Water-saving irrigation practices for rice yield information and nitrogen use efficiency under sub-tropical monsoon climate

Zheng Huabin, Zhou Wei, Chen Qimin, Chen Yuanwei and Tang Qiyuan

ABSTRACT

Simple and practical water-saving irrigation practices (WIP) with nitrogen-reduction are beneficial to the development of rice cultivation technology with promotion of resource-conservation and environmental friendliness. The effects of WIP with nitrogen-reduction on population quality, annual yield and nitrogen use efficiency were studied by a field experiment. WIP could maintain or increase the annual yield of rice production models. The highest annual yield of more-water-saving irrigation practice (WIP150) was 8.42 t hm^{-2} for the double-season rice production model and 12.71 t hm^{-2} for the ratoon rice production model, respectively. Compared with non-application of nitrogen, the annual yield of nitrogen-reducing practice (NRP) and farms' fertilizer practice (FFP) increased significantly ($p < 0.01$), while a non-significant difference of annual yield between the FFP and NRP was observed; the annual yield of the NRP and FFP was 9.73 and 10.02 t hm^{-2} of the double-season rice production model, and 12.84 and 14.34 t hm^{-2} of the ratoon rice production model, respectively. AE_N, PE_N, PFP_N and RUE_N of the NRP were higher than those of the FFP. Therefore, observing the change of water layer in the soil layer via a simple self-made PVC indicator tube, reducing about 20% nitrogen quantity was a feasible and simple cultivation technique for water-saving and nitrogen-reduction in the rice production models.

Key words | annual yield, double rice, nitrogen use efficiency, ratoon rice

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INTRODUCTION

Scarcity of water for agricultural production is becoming a major problem in many countries, particularly the world's leading rice-producing countries, China and India, where competing and growing demands for freshwater are coming from other sectors (Satyanarayana *et al.* 2007; Xiong *et al.* 2010). The sustainability of irrigated rice systems is increasingly threatened by the scarcity of fresh water resources (Li *et al.* 2006; Nie *et al.* 2012). Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice. Therefore, in addition to the development of water-saving and drought-resistant rice varieties (Luo 2010; Serraj *et al.* 2011), water-saving irrigation is another effective and important consideration. Different water-saving irrigation practices have been widely studied across the country, such as intermittent irrigation, alternating wetting and drying irrigation, and mid-season flooding and drainage with intermittent irrigation (e.g. Qin *et al.* 2010; Peng *et al.* 2011; Liu *et al.* 2013; Li *et al.* 2018). These controlled irrigation practices usually save water while decreasing rice yields (e.g. the review of Linquist *et al.* 2015) or maintaining and increasing rice

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yields (e.g. Liu *et al.* 2013; Li *et al.* 2018). In addition, previous studies have reported that global warming potential (GWP of CH_4 and N_2O emissions) was reduced by 45%–90%, and grain As concentrations were reduced by up to 64% under water-saving irrigation practices (the review of Linquist *et al.* 2015). Therefore, water-saving irrigation practices have met with the development of rice cultivation technology for promoting resource-conservation and environmental friendliness.

However, existing water-saving irrigation practices including intermittent irrigation and alternating wetting and drying irrigation need a subsidiary measuring instrument for judging irrigation or not, such as by soil water potential or soil moisture content. So, it has been difficult and uneconomic to adopting these water-saving irrigation practices for the farmer. In addition, nitrogen is an essential nutrient element in rice, and rational application of nitrogen fertilizer has been one of the most important cultivation measures in rice production. High nitrogen surplus (nitrogen fertilizer applied in excess of uptake by crops) and low nitrogen use efficiency (PFPN, nitrogen partial factor productivity, in kilograms of grain per kilogram of nitrogen applied) occur in high yields (owing to high nitrogen application), indicating the inefficiency and environmental damage associated both with farms' fertilizer practices and with attempts to increase yields simply by increasing inputs (Tilman *et al.* 2001; Chen *et al.* 2014). Reasonable nitrogen practice could improve rice yield, quality and nitrogen use efficiency. There is an interaction effect between water condition and fertilizer, namely, the changing of soil fertility and the nutrient absorbability of the rice with the changing of water condition in the paddy field, which will affect the growth and development of the rice.

