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Experimental study on water-saving and emission-reduction effects of controlled drainage technology

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Abstract

Field experiments and laboratory analysis were carried out to determine the effects of controlled drainage (CTD) and conventional drainage (CVD) technologies on drainage volume, concentrations of NH_4^+-N, NO_3^--N, and total phosphorus (TP), nitrogen and phosphorus losses, rice yield, and water utilization efficiency. Results show that CTD technology can effectively reduce drainage times and volume; NH_4^+-N, NO_3^--N, and TP concentrations, from the first to the fourth day after four rainstorms decreased by 28.7%−46.7%, 37.5%−47.5%, and 22.7−31.2%, respectively, with CTD. These are significantly higher rates of decrease than those observed with CVD. CTD can significantly reduce nitrogen and phosphorus losses in field drainage, compared with CVD; the reduction rates observed in this study were, respectively, 66.72%, 55.56%, and 42.81% for NH_4^+-N, NO_3^--N, and TP. Furthermore, in the CTD mode, the rice yield was cut slightly. In the CVD mode, the water production efficiencies in unit irrigation water quantity, unit field water consumption, and unit evapotranspiration were, respectively, 0.85, 0.48, and 1.22 kg/m^3, while in the CTD mode they were 2.91, 0.84, and 1.61 kg/m^3—in other words, 3.42, 1.75, and 1.32 times those of CVD. Furthermore, the results of analysis of variance (ANOVA) show that the indicators in both the CVD and CTD modes, including the concentrations of NH_4^+-N, NO_3^--N, and TP, the losses of NH_4^+-N, NO_3^--N, and TP, irrigation water quantity, and water consumption, showed extremely significant differences between the modes, but the rice yield showed no significant difference.

Keywords: Controlled drainage; Nitrogen; Phosphorus; Rice yield; Drainage volume; Water utilization efficiency

1. Introduction

To ease the tension between supply and demand of water resources, water-saving irrigation techniques for paddy fields were widely investigated (Tabbal et al., 2002; Belder et al., 2004). As China is the largest producer and consumer of synthetic fertilizers in the world, large amounts of nitrogen have entered its water bodies through various means, resulting in water eutrophication in China (Li et al., 2008; Chirinda et al., 2010). However, paddy fields can achieve the effect of water purification through maintenance of a proper water level for a certain number of days after fertilization, pollutant control, and heavy rain. Therefore, controlled drainage (CTD) technology for paddy fields has attracted attention of researchers (Wesström et al., 2001), and been a focus of study for agricultural water environment protection. This technology can effectively improve the utilization efficiency of irrigation water and water productivity (Zhang et al., 2003), ease the tension between supply and demand of water resources, reduce nitrogen and phosphorus losses from paddy fields, improve the water environment, maintain the nutrient cycle of paddy fields, improve the utilization efficiency of rainfall,

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effectively reduce the concentrations of nitrogen and phosphorus in drainage, and maintain the yield (Peng et al., 2009; Li et al., 2008).

With the development of the theory and practice of modern irrigation and drainage technology, people have fully realized that it would be more conducive to improving the efficiency of rice production by combining water-saving irrigation with CTD (Peng et al., 2011; Xiao et al., 2013). Through the combination of existing water-saving irrigation and CTD theories for paddy rice, an irrigation-drainage technology that saves water, reduces emissions, and generates a high yield can be developed. Based on its characteristics as a semi-aquatic plant, we can make full use of the stress of drought and, especially, water-logging on rice to coordinate the stress degree (Xiao et al., 2012). While the lower irrigation limit is maintained, appropriately increasing the upper rain water storage limit can make full use of rainfall, thus reducing the irrigation quota as well as nitrogen and phosphorus loads (Yu et al., 2002). While meeting the requirements of no significant reduction of crop yield and quality, CTD technology can also achieve the goals of saving water and reducing emissions (Ng et al., 2002; Ju et al., 2009). According to the research on the key supporting technologies of large-scale agricultural water-saving improvement projects in China, research on water-saving irrigation and CTD systems was carried out, and the results show that the water level in the paddy field can be used as an efficient irrigation and drainage indicator (Xie et al., 2007; Yang et al., 2009).

