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Nitrogen economy and water productivity of lowland rice under water-saving irrigation

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Abstract

Water saving in irrigated lowland rice production is increasingly needed to cope with a decreasing availability of fresh water. We investigated the effect of irrigation regimes on grain yield and nitrogen (N) uptake and recovery, and the effect of N management on water productivity (grain yield/evapotranspiration (ET)).

Four field experiments were carried out—three summer seasons at Tuanlin (2000–2002), China, and one dry season at Muñoz (2001), Philippines—using a hybrid for Tuanlin and an inbred cultivar for Muñoz. Several water-saving regimes were compared with continuous submergence. N fertilizer was applied at 180 kg ha^{-1} at Tuanlin and at 90 and 180 kg ha^{-1} at Muñoz and compared with a 0-N application.

Grain yield ranged from 4.1 t ha^{-1} at Muñoz in 0-N plots to 9.5 t ha^{-1} at Tuanlin in 2001 with 180 kg N ha^{-1}. Alternately submerged–non-submerged regimes showed a 4–6% higher yield than continuous submergence. Other water-saving regimes led to yield reduction. In all seasons, N application significantly increased grain yield largely through an increased biomass and grain number. Water productivity was significantly increased by N application in three out of four seasons and under limited water stress ranged from 0.70 to 1.17 in 0-N plots and from 1.27 to 1.66 kg m^3 at 180 kg N ha^{-1}. Water-saving regimes also increased water productivity under non-water-stressed conditions compared with continuous submergence. A synthesis of the data of three seasons at Tuanlin showed that biomass and apparent N recovery declined linearly with the duration of the crop growth without submergence.

We concluded that the absence of an effect of water-saving regimes was caused by shallow groundwater tables of <40-cm depth in 2000–2001 at Tuanlin and at Muñoz, whereas at Tuanlin in 2002 there was water deficit in all treatments caused by a deeper drainage. In irrigation systems with a relatively shallow water table, optimal N management is as important as water-saving irrigation to enhance water productivity.

Keywords: Water savings; Lowland rice; Water productivity; Nitrogen uptake; Apparent nitrogen recovery; Evapotranspiration

Abbreviations: ET, evapotranspiration; WP, water productivity; SNS, submerged–non-submerged; DAT, days after transplanting; LAI, leaf area index; ANR, apparent N recovery; TL00, Tuanlin 2000; TL01, Tuanlin 2001; TL02, Tuanlin 2002; MU01, Muñoz 2001

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1. Introduction

Decreasing availability of good-quality fresh water (Postel, 1997) and population growth necessitate a more efficient water use in irrigated rice production systems in Asia. The high water demand of irrigated lowland rice mainly arises from keeping a permanent layer of water on the field (Guerra et al., 1998). The permanent water layer causes evaporation and seepage and percolation to be higher than in non-flooded fields.

To reduce water use in irrigated lowland rice, water-saving techniques are being developed. These techniques include shorter/no wet land preparation, direct (dry) seeding, and introducing periods of non-submergence (Mao, 1993). Researchers in China (Wu, 1999; Li, 2001; Mao, 1993) found that alternately submerged–non-submerged (SNS) field conditions significantly reduced water inputs and increased yields. However, Bouman and Tuong (2001) reported that SNS conditions did reduce water inputs but yields usually declined when soil water potential (SWP) in the root zone reached −10 to −30 kPa and below.

Under water-short conditions, it has been argued that water productivity (i.e., the amount of harvested product per unit water use), becomes more important than yield or ''land productivity'' (Guerra et al., 1998; Tuong and Bouman, 2003). Water use can be defined as total water input through rainfall and irrigation or as evapotranspiration (*ET*). It was found that *ET* as the water use term enables a better comparison between sites, cultivars, seasons, and management options (Tuong and Bouman, 2003). Reported values for water productivity in rice based on *ET* range from 0.4 to 1.6 kg m^{-3} (Tuong and Bouman, 2003), suggesting scope for improvement in crop and water management and cultivar selection for higher assimilation/transpiration rates (Peng et al., 1998).

Photosynthetic rates depend on leaf N concentration (Peng et al., 1995; Hasegawa and Horie, 1996; Sheehy et al., 1998) and play a crucial role in biomass production and yield formation. Enhanced leaf growth will lead to increased transpiration and to decreased evaporation through increased shading of the soil.

Current N-fertilizer recommendations for rice in Asia have generally been established under continuously submerged conditions. The adoption of SNS-based technologies could change N dynamics and stimulate N losses (Sah and Mikkelsen, 1983; Eriksen et al., 1985). However, some researchers reported no increase in N losses under SNS conditions (Maeda and Onikura, 1976; Manguiat and Broadbent, 1977; Fillery and Vlek, 1982). Most of these results were obtained in pot experiments, and the interaction between water and N has been little studied under field conditions (Guerra et al., 1998). With the development and introduction of SNS-based water-saving practices, there is a need to re-evaluate the N economy of rice fields.

In this research, we studied crop growth and development, nitrogen economy and water productivity under submerged and SNS regimes. The study aims at increasing insight into how nitrogen and water management interact and how they can be improved to increase yield and water productivity.

2. Materials and methods

Field experiments were conducted in irrigated lowland rice areas. Three experiments were located at Tuanlin (30°52′N, 112°11′E), Hubei Province, China, at an altitude of 100 m, and were conducted in the summer seasons in 2000 (TL00), 2001 (TL01), and 2002 (TL02). The fourth experiment was carried out at the experimental farm of the Philippine Rice Research Institute (PhilRice) at Muñoz (15°40′N, 120°54′E), Nueva Ecija Province, Philippines, at an altitude of 35 m, in the dry season of 2001 (MU01). The experimental site at Tuanlin was a farmer's field surrounded by lowland rice fields within the 160,000 ha Zhanghe Irrigation System (see Hong et al. (2001) for more details of the area). The experimental farm at Muñoz was surrounded by lowland rice fields in the 100,000 ha Upper Pampanga River Integrated Irrigation System (see Tabbal et al. (2002) for more details of the area).

At both Tuanlin and Muñoz, the soil texture was silty clay loam. At Tuanlin, the hybrid cultivar 2You725 was sown in April and harvested early September. At Muñoz, the tropical inbred cultivar IR72 was sown in late December and harvested in April. Following local practices, seedlings were transplanted at 20-cm × 20-cm spacing with 3–5 plants per hill. Seedling age at transplanting was 38, 44, 41, and 21 days at TL00, TL01, TL02, and MU01,