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The high yield of irrigated rice in Yunnan, China 'A cross-location analysis'

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Abstract

A number of field trials on rice productivity have demonstrated very high yield, but reported limited information on environmental factors. The objective of this study was to reveal the environmental factors associated with high rice productivity in the subtropical environment of Yunnan, China. We conducted cross-locational field experiments using widely different rice varieties in Yunnan and in temperate environments of Kyoto, Japan in 2002 and 2003. The average daily radiation throughout the growing season was greater at Yunnan (17.1 MJ m^{-2} day^{-1} average over 2 years) relative to Kyoto (13.2 MJ m^{-2} day^{-1}). The average daily temperature throughout the growing season was 24.7 °C at Yunnan, and 23.8 °C at Kyoto. The highest yield (16.5 tonnes ha^{-1}) was achieved by the F1 variety Liangyoupeijiu at Yunnan in 2003, and average yield of all varieties was 33% and 39% higher at Yunnan relative to Kyoto in 2002 and 2003, respectively. There was a close correlation between grain yield and aboveground biomass at maturity, while there was little variation in the harvest index among environments. Large biomass accumulation was mainly caused by intense incident radiation at Yunnan, as there was little difference in crop radiation use efficiency (RUE) between locations. Large leaf area index (LAI) was also suggested to be an important factor. Average nitrogen (N) accumulation over 2 years was 49% higher at Yunnan than at Kyoto, and also contributed to the large biomass accumulation at Yunnan. The treatments of varied N application for Takanari revealed that the ratio of N accumulated at maturity to the amount of fertilized N was significantly higher at Yunnan than at Kyoto, even though there was no great difference in soil fertility. The Takanari plot with high N application showed a N saturation in plant growth at Kyoto, which might be related to low radiation and relatively high temperatures during the mid-growth stage. These results indicate that the high potential yield of irrigated rice in Yunnan is achieved mainly by intense incident solar radiation, which caused the large biomass and the N accumulation. The low nighttime temperature during the mid-growth stage was also suggested to be an important factor for large biomass accumulation and high grain yield at Yunnan.

Keywords: Rice (*Oryza sativa*); Radiation use efficiency (RUE); Yield; Yunnan; Nitrogen; Leaf area index (LAI); Temperature

1. Introduction

Due to rising population numbers, Asian irrigated rice production must increase by 43% over the next 30 years (Cassman, 1999). However, further expansion of rice planted area is difficult, because most arable land is already used for rice production or converted into urban infrastructure (Horie et al., 2005). Many farmers are now obtaining yields close to those produced at experimental stations (Conway and Toenniessen, 1999), and yield potential of modern rice varieties in irrigated rice fields has stagnated around 10 tonnes ha^{-1} since the first semidwarf tropical indica variety, IR8, was released in 1966 (Peng et al., 1999). To break this yield barrier, it is very important to clarify the environmental effects on rice productivity, as well as the physiological traits causing high productivity.

A number of field observations of grain yields over 13 tonnes ha^{-1} has been reported, for example in Yunnan,

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China (Amano et al., 1996a,b), Yanco, Australia (Williams, 1992), Tsaranoro, Madagascar (Rafaralahy, 2002), Nile Delta, Egypt (Namba, 2003), Governorate, Egypt (Badawi, 2004), and Maharashtra, India (Suetsugu, 1975). Only a little scientific knowledge, however, is available to clarify the environmental factors associated with a high record yield of rice. Ying et al. (1998a) suggested that the high yield potential of irrigated rice in Yunnan, China was brought about by long growth duration and high crop growth rate (CGR). Horie et al. (1997) suggested that high yield potential of irrigated rice in Yanco, Australia was a result of intense solar radiation because of a similar efficiency of dry matter production per unit of incident radiation among all the experimental sites. In these experiments, however, crop management techniques such as chemical fertilizer application or planting densities were different between the sites for which productivity was compared. Additionally, the growth durations were largely different between the experimental sites. For example, in a cross-locational experiment between subtropical environments of Yunnan, China and tropical environments of the International Rice Research Institute (IRRI), Philippines (Ying et al., 1998a), there was a near 40-day difference in growth duration between the two sites. This makes it difficult to evaluate the effects of environmental or physiological factors on high productivity. Moreover, the rice varieties used in these experiments were very limited. Therefore, cross-locational experiments using widely different rice varieties with similar crop management at both sites were needed, in order to better understand the major factors affecting high yield records of rice.

The objective of this study was to clarify the environmental factors promoting a high yield of irrigated rice in subtropical environments of Yunnan, China by conducting a cross-locational experiment in Yunnan and temperate environments of Kyoto, Japan. Special attention was paid to light interception and its utilization by crops, using on-site measurements of solar radiation and leaf area dynamics. Attention was also paid to nitrogen utilization by observing crops with varied amounts of chemical nitrogen fertilizer application.