In Hunan Province, the planting areas of the ratoon rice production model and double-season rice production model were 1,400 thousand hm^2 and 130 thousand hm^2, respectively. In this study, with the maneuverability of the water-saving measures as a starting point, we designed a simple self-made PVC indicator tube (Figure 1) for observing the change of water layer in the soil layer. The aim of the study was to investigate annual yield, aboveground biomass, and nitrogen use efficiency in the ratoon rice production model and double-season rice production model under the water regimes, which provided a feasible, simple and easy water-saving irrigation practice without sacrificing yield.

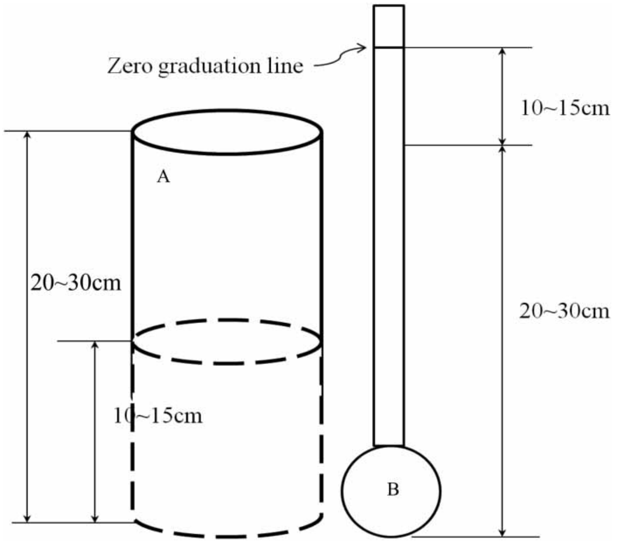

Figure 1 | A sketch of a simple PVC indicator tube including cylinder (A) and spherical buoy (B).

MATERIALS AND METHODS

Test site and materials

The experiment was carried out in the Datong Lake district of Yiyang city in 2016 and Yongan town of Liuyang city in 2017, and the climate of the site was sub-tropical monsoon climate. The average temperature was 18.3 °C (multi-year average 17.3 °C) in the Datong Lake district and 18.3 °C (multi-year average 17.5 °C) in Yongan town; total precipitation from April to October was 1,443 mm (multi-year average 1,240 mm) in the Datong Lake district and 1,365 mm (multi-year average 1,172 mm) in Yongan town. The tested varieties were Huanghuazhan (inbred rice) in the ratoon rice production model, Zhongzao 39 (inbred rice), Lingliangyou 104 (hybrid rice) for the early season and Wushansimiao (inbred rice) and Wuyou308 (hybrid rice) for the late season in the double-season rice production model.

Experimental design

Three water regimes were applied during the rice-growing seasons: (1) conventional irrigation practice (CIP): according to the local farmer's habit of irrigation, 30–50 mm water layer at the re-greening stage, 20–30 mm water layer continuously flooded at the tillering stage, and draining at late tillering and maturity stages; (2) water-saving irrigation practice (WIP100): after rice transplanting, 30–50 mm water layer at the re-greening stage, and the water is irrigated and dried naturally while the groundwater level is lower than 100 mm; (3) more-water-saving irrigation practice (WIP150): (W3): after rice transplanting, 30–50 mm water layer at the re-greening stage, and the water is irrigated and dried naturally while the groundwater level is lower than 150 mm. The self-made PVC indicator tube was used for observation (Figure 1), and the rest of the time there was no irrigation.

Three kinds of nitrogen quantity were adopted in the experiment: (1) non-application of nitrogen (N0); (2) farms' fertilizer practice (FFP): annual quantity of applying nitrogen in the ratoon rice and double rice model was 375 and 330 kg N hm^{-2}, respectively; and (3) nitrogen-reducing practice (NRP): based on the FFP, the annual quantity of nitrogen applied in the ratoon rice and double rice was reduced 24% and 20%, respectively.

A randomized complete block design was employed with three replicates; each plot area was 30 m^2 (5 m × 6 m) and separated by ridges (0.2 m high × 0.3 m wide). In order to prevent water movement between adjacent plots, the ridges were covered with plastic sheet inserted into the soil at a depth of 0.5 m.

