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Effects of integrated high-efficiency practice versus conventional practice on rice yield and N fate

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ABSTRACT

With the aim of achieving a win–win goal of increased productivity and high nitrogen use efficiency (NUE), an integrated high-efficiency (IH) practice, which combined optimal fertilization and irrigation management practices with improved crop cultivation technologies, is projected to replace the local conventional (CT) practice for rice production in the Taihu Lake region. A field experiment was conducted at the Changshu Agro–Ecological Experimental Station located in the Taihu Lake region to compare dry matter yields and nitrogen processes with IH and CT agronomic schemes. ^{15}N-labeled urea was applied into micro-plots to investigate the fate of fertilizer-N. Both the aboveground biomass and N uptake by the plants were significantly affected ($p < 0.05$) by agronomic scheme. Grain yield and straw biomass were 14% and 13% higher under IH than those under CT (8.76 versus 7.67 Mg ha^{-1} and 11.3 versus 9.96 Mg ha^{-1}), respectively. 48% and 32% of fertilizer-N was absorbed by the plants for the IH and CT treatments, respectively. Irrespective of agronomic scheme, ca. a quarter of fertilizer-N accumulated in 0–60 cm soil layers after rice was harvested. Ammonia volatilization was an important N loss pathway and for the IH and CT treatments accounted for 6.7% and 14% of the applied N, respectively. And fertilizer-N that was unaccounted for corresponded to 22% and 30% of the applied N for the IH and CT treatments, respectively. The present study suggests that optimal fertilization and irrigation management in combination with improved crop cultivation is likely to positively affect rice production and agricultural environment in the Taihu Lake region.

1. Introduction

China is now facing the unprecedented challenge of agricultural production. By 2030, its grain demand is expected to increase by 40% to 680 Mt (Zhao et al., 2008), resulting from continuing population growth and changes in food consumption patterns (Pingali, 2007; Tilman et al., 2011). This rising demand will call for 2% annual increase in total grain production from arable land currently available. However, its arable land has declined to only 0.106 ha per capita, due to the processes of agricultural restructuring, rural urbanization, industrialization, and economic reforms (Khan et al., 2009). The only way against the challenge will require significant increases in grain production per unit area and rice in particular.

China's grain production has more than tripled in the past 50 years, mainly from increased yield (FAOSTAT, 2014). The intensive high-yield agriculture depends on great inputs of fertilizers, especially synthetic N fertilizer (Tilman et al., 2002). For example, the annual application rate of N fertilizer for the conventional agricultural practices in major grain production areas is now up to 600 kg N ha^{-1} for typical double-cropping systems (Zhu and Chen, 2002; Ju et al., 2009). However, when N fertilizer is applied to soil it is not used efficiently, and only 35% or less of applied N fertilizer is taken up by crops in farms' fields (Raun and Johnson, 1999; Zhu and Chen, 2002). A considerable amount of the applied N fertilizer is lost to the environment through different pathways, contributing to the degradation of air, water and soil quality (Vitousek et al., 2009; Guo et al., 2010; Liu et al., 2013). The conventional agricultural practices, which are characterized by great external N inputs with low NUE, are unlikely to be as effective at increasing yield without degrading environmental quality.

Meeting the demands of increasing yields with protecting environmental quality poses a large challenge for domestic grain production. This challenge requires significant increases in

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grain production per unit synthetic N, viz., NUE (Foley et al., 2011; Chen et al., 2014). There are a variety of improved agricultural practices that have shown increased NUE, such as genetic improvements, optimal water and fertilizers management, and improved crop cultivation (Cassman et al., 2002, 2003; Tilman et al., 2002; Xu et al., 2012). However, in many cases, grain yield is unlikely to be significantly increased by adopting a single high-efficiency practice. Considering their synergistic effects on grain yield response to the applied N, these high-efficiency practices should be applied in an integrated manner (Dobermann, 2007).

Taihu Lake region, within lat. 30°5′N and 32°8′N and long. 119°8′E and 121°5′E is a major grain production region in China, and summer rice–winter wheat rotation is a common farming pattern in the region. Local agricultural system has been challenged by stagnant or declining grain production per unit area (CSSD, 2010), and by N pollution (Xing and Zhu, 2000; Zhu and Chen, 2002; Xie et al., 2008). Integrated high-efficiency practices are likely to respond to the challenge (Zhang et al., 2011, 2012). In this study, an integrated high-efficiency practice was developed by combining improved crop cultivation technologies with optimal water and fertilizers management practices, including low sowing rate, high plant density, alternate wetting and drying irrigation, low application rate and high application frequency. A rice-season field experiment was conducted with the following main objectives: (a) to examine whether the integrated high-efficiency practice affects rice yield and NUE, (b) to quantify the fate of ^{15}N-labeled fertilizer-N applied to the paddy soil. Our study compared two distinct agricultural practices, viz., the conventional agricultural practice in the Taihu Lake region and an integrated high-efficiency practice.

