Field Crops Research 216 (2018) 217–224

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Liming and straw retention interact to increase nitrogen uptake and grain yield in a double rice-cropping system

Ping Liao[a], Shan Huang[a,*], Natasja C. van Gestel[b], Yongjun Zeng[a], Ziming Wu[a], Kees Jan van Groenigen[c]

[a] Ministry of Education and Jiangxi Key Laboratory of Crop Physiology, Ecology and Genetic Breeding, Jiangxi Agricultural University, Nanchang, China
[b] Climate Science Center, Texas Tech University, Lubbock, TX, United States
[c] Geography, College of Life and Environmental Sciences, University of Exeter, Exeter, UK

ARTICLE INFO

Keywords:
Crop residue
Subtropical
Enzyme activity
Litter decomposition
Nitrogen availability

ABSTRACT

Liming and straw retention are often applied to increase yield in rice cropping systems on acidic soils. Although these practices affect soil fertility and rice growth through different mechanisms, it is still unclear whether or how these two management practices interact. Here we report on the first experiment to study the interaction between liming and straw management practices on rice yield. We conducted a two-year factorial field experiment 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. We found that straw retention significantly interacted with liming to increase rice yields; without liming, straw retention increased yield by 4.2% on average, whereas with liming, straw retention increased yield by 11.6%. Straw retention also significantly interacted with liming to improve N uptake, with a stronger response for late rice compared to early rice. Liming and straw retention increased soil N availability and the activities of soil enzymes involved in both carbon and N cycling, suggesting increased organic matter decomposition and enhanced N mineralization rates. Across treatments, rice yields significantly correlated with soil N availability. Therefore, we conclude that in this short-term experiment, liming and straw retention interacted to increase rice yield, likely due to their effect on soil fertility and plant N uptake.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for nearly half of the world's population. China is the world's largest rice producer, and thus China's rice cropping systems play a critical role in bolstering global food security (Alexandratos and Bruinsma, 2012). The double rice-cropping system (i.e., rice is cropped twice annually) accounts for nearly 40% of the rice planting area in China (Ministry of Agriculture of China MOA, 2017). However, increasing evidence suggests that rice yields in China have stagnated, particularly in subtropical regions (Ray et al., 2012; Li et al., 2016; Liu et al., 2016). Declining soil fertility, e.g., soil nutrient depletion and soil acidification, may be an important factor leading to the stagnation of rice yield (Ladha et al., 2003; Bi et al., 2009; Chen et al., 2016).

A number of studies have shown that long-term straw retention can increase rice yield due to nutrient replenishment and improved soil fertility (Malhi et al., 2011; Serraj and Siddique, 2012; Huang et al., 2013; Murphy et al., 2016). However, the short-term effect of crop residue incorporation on rice yield varies (Singh et al., 2008). For instance, several short-term studies have reported that straw retention may not increase or may even lead to a reduction in rice yield in the first one or two growing seasons, which is mainly attributed to the high carbon (C): nitrogen (N) ratio of crop residues that results in microbial N immobilization (Singh et al., 2008; Zhang et al., 2015; Pan et al., 2017). Furthermore, the anaerobic decomposition of organic matter may lead to the accumulation of organic acids that adversely affect rice growth (Singh et al., 2008). Growth inhibition may be substantial, especially for late rice in double rice-cropping systems in China, where the second crop is usually established within one week following the harvest of the first crop (Xu et al., 2010).

In addition, soil acidification is an important factor limiting rice yield, particularly in subtropical China due to the inherent low soil pH and excess N input (Guo et al., 2010). The application of lime is a common practice for ameliorating soil acidity and enhancing crop yield

* Corresponding author at: Ministry of Education and Jiangxi Key Laboratory of Crop Physiology, Ecology and Genetic Breeding, Jiangxi Agricultural University, Nanchang 330045, China.
E-mail addresses: 763979314@qq.com (P. Liao), ecohs@126.com (S. Huang), natasja.van-gestel@ttu.edu (N.C. van Gestel), zengyj2002@163.com (Y. Zeng), wuzmjxau@163.com (Z. Wu), KJ.VanGroenigen@exeter.ac.uk (K.J. van Groenigen).

https://doi.org/10.1016/j.fcr.2017.11.026
Received 28 October 2017; Received in revised form 25 November 2017; Accepted 26 November 2017

in acidic soils (Alleoni et al., 2010; Caires et al., 2015; Holland et al., 2018). Because liming generally increases C solubility and microbial activity, it can promote the mineralization of organic matter (Page et al., 2009; Fornara et al., 2011; Ahmad et al., 2014; Aye et al., 2016; Heyburn et al., 2017). Therefore, we hypothesized that liming reduces the short-term adverse effect of straw incorporation on rice growth and enhances plant N uptake. To test our hypothesis, we conducted a two-year factorial field experiment to investigate the interactive effect of liming and straw retention on rice yield, N uptake, and microbial activity in a double rice-cropping system in subtropical China.

2. Materials and methods

2.1. Site description and experimental design

The experiment was conducted in a rice paddy field in 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 the previous year until April of the following year). This site has a typical subtropical climate with a mean annual precipitation of 1650 mm and a mean annual temperature of 17.5 °C. Monthly mean air temperature and precipitation over the period 2015–2016 are shown in Fig. S1. The soil developed from Quaternary red clay is classified as a Typic Stagnic Anthrosol (IUSS Working Group, WRB, 2006). Prior to the experiment, soil from the upper 15 cm depth contained 18.1 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, 115 mg kg^{-1} available N (alkaline hydrolyzable-N), 15.9 mg kg^{-1} available P (Olsen-P), and 17.0% clay (< 0.002 mm) with an initial pH of 5.2.