In 2016, the annual quantity of nitrogen applied in the ratoon rice production model was with 60% in the main season and 40% in the ratoon season. In the main season, nitrogen fertilizer was split in four with 40% as basal fertilizer, 30% as tillering fertilizer, 20% as panicle fertilizer and 10% as budding fertilizer; phosphate fertilizer was applied at 105 kg P_2O_5 hm^{-2} as the base fertilizer, and potassium fertilizer was applied at 225 kg K_2O hm^{-2} (40% as base fertilizer, 40% as panicle fertilizer, 20% as budding fertilizer). In the ratoon season, all nitrogen fertilizer was applied 3 days after the main season rice was harvested; potassium fertilizer was applied at 45 kg K_2O hm^{-2}.

In 2017, the annual quantity of nitrogen applied in the double-season rice production model was with 45% in the early season and 55% in the late season. Nitrogen fertilizer was split in three with 50% as basal fertilizer, 30% as tillering fertilizer, 20% as panicle fertilizer; phosphorus fertilizer as basal fertilizer was applied at 75 kg P_2O_5 hm^{-2} in the early season and 90 kg P_2O_5 hm^{-2} in the late season; potassium fertilizer was applied at 120 kg K_2O hm^{-2} in the early season and 144 kg P_2O_5 hm^{-2} in the late season (50% as base fertilizer, 50% as panicle fertilizer). Weeds, diseases, and insects were intensively controlled throughout the entire growing season in both rice production models.

Aboveground biomass at the full heading stage

At the full heading stage, eight hills were sampled per replicate at different stages to determine the aboveground biomass after oven-drying at 70 °C to a constant weight. Leaf area index (LAI) was determined by a LICOR-3100 leaf area analyzer with specific leaf weight.

Yield and aboveground biomass at the mature stage

Ten hills were sampled diagonally from a 5 m^2 harvest area for each replicate at maturity to determine the panicle number per hill, aboveground total biomass, harvest index (HI), and yield components, as described by Zhang *et al.* (2009). Rice yield was determined from a 5 m^2 area per replicate and adjusted to a water content of 0.14 g g^{-1} fresh weight.

Nitrogen content in different parts of plants

Straw, filling grain and unfilling grain for each replicate at maturity were crushed by a micro-mill and stored in a vacuum bag. Total N was determined with the Kjeldahl method, involving two steps: (1) digestion of the sample to convert organic N into NH-N and (2) determination of NH-N in the digested sample by a Skalar San + flow injection analyzer.

Data processing and statistical analysis

Nitrogen use efficiency, including nitrogen agronomic efficiency (AE_N, kg kg^{-1} N), physiological efficiency (PE_N, kg kg^{-1} N), nitrogen partial factor productivity (PFP_N, kg kg^{-1} N), and nitrogen recovery use efficiency (RUE_N, kg kg^{-1} N), was calculated with the method of Xue *et al.* (2013). The transport rate of biomass before the full-heading stage (%) was the biomass difference of vegetative organs (stem and sheath, and leaf) between the full-heading stage and mature stage divided by the biomass of vegetative organs (stem and sheath, and leaf) at the full-heading stage; the contribution rate of biomass before the full-heading stage (%) was the biomass difference of vegetative organs (stem and sheath, and leaf) between the full-heading stage and mature stage divided by the rice grain yield. Statistical analyses were carried out using Statistix ver. 8.0 (2004).

RESULTS

Annual yield of different rice production models

There was no significant difference in the annual yield of the ratoon rice production model and the double rice model treated with different water regimes (Table 1). The highest annual yield for water-saving irrigation practice (WIP150) was 8.42 t hm^{-2} with the double-season rice production model and 12.71 t hm^{-2} with the ratoon rice production model, respectively. Compared with non-application of nitrogen (N0), annual yields of NRP and FFP increased significantly ($p < 0.01$), while no significant difference of annual yield between the FFP and the NRP was observed: the highest annual yield of the FFP was 10.02 t hm^{-2} with the double-season rice production model and 14.34 t hm^{-2} with the ratoon rice production model, respectively. There was no interaction between water treatment and nitrogen treatment.

Aboveground biomass of different rice production models

There was no effect on aboveground biomass at full-heading and mature stage under water-saving irrigation practices (WIP100 and WIP150) in the ratoon rice production model and double rice production model (Tables 2 and 3). There were differences of aboveground biomass at the mature stage between rice cultivars in the double-season rice production model, aboveground biomass of the WIP150 was lower than that of the CIP in the early season, and aboveground biomass of the WIP150 with the late rice cultivar WY308 was higher than that of the CIP. Similarly, there was no significant difference of aboveground biomass between the FFP and the NRP under different rice production models, and it was significantly higher than that of the N0 treatment. Other indicators, including leaf area index and crop growth rate, showed a similar trend with aboveground biomass.

