Water-saving irrigation practices for rice yield information and nitrogen use efficiency under sub-tropical monsoon climate
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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. AEN, PEN, PFPN 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

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 CH₄ and N₂O 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 hm² and 130 thousand hm², 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.

**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 m² (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 P₂O₅ hm⁻² as the base fertilizer, and potassium fertilizer was applied at 225 kg K₂O 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 K₂O 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 P₂O₅ hm⁻² in the early season and 90 kg P₂O₅ hm⁻² in the late season; potassium fertilizer was applied at 120 kg K₂O hm⁻² in the early season and 144 kg P₂O₅ 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 m² 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 m² 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 (AEN, kg kg⁻¹ N), physiological efficiency (PEN, kg kg⁻¹ N), nitrogen partial factor productivity (PPFN, kg kg⁻¹ N), and nitrogen recovery use efficiency (RUEN, 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 (AEN) 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.

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

| Treatment | Ratoon rice production model (t ha⁻¹) | Double-season rice production model (t ha⁻¹) |
|-----------|--------------------------------------|--------------------------------------------|
|           | Annual yield | Main yield | Ratoon yield | Annual yield | Early rice yield | Late rice yield |
| CIP       | 8.30a⁹       | 5.55a      | 2.75a        | 12.46a       | LLY104           | WY308          |
| WIP100    | 8.31a        | 5.43a      | 2.88a        | 12.40a       | 6.66a            | 6.42a          |
| WIP150    | 8.42a        | 5.56a      | 2.87a        | 12.71a       | 6.64a            | 6.46a          |
| FFP       | 10.02a       | 6.45a      | 3.57a        | 14.34a       | 7.87a            | 7.20a          |
| NRP       | 9.73a        | 6.47a      | 3.26a        | 12.84a       | 7.09a            | 7.19a          |
| N0        | 5.29b        | 3.61b      | 1.68b        | 9.29b        | 4.89b            | 4.48b          |
| Water regime | ns           | ns         | ns           | ns           | ns               | ns             |
| Nitrogen  | **           | **         | **           | **           | **               | **             |
| Water regime × Nitrogen | ns           | ns         | ns           | ns           | ns               | ns             |

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

⁹Different 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 (PE\textsubscript{N}) and nitrogen partial factor productivity (PFP\textsubscript{N}). The highest nitrogen recovery use efficiency (RUE\textsubscript{N}) was with the CIP, while there was no significant difference between the treatments. AE\textsubscript{N}, PE\textsubscript{N}, PFP\textsubscript{N} and RUE\textsubscript{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 AE\textsubscript{N} and PE\textsubscript{N} of the cultivar ZZ39 were with the CIP, while there was significant difference between the CIP and WIP150. The highest PE\textsubscript{N} of the cultivar LLY104 was 33.07 kg kg\textsuperscript{-1} N with the WIP100. The highest AE\textsubscript{N} and PE\textsubscript{N} of the cultivar WY308 under the NRP was 15.61 kg kg\textsuperscript{-1} N and 31.03 kg kg\textsuperscript{-1} N, respectively, while there was significant difference between the FFP and NRP (p < 0.05). The PFP\textsubscript{N} and RUE\textsubscript{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 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

| Treatment | Full-heading stage | Mature stage | Transport rate of aboveground biomass before the full-heading stage (%) | Contribution rate of aboveground biomass before the full-heading stage (%) |
|-----------|---------------------|--------------|------------------------------------------------------------------------|--------------------------------------------------------------------------|
|           | Aboveground biomass (g m\textsuperscript{-2}) | LAI | CGR | Aboveground biomass (g m\textsuperscript{-2}) | CGR | HI |
| 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 | 48.78b | 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 | 46.81b |

\*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 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

| Treatment | Full-heading stage | Mature stage | Transport rate of aboveground biomass before the full-heading stage (%) | Contribution rate of aboveground biomass before the full-heading stage (%) |
|-----------|--------------------|--------------|---------------------------------------------------------------------|---------------------------------------------------------------------|
|           | Aboveground biomass (g m⁻²) | LAI | CGR | Aboveground biomass (g m⁻²) | CGR | HI | before the full-heading stage (%) | 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    | 707.65a             | 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 | 14.76a | 0.54a | 17.28a | 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       | 872.65a             | 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 | 15.1a | 7.90a |

*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. 2018). Previous studies reported that nitrogen-reduction did not significantly reduce rice yield or improve nitrogen use efficiency (e.g. Du et al. 2016; Liu et al. 2015; 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, AEN, PEN, PFPN and RUEN 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. (2015) 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 4 | Agronomic efficiency (AEN), physiological efficiency (PEN), nitrogen partial factor productivity (PFPN), and nitrogen recovery use efficiency (RUEN) in the ratoon rice production model under water-saving irrigation practice with N fertilizer management

| Treatment | AEN (kg kg⁻¹ N) | PEN (kg kg⁻¹ N) | PFPN (kg kg⁻¹ N) | RUEN (kg kg⁻¹ N) |
|-----------|----------------|----------------|------------------|------------------|
| Main season |          |                |                  |                  |
| CIP       | 13.83b     | 14.88a         | 31.16a           | 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.

Table 5 | Agronomic efficiency (AEN), physiological efficiency (PEN), nitrogen partial factor productivity (PFPN), and nitrogen recovery use efficiency (RUEN) in the double-season rice production model under water-saving irrigation practice with N fertilizer management

| Treatment | AEN (kg kg⁻¹ N) | PEN (kg kg⁻¹ N) | PFPN (kg kg⁻¹ N) | RUEN (kg kg⁻¹ N) |
|-----------|----------------|----------------|------------------|------------------|
| Early rice |               |                |                  |                  |
| CIP       | 21.39a*       | 24.34a         | 29.49ab          | 34.97a           |
| WIP100    | 19.72a        | 21.54ab        | 33.07a           | 30.19ab          |
| WIP150    | 16.98a        | 15.21b         | 24.35b           | 22.56b           |
| FFP       | 20.08a        | 18.15a         | 32.35a           | 28.01a           |
| NRP       | 18.64a        | 22.57a         | 25.58b           | 30.46a           |
| Late rice |               |                |                  |                  |
| WSSM      | LLY104        | 21.06a         | 25.58b           | 30.46a           |
| WY308     | ZZ39          | 22.57a         | 30.46a           | 34.49a           |
| FFP       | 13.39a        | 11.07b         | 33.07a           | 23.19b           |
| NRP       | 14.84a        | 15.61a         | 33.91a           | 31.03a           |

*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. $A_{EN}$, $P_{EN}$, $PFP_{N}$ 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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