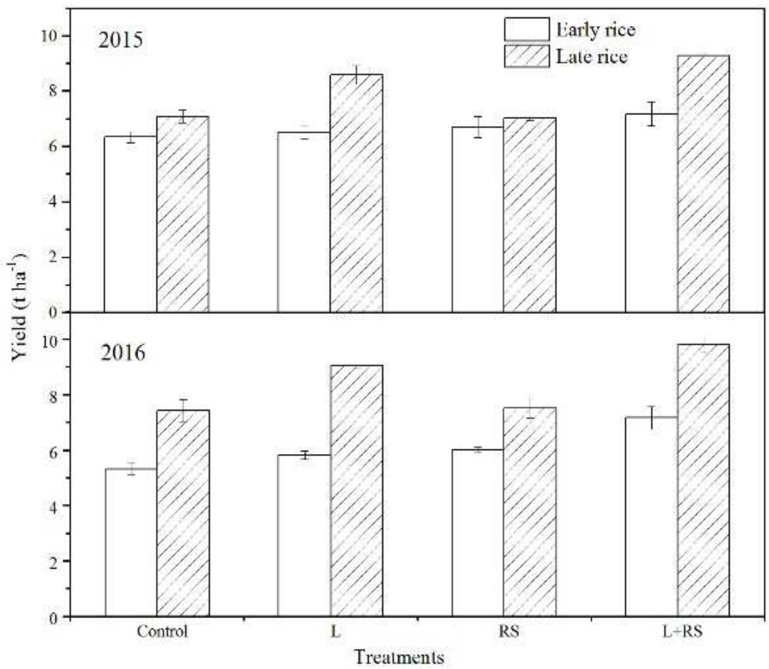

Figure 1. Effects of liming (L) and rice straw retention (RS) on grain yield in 2015 and 2016. Error bars represent standard error of the mean. Control = without liming and straw retention; L = liming; RS = rice straw retention; L+RS = combined liming and straw retention.

N uptake

Like grain yield, N uptake of both early- and late-rice was significantly increased by both liming and straw retention (Table 2 and Figure 2). Liming significantly interacted with straw retention to improve N uptake in the late-rice growing season, but not in the early-rice season.

Table 2. Results (*F*-values) of ANOVAs on the effects of liming (L) and rice straw retention (RS) on the aboveground N uptake in 2015 and 2016.

Source of variations	2015		2016	
	Early rice	Late rice	Early rice	Late rice
L	12.7*	34.9**	15.6**	78.6**
RS	17.7**	26.1**	37.1**	54.4**
L×RS	NS	18.7**	NS	27.2**

Levels of significance indicated: NS = not significant; * Significant at $P \le 0.05$; ** Significant at $P \le 0.01$.

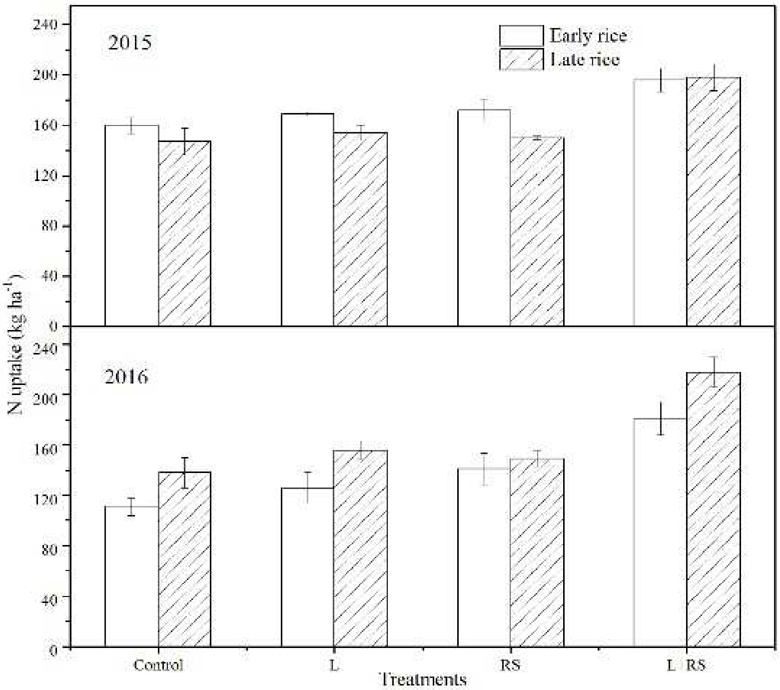

Figure 2. Effects of liming (L) and rice straw retention (RS) on the aboveground N uptake in 2015 and 2016. Error bars represent standard error of the mean. Control = without liming and straw retention; L = liming; RS = rice straw retention; L+RS = combined liming and straw retention.

Discussion and Conclusions

In agreement with previous results, liming and straw incorporation could significantly increase rice yield in acidic soils (Fageria et al. 2004; Huang et al. 2013). Furthermore, there were synergistic effects of liming and straw incorporation to improve yield in the late rice season. The reason may be that liming enhance the rate of straw decomposition and thus mitigate the N immobilisation due to the high C:N ratio in crop residues. Our results demonstrated that liming significantly interacted with straw retention to improve the N uptake of late rice. Thus, our hypothesis that there were interactive effects of liming and straw retention in enhancing rice yield was supported. However, no interactive effects of liming and straw retention were found in the early rice season. As there is a more than 5-month fallow period following straw incorporation until the transplanting of early rice in the next year, the crop residues may have been decomposed to a large extent that the N immobilisation is mitigated during the early rice season (Huang et al. 2013). The present results also showed that there were no interactive effects of liming and straw retention in increasing the N uptake of early rice.

Both liming and straw retention could significantly enhance grain yield and N uptake in both early- and late-rice growing season in subtropical China. There were interactive effects of liming and straw retention on late-rice yield in both years, but not for early rice. Therefore, crop residues should be incorporated into paddy fields along with liming to improve both rice yield and soil fertility in subtropical China.

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