Nitrogen use efficiency of different rice production models

Under the ratoon rice production model (Table 4), the highest nitrogen agronomic efficiency (AE_N) of the main and ratoon seasons was 15.60 kg kg^{-1} N and 16.19 kg kg^{-1} N with the water-saving irrigation practices (WIP150), respectively. A

Table 1 | Yield of ratoon rice and double rice production model under water-saving irrigation practice with N fertilizer management

	Ratoon rice production model (t ha^{-1})			**Double-season rice production model (t ha^{-1})**				
					Early rice yield		**Late rice yield**	
Treatment	**Annual yield**	**Main yield**	**Ratoon yield**	**Annual yield**	**LLY104**	**ZZ39**	**WSSM**	**WY308**
CIP	8.30a[#]	5.55a	2.75a	12.46a	6.66a	6.42a	5.40a	6.44a
WIP100	8.31a	5.43a	2.88a	12.40a	6.55a	5.99a	5.69a	6.56a
WIP150	8.42a	5.56a	2.87a	12.71a	6.64a	6.46a	5.80a	6.52a
FFP	10.02a	6.45a	3.57a	14.34a	7.87a	7.20a	6.52a	7.09a
NRP	9.73a	6.47a	3.26a	12.84a	7.09a	7.19a	6.25a	7.34a
N0	5.29b	3.61b	1.68b	9.29b	4.89b	4.48b	4.11b	5.10b
Water regime	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen	**	**	**	**	**	**	**	**
Water regime × Nitrogen	ns	ns	ns	ns	ns	ns	ns	ns

CIP, conventional irrigation practice; WIP100, water-saving irrigation practice; WIP150, more-water-saving irrigation practice.

[#] Different letters indicate statistical significance at the $p = 0.05$ level within the same column and the same year.

Table 2 | Aboveground biomass, leaf area index (LAI), harvest index(HI), crop growth rate(CGR), transport rate and contribution rate of aboveground biomass before the full-heading stage in the ratoon rice production model under water-saving irrigation practice with N fertilizer management

	Full-heading stage			**Mature stage**				
Treatment	**Aboveground biomass (g m^{-2})**	**LAI**	**CGR**	**Aboveground biomass (g m^{-2})**	**CGR**	**HI**	**Transport rate of aboveground biomass before the full-heading stage (%)**	**Contribution rate of aboveground biomass before the full-heading stage (%)**
Main season								
CIP	698.82a$^{\#}$	4.48a	6.26a	1,015.20a	7.39a	49.48a	25.74a	38.24a
WIP100	723.29a	4.54a	6.48a	1,018.70a	7.41a	50.24a	30.87a	46.82a
WIP150	688.30a	4.06a	6.17a	1,002.70a	7.30a	49.72a	27.69a	40.76a
FFP	848.97a	5.71a	7.65a	1,227.50a	8.96a	48.78 b	26.27b	39.92a
NRP	814.37a	5.53a	7.34a	1,186.60a	8.66a	49.56ab	26.13b	37.66a
N0	447.08b	1.85b	3.92b	622.50b	4.48b	51.11a	31.90a	48.24a
Ratoon season								
CIP	530.68a	1.61a	16.58a	649.59a	9.99a	42.35a	28.79a	55.77a
WIP100	499.14b	1.47a	15.60b	634.78a	9.77a	44.89a	28.58a	51.43a
WIP150	524.84ab	1.56a	16.40ab	665.95a	10.25a	43.20a	27.48a	50.64a
FFP	646.55a	2.13a	20.21a	803.87a	12.37a	45.42a	30.76a	55.81a
NRP	607.83b	1.81b	19.00b	762.95a	11.74a	45.18a	30.84a	55.21ab
N0	300.27c	0.70c	9.38c	383.50b	5.90b	39.85b	23.25b	46.81 b

$^{\#}$Different letters indicate statistical significance at the $p = 0.05$ level within the same column and the same year.

similar trend was found in the nitrogen physiological efficiency ($\mathrm{PE_N}$) and nitrogen partial factor productivity ($\mathrm{PFP_N}$). The highest nitrogen recovery use efficiency ($\mathrm{RUE_N}$) was with the CIP, while there was no significant difference between the treatments. $\mathrm{AE_N}$, $\mathrm{PE_N}$, $\mathrm{PFP_N}$ and $\mathrm{RUE_N}$ of the NRP in the main and ratoon seasons were higher than those of the FFP.