2. Materials and methods

Field experiments were conducted in 2002 and 2003 in the subtropical environment of Taoyuan Village's farm, Taoyuan township, Yongsheng county, Yunnan province, China (26°12′N, 100°34′E, 1170 altitude) during the rice growing season from mid March to mid September and in the temperate environment of Kyoto University Farm, Kyoto, Japan (35°1′N, 135°7′E, 20 m altitude) during the rice growing season from late April to early October. At Yunnan, about 30 tonnes ha^{-1} farmyard manure was applied in both years before beginning irrigation (Technical officials in Taoyuan Agricultural Station, personal communication, 2003).

Soil samples were taken at both sites from the plow layer (0–15 cm) of five randomly chosen plots before beginning irrigation in 2002. The samples were air-dried and passed through a 2 mm sieve to remove the debris and stones. The measurements included total carbon and nitrogen, cation exchange capacity (CEC), organic carbon (SOC), mineralizable N, and soil texture. Total carbon and nitrogen were analyzed with the elemental analyzer (EA-1108, Fisons Instruments, Milano). CEC was measured by the ammonium acetate extract method at pH 5.0 and 7.0 (Soil and Plant Analysis Council, 1999). SOC content was determined by Walkeley method (Walkeley, 1947). Mineralizable N was determined by a 4-week anaerobic incubation at 30 °C and by measuring the increase of NH_4^+–N in soil water. Soil texture was examined by the sieving and pipetting method (Gee and Bauder, 1986).

In 2002, seven common varieties, Nipponbare (japonica, standard variety in Japan), Takenari (japonica, old variety in Japan), Shanguichao (indica, high yielding variety in China), Takanari (its parents are indica–japonica crossbred, high yielding variety in Japan), IR72 (indica, standard variety in IRRI), IR65564-44-2-2 (NPT), WAB450-I-B-P-38-HB (NERICA, *O. sativa* × *O. glaberrima*) were grown at Yunnan and Kyoto. These varieties were selected to test as diverse a selection of varieties as possible. Twenty-eight-day-old seedlings were transplanted on 5 May in Yunnan, and 22-day-old seedlings were transplanted on 22 May in Kyoto. Chemical fertilizers were applied 12 g P_2O_5, 12 g K_2O and 4 g N m^{-2} as basal dressing, and 2 g N m^{-2} as top-dressing every 20 days after transplanting until 10 days after heading.

In 2003, six common varieties, Nipponbare, Takenari, Shanguichao, Takanari, Jinyou207 and Liangyoupeijiu were grown in Kyoto and Yunnan. The latter two, which are recently bred Chinese "super-hybrid" varieties (Li et al., 2001; Zou et al., 2003), were added to anticipate the high rice yield. Twenty-nine-day-old seedlings were transplanted on 16 April in Yunnan, and 20-day-old seedlings were transplanted on 21 May at Kyoto. Fertilizer application rates were changed to emphasize the later topdressing, in order to ensure the high rice yield in 2003. Chemical fertilizers were applied as following: 14 g P_2O_5 and 7 g K_2O m^{-2} as basal dressing, 3 g N m^{-2} at 7 days after transplanting, 7 g K_2O and 4 g N m^{-2} at panicle initiation, 4 g N m^{-2} at 2 weeks before heading and 3 g N m^{-2} at heading as top dressings. Heavy nitrogen plots (28 N), in which N was applied twice as much as normal fertilized plots (14 N) for basal and top-dressing, were prepared for Takanari and Liangyoupeijiu. Total N application of 28 g m^{-2} was quite high compared with conventional cultivation in Kyoto, but it is relevant compared with conventional cultivation in Taoyuan village, Yunnan. Additionally, no-nitrogen fertilized plots (0 N) were prepared for Takanari to compare environmental N availability between the two sites.

Except for the chemical fertilizer application shown above, similar crop management and experimental methods were adopted for both sites and years. Rice varieties were arranged in a completely randomized block design with three replicates. Plot sizes at Yunnan were 15.12 m^2 (3.6 m × 4.2 m) and 19.44 m^2 (2.7 m × 7.2 m) in 2002 and 2003, respectively and at Kyoto were 21.87 m^2 (2.7 m × 8.1 m) and 21.6 m^2 (3.0 m × 7.2 m) in 2002 and 2003, respectively. Planting density was 22.2 plants per m^2 (0.3 m × 0.15 m) with two seedlings per hill. Water, weeds, insects and disease were controlled as required to avoid yield loss.