In this study, an experiment was conducted in Suqian City, in Jiangsu Province, China to further confirm the environmental effect of CTD. The aims of this study were to investigate the application of CTD technology and water level control rules in farmland experiments, to improve rice irrigation-drainage systems, to verify the water-saving and emission-reduction effects of CTD, and to provide a scientific basis for optimal design of irrigation-drainage projects in rice irrigation districts.

2. Materials and methods

2.1. Experimental site

An experiment was conducted from October 2011 to October 2012, in the Sankeshu experimental field in the Yunnan irrigation district, which is located in the Sucheng District of Suqian City, in China (Fig. 1). The experimental site has a warm temperate zone monsoon climate, with four distinct seasons and mild average temperatures. The average annual rainfall is 892.3 mm, and the average annual amount of rainfall days is 120 d, with rainfall in the main flooding season accounting for nearly 70% of the total. The average annual evaporation amount is 900 mm, the annual average temperature is 14.1°C, the highest monthly average temperature is 27.2°C, the average annual amount of sunshine hours is 2 314 h, and the annual non-frost period is 211 d. The topsoil (from 0 to 30 cm), with a pH value of 6.95, contains 2.35% of soil organic matter, 0.894 5 g/kg of total nitrogen (TN), 27.95 mg/kg of available nitrogen, 0.34 g/kg of total phosphorus (TP), and 12.2 mg/kg of available phosphorus.

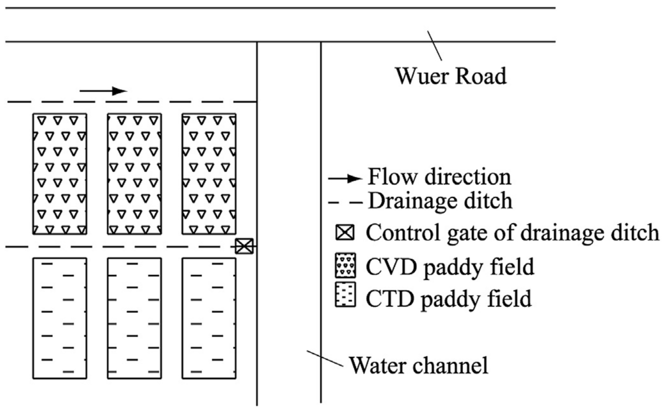

Fig. 1. Layout of experimental site and experimental management.

2.2. Experimental design

The variety of rice used in the experiment was Japonica rice, according to the local custom. There were two irrigation-drainage modes, conventional drainage (CVD) and CTD. Each mode included three replications. Plastic isolating film was used at each experimental plot at 50 cm below the balk, in order to avoid water exchange. The fertilizer regime was determined according to the local custom. There were three fertilizer applications: a base fertilizer on June 25, a tillering fertilizer on July 9, and an earing fertilizer on August 10, with pure nitrogen amounts of 120, 60, and 60 kg/hm^2, respectively, for a total of 240 kg/hm^2. In addition, a total of 50 kg/hm^2 P_2O_5 and K_2O were applied to each mode.

Water management of a paddy field in CVD was based on local custom. The water level control indicators in CVD are shown in Table 1, while those in CTD are shown in Table 2.

2.3. Experimental mechanism and methods

In this study, the evapotranspiration for a paddy field was calculated based on the water balance principle as follows:

$$ET_t = P_t + I_t + W_{t-1} + W_t - D_t \qquad (1)$$

Table 1
Water level control indicators at each growth stage in CVD mode.

Growth stage	Upper water level limit (mm)	Lower water level limit (mm)	Allowed water depth (mm)
Regreening stage	30	10	50
Early tillering stage	30	0	50
Late tillering stage	0	0.6θ	0
Jointing-booting stage	30	0	70
Heading-flowering stage	30	0	70
Milking stage	30	0	70

Note: θ is the observed saturated water content of soil bulk in the root zone.