Under the double rice production model (Table 5), the highest $\mathrm{AE_N}$ and $\mathrm{PE_N}$ of the cultivar ZZ39 were with the CIP, while there was significant difference between the CIP and WIP150. The highest $\mathrm{PE_N}$ of the cultivar LLY104 was 33.07 kg kg^{-1} N with the WIP100. The highest $\mathrm{AE_N}$ and $\mathrm{PE_N}$ of the cultivar WY308 under the NRP was 15.61 kg kg^{-1} N and 31.03 kg kg^{-1} N, respectively, while there was significant difference between the FFP and NRP ($p < 0.05$). The $\mathrm{PFP_N}$ and $\mathrm{RUE_N}$ of the NRP in the early and late seasons were significantly higher than those of the FFP.

DISCUSSION

In this study, the variation of water layer in the soil layer was determined by a simple self-made PVC indicator tube, which was used to determine whether artificial irrigation was needed; the water was irrigated and dried naturally under the water-saving irrigation practice (WIP100) and more-water-saving irrigation practice (WIP150) while the groundwater level was lower than 100 mm or 150 mm. Our study found that water-saving irrigation practice could guide irrigation practice during the whole rice production model by observing the change of groundwater layer, while there was no significant difference in the annual yield in the ratoon rice production model and double-season rice production model. Liu *et al.* (2013) reported that compared with that under continuously flooded (CF) and farmer's N practice (FNP) treatment, grain yield was increased by 6.0%–14.5% under either FNP or SSNM (site-specific nitrogen management). Linquist *et al.* (2015) reported that relative to the flooded control treatment and depending on the alternate wetting and drying (AWD – flooding the soil and then allowing it to dry down before being reflooded) water management practices, yields were reduced by <1%–13%. Li *et al.* (2018) reported that compared with urea with conventional irrigation, grain yield decreased by 7% under urea + SWD

Table 3 | Aboveground biomass, leaf area index (LAI), harvest index (HI), crop growth rate (CGR), transport rate and contribution rate of aboveground biomass before the full-heading stage in the double-season rice production model under water-saving irrigation practice with N fertilizer management

	Full-heading stage			**Mature stage**				
Treatment	**Aboveground biomass (g m^{-2})**	**LAI**	**CGR**	**Aboveground biomass (g m^{-2})**	**CGR**	**HI**	**Transport rate of aboveground biomass before the full-heading stage (%)**	**Contribution rate of aboveground biomass before the full-heading stage (%)**
Early rice LLY104								
CIP	688.02a[#]	4.81a	11.87a	924.4a	9.46a	0.51a	18.38a	23.54a
WIP100	650.67a	4.21a	11.21a	911.2a	10.43a	0.52a	15.62a	20.93a
WIP150	707.63a	5.13a	12.18a	902.9a	7.81a	0.50a	21.59a	27.93a
FFP	773.03a	5.64a	13.10a	1,000.0b	9.08b	0.50a	18.26a	25.89a
NRP	804.48a	6.16a	13.64a	1,110.2a	12.23a	0.52a	18.98a	22.80a
N0	468.81b	2.35b	8.52b	628.5c	6.39c	0.50a	18.36a	23.70a
Early rice ZZ39								
CIP	665.97a	3.62a	12.34a	1,000.6a	12.39a	0.53a	10.21a	12.86a
WIP100	672.64a	3.04a	12.46a	999.6a	12.11a	0.51a	8.40a	9.03a
WIP150	704.74a	3.96a	13.00a	951.8a	9.24a	0.52a	17.48a	20.66a
FFP	768.64a	4.34a	13.98a	1,121.1a	13.05a	0.51b	10.67a	12.41a
NRP	773.21a	4.34a	14.06a	1,120.6a	12.87a	0.54a	14.76a	17.28a
N0	501.50b	1.94b	9.77b	710.3b	7.82b	0.51b	10.67a	12.86a
Late rice WSSM								
CIP	911.58a	5.14a	16.92a	1,001.7a	1.84a	0.46b	21.57a	34.52a
WIP100	864.68a	5.12a	16.05a	1,004.4a	2.85a	0.48a	20.21a	29.54a
WIP150	870.71a	5.04a	16.15a	1,002.4a	2.69a	0.46b	16.57a	24.85a
FFP	951.74a	5.54b	17.30a	1,136.9a	3.78a	0.48a	15.60a	21.70a
NRP	997.02a	6.36a	18.13a	1,097.3a	2.04a	0.45a	21.54a	34.03a
N0	698.20b	3.39c	13.69b	774.3b	1.55a	0.47a	21.22a	33.18a
Late rice WY308								
CIP	790.03a	5.41a	16.39a	996.3a	3.97a	0.52a	18.33a	23.45a
WIP100	810.59a	5.31a	16.82a	1,147.9a	6.49a	0.52a	5.00a	7.30a
WIP150	782.27a	5.32a	16.24a	1,111.4a	6.33a	0.54a	9.64a	12.64a
FFP	872.63a	5.79b	17.81a	1,139.7a	5.13a	0.51b	14.51a	19.55a
NRP	894.59a	6.55a	18.26a	1,184.4a	5.58a	0.53ab	13.33a	15.94a
N0	615.67b	3.70c	13.38b	931.6b	6.07a	0.54a	5.14a	7.90a

