Field Crops Research 184 (2015) 50–57

Contents lists available at ScienceDirect

Field Crops Research

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

Crop management based on multi-split topdressing enhances grain yield and nitrogen use efficiency in irrigated rice in China

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ARTICLE INFO

Article history:
Received 7 July 2015
Received in revised form 23 August 2015
Accepted 5 September 2015
Available online 19 September 2015

Keywords:
Multi-split topdressing
Nitrogen use efficiency
Grain yield
Crop management
Rice

ABSTRACT

Numerous prior studies on improving crop managements in new commercial rice varieties focused on optimizing N rates and its splitting during the rice growth cycle. Studies concerning how multi-split topdressing fertilizer-N can affect rice growth, grain yield, and nitrogen use efficiencies (NUEs) are limited. A field experiment was conducted in an irrigated rice system using hybrid rice variety Yangliangyou-6 during 2012 and 2013 in Wuxue county, Hubei Province, China. Five treatments were investigated, including nitrogen omission plot (N0), and the other four typical crop management patterns in irrigated rice system in southern China: the conventional farmer's practice (FP), modified farmer's practices (MFP), super-high-yielding management (to obtain a high yield regardless labour or fertilizer input, SHY), and multi-split topdressing fertilizer-N (MST). Data from the two years revealed that the SHY produced the highest grain yields (10.27 and 9.63 t ha^{-1}) in two of the four trials, while the MST achieved the highest grain yields (10.08 and 9.67 t ha^{-1}) in the other two trials. The higher grain yields of the SHY and MST were ascribed to the greater N uptake, biomass accumulation, and total spikelet numbers per m^2 compared to the other treatments. The FP showed a lower N uptake, agronomic efficiency (AE), and recovery efficiency (RE) than those of the MFP, SHY, and MST. Compared with the FP, the MFP increased the planting density and delayed partial fertilizer-N at the panicle initiation stage, which resulted in greater N uptake and RE. However, the MST reduced N application but significantly increased N uptake, AE, and RE compared to that observed in the FP and MFP. Overall, these results indicate that the crop management for N application to achieve greater yield and higher NUEs in hybrid rice is primarily associated with fertilizer-N application splits, rather than N rates. Our findings demonstrate that the crop management based on the MST may obtain a higher grain yield and reduced N application comparing to other crop managements, which results in a greatest profit assuming it is adapted by the large-scaled farmers in South China. Therefore, the MST is recommended as one of alternative approaches to synchronously increase the grain yield, NUEs and production profit with a lower N application in the irrigated rice systems in the Yangtze River Basin in China.

1. Introduction

The application of chemical nitrogen fertilizer has contributed to a spectacular grain yield increase for irrigated rice production in China between the 1960s and 1990s. Recent studies show that yields could not increase as rapidly as before despite the increasing rate of fertilizer application, which is mainly due to the excessive and inappropriate timing of fertilizer application (Lemaire and Gastal, 1997; Peng et al., 2002). It was reported that the average N rate was 193 kg ha^{-1} for irrigated rice in 2006 in China (Peng et al., 2010), approximately 90% higher than the world average (FAOSTAT, 2008). Many rice farmers in China apply 50–90% of the N as a basal dressing and an early top-dressing within the first 10 days after transplanting to reduce transplanting shock and stimulate early tillering (Zhang et al., 2011). Clearly, this large amount of N fertilizer at the early growth stages has resulted in a poor synchronization between the soil N supply and the crop demand, leading to a high

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http://dx.doi.org/10.1016/j.fcr.2015.09.006
0378-4290/

soil inorganic N concentration before the occurrence of rapid crop N uptake (Chen et al., 2006).

The agronomic efficiency of fertilizer-N, which is defined an incremental increase in grain yield resulting from N application, decreased from 15 to 20 kg kg^{-1} in 1958 to 1960 to 9.1 kg kg^{-1} in 1981 to 1983, and declined even further (Peng et al., 2002, 2006). The low nitrogen use efficiencies (NUEs) not only have decreased the stability of the rice grain yield, but have also raised concerns about environmental sustainability and these outcomes leading to water eutrophication (Guo et al., 2010).

Numerous studies have pioneered various improved nitrogen-management approaches to achieve higher NUEs in irrigated systems, such as specific site nitrogen management (Peng et al., 2010; Thakur et al., 2014), deep placement of fertilizer (Li et al., 2014), precise quantitative cultivation techniques (Ling et al., 2005), a set of integrated soil–crop system management practices (Chen et al., 2014), and a computer-based decision support system for fertilizer management (Bouman and Van Laar, 2006; Jing et al., 2007). These improved nitrogen management technologies either optimize the total N input, adjust the topdressing time, or decrease the N losses. However, those fertilizer-N applications within a rice growth cycle are split fewer than 3–4 times, which produces 3 to 4 greater ammonia concentration peaks in paddy soil. Previous studies observed that higher ammonia concentration leads to a large amount of N loss through leaching and volatilization (Tian et al., 2007; Xu et al., 2012). In addition, most optimal fertilizer-N management technologies require extensive technical support based on monitoring tools or laboratory analysis, which limits its dissemination to farmers.