A factorial experiment that included two factors (liming and rice straw retention) was established following a completely randomized block design with three replicates. Each plot was 25 m^2 in size (5 m × 5 m); plots were separated by 20-cm thick levees with plastic covering. The four treatments included straw removal without liming (−RS − L), straw removal with liming (−RS + L), straw retention without liming (+RS − L), and straw retention with liming (+RS + L). Thus, our field experiment consisted of twelve plots. Half of these plots received no lime; the other half of the plots received lime in the form of $Ca(OH)_2$, which was broadcast once before soil plowing in the early-rice season in 2015 at a rate of 2.1 t ha^{-1}. The quantity of lime required was determined by adding 10.0 g of surface soil (0–15 cm) (sieved through a 2 mm mesh) to 40 mL 0.2 mol L^{-1} $CaCl_2$ followed by titration with 0.15 mol L^{-1} $Ca(OH)_2$ to increase the soil pH to 7.0 (Lu, 2000). In half of the limed plots and half of the unlimed plots, aboveground straw was removed after each harvest. In the other half, aboveground straw was cut into 10-cm long pieces (10-cm residual stubble height). The chopped straw was incorporated into the soil by plowing following the harvesting of the early rice in mid-July. By contrast, the straw was left on the soil surface after the late rice was harvested in late October, and the residues were incorporated into the soil by plowing in early April of the following year. Other practices, which included inorganic fertilizer application, irrigation, and plant control, were the same for all plots. The rates of inorganic N, P_2O_5, and K_2O fertilizers were 120, 75, and 75 kg ha^{-1} for the early rice and 150, 75, and 75 kg ha^{-1} for the late rice, respectively. Half of the inorganic N and K fertilizers and all the P fertilizer were applied as basal dressing. Twenty percent of the N fertilizer was broadcast 10 days following rice transplanting; the remaining 30% of the N fertilizer and the other half of the K fertilizer were top-dressed at the panicle initiation stage in each rice-growing season. The inorganic N, P, and K fertilizers were applied in the form of urea, calcium magnesium phosphate, and potassium chloride, respectively.

An inbred rice variety 'Zhongjiazao 17′ and a hybrid rice variety 'Wuyou 308′ were used in the early- and late-rice season, respectively. Seedlings were grown in a seedbed from pre-germinated seeds, and were transplanted at the seedling age of 30 days and 25 days for the early and late rice, respectively. The seedlings were transplanted on 24 April and 22 July in the early- and late-rice season, respectively, in 2015; the corresponding dates for 2016 were 21 April and 20 July. Transplanting was performed at a spacing of 13.2 cm × 23.1 cm with four seedlings per hill for the early rice and 13.2 cm × 26.4 cm with two seedlings per hill for the late rice. The field was maintained under flooded conditions with a water depth of about 3 cm from transplanting until midseason drainage. A one-week midseason drainage was conducted about 28 days and 18 days following transplanting the early and late rice, respectively. The field was then intermittently irrigated but without water logging until one week before maturity. Pesticides and herbicides were applied according to standard commercial practice.

2.2. Measurements

2.2.1. Grain yield and yield components

At maturity, 12 hills were sampled diagonally from a 5 m^2 harvest area to determine the yield components following the method of Xu et al. (2010). The filled spikelets were separated from unfilled spikelets by submerging them in tap water. Grain yield was determined from a 5 m^2 sampling area in each plot and then was adjusted to a moisture content of 0.14 g H_2O g^{-1} fresh weight.

2.2.2. Nitrogen uptake

At maturity, plant samples were separated into leaf blades, stems (leaf sheaths and culms), and panicles. The plant materials were dried at 105 °C for 30 min to remove greenness and then at 70 °C to a constant weight. Tissue N concentration was determined by micro Kjeldahl digestion to calculate the aboveground total N uptake (Lu, 2000).

2.2.3. SPAD values

We determined the SPAD values on the 30 uppermost completely unfolded leaves per plot using a chlorophyll meter [SPAD-502, Soil-Plant Analysis Development (SPAD) Section, Minolta Camera Co., Osaka, Japan] at the mid-tillering (MT), panicle initiation (PI), heading (HD), and maturity (MA) stages.

2.2.4. Soil properties

In the first year of our experiment, we collected five soil cores (3 cm in diameter) to a depth of 15 cm in each plot at the MT, PI, HD, and MA stages for both early and late rice. Soil cores were pooled per plot as a composite sample, air-dried and then passed through a 2 mm sieve for analyses. Alkaline hydrolyzable-N was determined using the microdiff ; ;usion method with NaOH (Lu, 2000).

At the MA stage for late rice in the second year of our experiment, we collected another five soil cores (3 cm in diameter) per plot. The samples were pooled, dried and sieved as described above. Soil pH was measured using a pH meter in a 1:2.5 (*w/w*) soil to water mixture. Soil total N was determined by dry combustion using an elemental analyzer (Elementar, Vario Max, Germany). Soil enzyme activities were assayed using air-dried samples as described by Guan (1986). Briefly, urease activity, expressed as mg NH_3-N g^{-1} h^{-1}, was determined using urea as a substrate, and the soil mixture was incubated at 37 °C for 24 h, after which the produced NH_3-N was determined using a colorimetric method. Invertase activity, expressed as mg glucose g^{-1} h^{-1}, was determined using sucrose as a substrate under incubation at 37 °C for 24 h; glucose production was determined using a colorimetric method. Cellulase activity, expressed as mg glucose g^{-1} h^{-1}, was determined using carboxyethyl cellulose as a substrate under incubation at 37 °C for 72 h; glucose production was measured using a colorimetric method. Protease activity, expressed as μg tyrosine g^{-1} h^{-1}, was determined using casein as a substrate under incubation at 37 °C for 24 h; tyrosine production was determined using a colorimetric method.