[#] Different letters indicate statistical significance at the $p = 0.05$ level within the same column and the same year.

in the early rice season and increased by 9% in the late rice season. Other results about AWD reported that previous studies observed a yield penalty under AWD compared with CF (Bouman & Tuong 2001; Belder *et al.* 2004). A possible reason was that other agronomic measures including rice cultivar, N fertilizer, in association with water-saving irrigation practices (WIP) could affect rice grain yield (e.g. Xu *et al.* 2000; Linquist *et al.* 2015). Our results also found that annual yield under the WIP was maintained or increased compared with CIP and yield of the early rice was decreased and of the late rice was increased under the WIP compared with the CIP. Importantly, the WIP via simple self-made PVC indicator tube with N-reduction are economically attractive and can be adapted to field scales, and it is easier to master these practices for the farmer.

Table 4 | Agronomic efficiency ($\mathrm{AE_N}$), physiological efficiency ($\mathrm{PE_N}$), nitrogen partial factor productivity ($\mathrm{PFP_N}$), and nitrogen recovery use efficiency ($\mathrm{RUE_N}$) in the ratoon rice production model under water-saving irrigation practice with N fertilizer management

Treatment	$\mathrm{AE_N}$ (kg kg^{-1} N)	$\mathrm{PE_N}$ (kg kg^{-1} N)	$\mathrm{PFP_N}$ (kg kg^{-1} N)	$\mathrm{RUE_N}$ (kg kg^{-1} N)
Main season				
CIP	13.83b$^{\#}$	14.88ab	31.16ab	65.09a
WIP100	12.27b	13.22b	29.87b	62.41a
WIP150	15.60a	17.53a	31.79a	60.93a
FFP	13.14a	14.74a	28.70b	60.81a
NRP	14.66a	15.69a	33.18a	64.81a
Ratoon season				
CIP	15.26a	18.43a	29.54a	57.97a
WIP100	13.89b	18.53a	30.07a	52.61a
WIP150	16.19a	20.25a	30.44a	56.93a
FFP	12.60b	18.28a	23.78b	48.62a
NRP	17.63a	19.86a	36.25a	63.06a

$^{\#}$Different letters indicate statistical significance at the $p = 0.05$ level within the same column and the same year.

Rice grain yield and nitrogen uptake showed a rule of diminishing returns when the amount of nitrogen fertilizer exceeded a certain range (Zou *et al.* 2015). Previous studies reported that nitrogen-reduction did not significantly reduce rice yield or improve nitrogen use efficiency (e.g. Du *et al.* 2013; Liu *et al.* 2013; Li *et al.* 2018). In this study, based on the FFP under the ratoon rice production model and double rice production model, there was no significant difference in rice grain yield between the FFP and the NRP. Our results indicated that nitrogen fertilizer reduction by 80% and 76% in the above models compared with the FFP was a more reasonable range of nitrogen-reduction. Meanwhile, from the point of nitrogen use efficiency, $\mathrm{AE_N}$, $\mathrm{PE_N}$, $\mathrm{PFP_N}$ and $\mathrm{RUE_N}$ of the NRP were higher than those of the FFP, but there were differences of rice cultivars between the NRP and the FFP under the double-season rice production model.