Controlled and slowly released fertilizer can control nutrients release rate so that nutrient availability to the plant lasts significantly longer than with traditional fertilizers (Trenkel, 2010), which results in significant increases in grain yield and NUE in rice (Fu et al., 2001). Because the controlled-release fertilizer is not satisfactory to rice farmers due to its high cost, an alternative approach or technology needs to be developed. Ohnishi et al. (1999) applied a topdressing of urea 6 times to rice throughout the whole growing season in the northeast of Thailand; they observed that the new method significantly increased the nitrogen recovery efficiency compared with the application of organic fertilizers. We also observed that real-time fertilizer-N management based on real-time monitoring N status of crop canopy using SPAD was effective in achieving higher grain yield and fertilizer-N use efficiency in the two hybrid rice varieties, Shanyou-63 and Liangyoupei-9, when applied at 120–165 kg N ha^{-1} with 5–6 splits of topdressing (He et al., 2008).

Most prior studies on improving fertilizer-N management with new commercial rice varieties focused on N rates and 3–4 times splitting (Peng et al., 1996, 2006; Wang et al., 2001; Dobermann et al., 2002). Studies on crop management patterns of incorporated nutrient management technologies and cultivations in irrigated rice are limited, particularly concerning the effects of multi-split topdressing fertilizer-N (MST) on rice growth, grain yield, along with its NUEs. The objectives of this study were to (1) compare the differences of rice growth and grain yield development between MST and other crop management patterns; (2) evaluate the N uptake and NUEs for these crop management patterns in irrigated systems in China.

2. Materials and methods

2.1. Experimental design and crop management

The experiments were conducted in Wuxue County in 2012 and 2013. The county lies southeast of Hubei Province and has a typical sub-tropical climate in the central part of the Yangtze River Basin in China. In 2012, three trials were carried out at the villages of Lanjie (30°0′N 115°44′E), Zhougan (29°29′N 115°37′E), and Zhangbang (29°59′N 115°36′E), respectively. The soil type is hydromorphic alluvial loam paddy soil at Lanjie and Zhougan villages and hydromorphic yellow-reddish clay paddy soil at Zhangbang Village. The soil chemical properties are presented in Table 1. Since there were not significant differences observed between locations in 2012, only one field trial was repeated at Lanjie Village in 2013.

We investigated the hybrid *indica* variety Yangliangyou-6 in this study, which has been certificated as a super-high-yielding variety by MOA of China and widely adopted in southern China in recent years. Five treatments were investigated, including nitrogen omission plot (N0), and other four typical crop management patterns in the irrigated rice system in southern China: the conventional farmer's practice (FP), modified farmer's practices (MFP), super-high-yielding management (to obtain a high yield regardless labour or fertilizer input, SHY), and MST. The crop establishment and nutrients managements detail for each treatment is given in Table 2. The plots were arranged in a randomized complete block design with four replications using a plot size of 7 m × 4.5 m. The seeding and transplanting dates in 2012 were May 11 and June 14, May16 and June 16, and May 16 and June 17 in Lanjie, Zhougan, and Zhangbang villages, respectively; the seeding and transplanting dates in 2013 in Lanjie Village were May 12 and June 15, respectively. The soils were mechanically ploughed and harrowed before sowing and transplanting. The basal fertilizers were applied one day before transplanting. Weeds, pests and diseases were intensively controlled to prevent yield loss. A water layer approximately 10 cm deep was maintained during tillering stage. This was then drained starting at the maximum tillering stage for 7–10 days and then refilled to a 5 cm layer when the visible water layer had disappeared.

2.2. Sampling and growth measurement

At the mid-tillering (MT), panicle initiation (PI), and full heading (HD) stages, 6 hill samples were taken from each plot. After investigated the tiller numbers and plant heights of each hill, the plants were then separated into green leaf blades and stems plus leaf sheaths at the MT and PI stages, and at HD the plants were separated into green leaf blades, stems plus leaf sheaths, and panicles. Green leaf blade areas were measured by a leaf area meter (Licor-3100C, Licor, USA).

At the maturity stage (MS), a 5 m^2 area in each plot was harvested to determine the grain yield and the value was adjusted to 14% moisture. To determine the yield components, 8 hill samples were taken from each plot. After determining the number of panicles, spikelets from the panicles were manually threshed. The spikelets were immersed in tap water and separated into filled and unfilled spikelets. Both the filled and unfilled spikelets were air dried and sub-samples of 30 g filled, and 2 g unfilled spikelets were then weighed and used to calculate the thousand-grain weight and grain-filling percentage. All the filled and unfilled spikelets were weighed three times as replications. The dry matter accumulated at each growing stage was determined by drying all the plant parts of each sample at 80 °C to a constant weight and then weighed.

2.3. Nitrogen accumulation and NUEs

The straw, the filled and unfilled grain of the maturity samples were ground into powder by a small grinding machine, and approximately 0.15 g of powder were taken for digestion using the Kjeldhal method. The digested solution was then diluted for analysis of ammonia concentration by an Alliance-Futura NP analyser (Alliance Instruments, France), and the N content was calculated.