Enhancing grain yield of rice (*Oryza sativa* L.) under upland conditions in Japan

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Abstract

Rice production in uplands has a low yield due to limited water availability, but it has a great potential to saving water. Field experiments were conducted to compare grain yield (GY) in flooded lowland (FL) and in uplands with three water regimes (rainfed [RU], irrigated [IU] and water deficit during panicle formation stage [WD]) in Japan from 2001 to 2003 by using three cultivars (Yumeno-hatamochi [YHM]; Lemont [LMT]; Nipponbare [NPB]). GY of NPB in RU equalled that in FL (only 6% reduction) in 2003, when it amply rained before heading, which suggested that it was possible to achieve high yield in favourable upland conditions as in lowlands in temperate climate conditions. In 2002 with less frequent rainfall, GY in RU was 21% less than GY in 2003. Among uplands in 2003, GY in IU was 9% higher than in RU, while that in WD was 37% lower than in RU. There was genotype by water regime interaction in GY, with NPB yielding highest in FL and LMT yielding highest in all upland conditions. These results suggested that the amount of water supply greatly affected GY in uplands and there were large potential for cultivar improvement adapted to both water deficit and favourable upland conditions.

Media summary

Water-use-efficient upland rice production was demonstrated in Japan, with grain yield comparable to irrigated lowlands by adequate and frequent water supply.

Key Words

Water availability; Water productivity

Introduction

Rice (*Oryza Sativa* L.) is the major staple food in Asia, and more than 75% of the worldwide rice supply comes from 79 million ha of irrigated lowland (IRRI 2002). However, the amount of water for irrigation is becoming scarce, thus there is a need to decrease water use in rice production and increase its use efficiency. Rice production in uplands with supplemental irrigation, called “aerobic rice”, is now regarded as one of the new concepts for water saving (Bouman 2001; Wang et al. 2002). However, grain yield in uplands are often less than that in lowlands by 20-30% (eg, McCauley 1990). Upland varieties have been developed not to achieve high yield such as lowland varieties, but to stabilize its yield against drought. It is also necessary to attain higher yield potential in favorable upland conditions. While most studies on such intensive upland conditions have been conducted in the tropical areas, we compared rice yield in lowland and favorable upland conditions, and also compared among upland conditions with different water availability by changing the amount of water supply under temperate climate conditions in Japan.

Methods

Field experiments were conducted at the Field Production Science Center in the University of Tokyo (UT FPSC) at Nishitokyo, Japan (lat. 35?43′N, long. 139?32′E) on Andosol fields for three years, from 2001 to 2003. In 2001, rainfall in July was scarce (15 mm), while it amply rained before heading in 2003. Experiments were conducted under rainfed upland (RU) and flooded lowland (FL) in 2001, under RU, irrigated upland (IU) and FL in 2002, under RU, IU, water deficit during panicle formation stage (57days) in upland (WD) and FL in 2003. In IU, total amount of irrigation were 60 mm in 2002 and 125 mm in 2003. Mild water deficit unexpectedly developed during early stage in IU in 2002 and nitrogen deficit occurred in later stage due to no top-dressing in FL in 2002. Total amount of water supply (rainfall plus irrigation) is shown in Table 1. One cultivar (Nipponbare [NPB]) in 2001, and three cultivars (Yumeno-hatamochi [YHM]; Lemont [LMT]; NPB) were selected in 2002 and 2003 with three replicates in each treatment, arranged in a randomized complete block design. YHM was an upland cultivar, while LMT and NPB were lowland cultivars. Total dry matter of above-ground organs (TDM) at maturity, grain yield (GY) and yield components were measured. Harvested area in each treatment was from 0.54 to 0.90 m^2, depending on the treatments and the years. In uplands, water productivity (i.e. grain yield over total amounts of water supply) was calculated. In 2002 and 2003, total nitrogen content of above-ground organs at maturity were also measured.

Table 1. Total amount of water supply (rainfall plus irrigation) in rainfed upland (RU), irrigated upland (IU) and water deficit during panicle formation stage (57 days) in upland condition (WD) in 2001, 2002 and 2003.

Water regime	2001		2002		2003	
	H[1] (mm)	M[2] (mm)	H (mm)	M (mm)	H (mm)	M (mm)
RU	431	895	622	992	794	1008
IU			676	1052	899	1132
WD					359	419

[1] Amount of water supply from sowing to heading.
[2] Amount of water supply from sowing to maturity.

Results

GY in RU was 25% less than in FL in 2001, however only 6% less in 2003 (Table 2). In 2001, both harvest index (HI) and TDM were reduced in RU compared with FL, while only HI was significantly reduced in 2003. Water productivity in RU in 2003 was 0.060 kg/ha/mm, which was much higher than that in continuous flooded lowland in our field (0.018 kg/ha/mm; Kamoshita et al. 2003). In 2002, rainfall was relatively high but slightly smaller and less frequent than 2003, and GY in RU in 2002 was much lower than in 2003. In 2003, GY in IU was 9% higher than in RU, while that in WD was 37% lower than in RU, which were mainly associated with changes in spikelet number per area (data not shown). TDM was also reduced in RU in 2002 and in WD in 2003, compared with in RU in 2003, due to reduction in nitrogen uptake caused by reduced water availability (data not shown). There was a genotype by water regime interaction in GY. In FL, NPB yielded highest, while LMT yielded highest in all upland conditions. Yield for NPB declined sharply with suboptimal water supply in uplands, and yield potential for YHM was not high due to low harvest index.

Table 2. Grain yield, total dry matter of above ground organs (TDM) and harvest index (HI) in rainfed upland (RU) and flooded lowland (FL) in 2001, 2002 and 2003 (cv. Nipponbare).

	Grain yield (t/ha)			TDM at maturity (t/ha)			HI		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
RU	4.7	4.8	6.1	11.0	10.8	13.1	0.38	0.39	0.41
FL	6.2	5.0	6.5	13.0	10.9	13.2	0.42	0.40	0.43
	**	NS	NS	*	NS	NS	*	NS	†

[1] GY in FL in 2002 would be affected by nitrogen deficit in later stage.
**, * and † mean significant difference at P = 0.01, 0.05 and 0.10, respectively.
NS mean not significantly different at P = 0.10.

Conclusions

It was possible to achieve as high yield as in lowlands and hence to use water more efficiently (i.e. higher water productivity) in uplands compared with flooded lowland, in temperate climate conditions in Japan. In order to achieve and stabilize high GY in both water-limiting and favourable upland conditions, cultivar development to raise yield potential as well as to increase the amount of available water will be necessary.

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