There is an interaction effect between water conditions and fertilizer, namely, the changing of soil fertility and nutrient absorbability of the rice with the changing of water conditions in the paddy field, which will affect rice's growth and development. Liu *et al.* (2013) reported that synergistic interaction between site-specific nitrogen management and AWD occurs in yield formation, and such an interaction could increase not only grain yield, but also resource-use efficiency in super rice, which could reduce the nutrient and water used in production of unproductive tillers and

Table 5 | Agronomic efficiency ($\mathrm{AE_N}$), physiological efficiency ($\mathrm{PE_N}$), nitrogen partial factor productivity ($\mathrm{PFP_N}$), and nitrogen recovery use efficiency ($\mathrm{RUE_N}$) in the double-season rice production model under water-saving irrigation practice with N fertilizer management

	$\mathrm{AE_N}$ (kg kg^{-1} N)		$\mathrm{PE_N}$ (kg kg^{-1} N)		$\mathrm{PFP_N}$ (kg kg^{-1} N)		$\mathrm{RUE_N}$ (kg kg^{-1} N)	
Treatment	LLY104	ZZ39	LLY104	ZZ39	LLY104	ZZ39	LLY104	ZZ39
Early rice								
CIP	21.39a$^{\#}$	24.34a	29.49ab	34.97a	56.91a	56.21a	72.60a	69.45a
WIP100	19.72a	21.54ab	33.07a	30.19ab	55.19a	52.41a	60.58b	69.94a
WIP150	16.98a	15.21b	24.35b	22.56b	55.21a	53.29a	70.27a	68.82a
FFP	20.08a	18.15a	32.35a	28.01a	52.44b	48.02b	62.51b	64.71b
NRP	18.64a	22.57a	25.58b	30.46a	59.10a	59.91a	73.11a	74.09a
	WSSM	WY308	WSSM	WY308	WSSM	WY308	WSSM	WY308
Late rice								
CIP	14.06a	15.47a	34.13a	33.65a	38.28a	45.48a	41.50a	46.17b
WIP100	16.21a	12.23a	37.14a	24.09b	40.84a	45.21a	44.10a	51.04a
WIP150	12.09a	12.32a	29.21a	23.59b	40.30a	44.87a	41.13a	52.15a
FFP	13.39a	11.07b	33.07a	23.19b	36.23b	39.37b	40.54b	48.52b
NRP	14.84a	15.61a	33.91a	31.03a	43.38a	50.99a	43.94a	51.04a

$^{\#}$Different letters indicate statistical significance at the $p = 0.05$ level within the same column and the same year.

transpiration from redundant leaf area, leading to increases in nitrogen and water use efficiency (Yang & Zhang 2010). In this study, however, there was no interaction effect between water regimes and nitrogen fertilizer. Based on rice yield and nitrogen use efficiency among different treatments, we speculate that water-saving irrigation practice with nitrogen-reduction could maintain or increase rice grain yield and improve nitrogen use efficiency.

CONCLUSIONS

Water-saving irrigation practice did not reduce the annual yields of the ratoon rice production model and double rice production model. Compared with non-application of nitrogen (N0), annual yields of nitrogen-reducing practice (NRP) and farms' fertilizer practice (FFP) increased significantly ($p < 0.01$), while no significant difference of annual yield between the FFP and the NRP was observed. AE_N, PE_N, PFP_N and RUE_N of the RFP were higher than those of the FFP. Therefore, observing the change of the water layer in the soil layer via a simple self-made PVC indicator tube, reduction of more than 20% nitrogen quantity was a feasible and simple cultivation technique for water-saving and nitrogen-reduction in the rice production models.

Two areas in particular deserve further investigative efforts. Firstly, the dynamic change of soil water potential and water consumption including precipitation and irrigation under the WIP100 and WIP150 need to be determined accurately. Secondly, the cost and the effect of these water-saving irrigation practices with nitrogen-reduction is to be verified by the farmer at field scale.

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