2. Materials and methods

2.1. Experimental site summarization

The field experiment was carried out at the Changshu Agro–Ecosystem Experimental Station (lat. 31°32′45″N, long. 120°41′57″E), which was located in Suzhou city, Jiangsu province, China. The site has a typical humid subtropical monsoon climate with an average annual temperature of 15.5 °C and an average annual precipitation of 1038 mm. The site soil is classified as Anthrosols, a gleyed paddy soil derived from lacustrine deposits. In 0–20 cm soil layer, pH (H_2O) was 7.36, soil organic matter was 35.0 g kg^{-1}, total N was 2.09 g kg^{-1}, total P was 0.93 g kg^{-1}, Olsen-P was 5.00 mg kg^{-1}, NH_4OAc-extractable K was 121.3 mg kg^{-1}, and cation exchange capacity was 17.7 cmol kg^{-1}.

A summer rice (*Oryza sativa* L.) and winter wheat (*Triticum aestivum* L.) rotation has been cultivated in the experimental field for the past several decades, and there was a low permeability layer at ca. 20 cm soil depth.

2.2. Experimental design and agricultural management practices

The present study was performed in the 2010 rice season. There were three treatments as follows: no N fertilizer application (NF), local conventional (CT) practice, and integrated high-efficiency (IH) practice. Agricultural management practices except N fertilization were identical for the NF and CT treatments. Improved crop cultivation technologies has been integrated with optimal water and fertilizer management practices in the IH treatment, including low sowing rate, high plant density, alternate wetting and drying irrigation, low fertilization rate and high fertilization frequency. A randomized complete block design with all the treatments and four replications, was established in twelve experimental field plots (6.7 m × 6.0 m). Each plot was isolated with field ridges (30 cm at the base and 30 cm of height) covered with plastic film to prevent lateral water movement.

After land preparation, rice seedling was transplanted with 20 cm × 20 cm hill spacing to CT plots and 20 cm × 15 cm to IH plots on June 18 and harvested on October 30, 2010 (Table 1). Urea (N 46%) was applied to supply 300 kg N ha^{-1} for the CT treatment and 225 kg N ha^{-1} for the IH treatment, and single superphosphate (P_2O_5 16%) and potassium chloride (K_2O 60%) to supply 60 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1} for both treatments. N and K fertilizers were broadcast at 180 kg N ha^{-1} and 120 kg K_2O ha^{-1} as basal fertilizers for the CT treatment and at 112.5 kg N ha^{-1} and 60 kg K_2O ha^{-1} for the IH treatment on the day before transplanting. P fertilizer was only applied as basal fertilizer for both treatments. Top dressing of N fertilizer was split into two doses of 60 kg N ha^{-1} on June 26 and August 25 for the CT treatment and three doses of 22.5 kg N ha^{-1} on June 26 and both 45 kg N ha^{-1} on July 30 and August 25 for the IH treatment. K fertilizer was top-dressed at 60 kg K_2O ha^{-1} on July 30 only for the IH treatment. For all the treatments, application of pesticide and herbicide were same. The CT plots were regularly irrigated to maintain ca. 5 cm of surface water until 1 week before rice was harvested, but the soil was not irrigated to enhance plant roots growth during the later tillering period (called mid-season aeration). At the same time, alternate wetting and drying irrigation was applied for the IH plots. The surface water of the IH plots was maintained at 2–3 cm above the soil surface in the first 2 weeks after transplanting. Hereafter, the IH plots were irrigated to 2–3 cm of surface water until the surface water dropped below the soil surface. The alternate wetting and drying irrigation lasted until 1 week before rice was harvested.

A micro-plot was established inside each plot by setting up a plastic pipe (0.38 m in internal diameter and 0.5 m in height) into the soil before the study was initiated. The pipe was inserted into the soil to a depth of 0.35 m, the top of which was 0.15 m above the soil surface. Based on the plant density in the plots, three and four hills of rice seedling were transplanted into the CT (NF) and IH micro-plots, respectively. ^{15}N-labeled urea (10% atom ^{15}N) was applied to determine how much fertilizer-N was recovered by the

Table 1
Fertilization, irrigation and cultivation practices summarization for all the treatments.

Practices		NF	CT	IH
Fertilization	N	No N application	Application in three splits: basal 60%, both the first and third topdressing 20%	Application in four splits: basal 50%, the first topdressing 10%, both the second and third topdressing 20%. 25% less N rate than CT
	P	Only as basal application		Only as basal application
	K	Only as basal application		Application in two splits: both basal and the second topdressing 50%
Irrigation	Continuous flooding except for mid-season aeration and final drainage			Alternate wetting and drying irrigation except for mid-season aeration and final drainage
Cultivation	20 cm × 20 cm hill spacing			20 cm × 15 cm hill spacing. 15% less seeding rate than CT

NF, CT and IH represent no N fertilizer application, local conventional, and integrated high-efficiency treatments, respectively.