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Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment

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Abstract

Yield penalty and yield stability of aerobic rice have to be considered before promoting this water-saving technology in the tropics. The objectives of this study were (1) to compare crop performance between aerobic and flooded rice continuously over several seasons, and (2) to identify yield attributes responsible for the yield gap between aerobic and flooded rice. Field experiments were conducted at the International Rice Research Institute farm in dry and wet seasons. Grain yield and its components were compared between aerobic and flooded rice continuously for eight seasons from 2001 to 2004 using the best available aerobic rice varieties in the tropics. The yield difference between aerobic and flooded rice ranged from 8 to 69% depending on the number of seasons that aerobic rice has been continuously grown, dry and wet seasons, and varieties. When the first-season aerobic rice was compared with flooded rice, the yield difference was 8–21%. The yield difference between aerobic and flooded rice was attributed more to difference in biomass production than to harvest index. Among the yield components, sink size (spikelets per m^2) contributed more to the yield gap between aerobic and flooded rice than grain filling percentage and 1000-grain weight. Yield decline was observed when aerobic rice was continuously grown and the decline was greater in the dry season than in the wet season. The yield decline of aerobic rice was attributed more to changes in biomass production than in harvest index. Our data suggest that new aerobic rice varieties with minimum yield gap compared with flooded rice and crop management strategies that can reverse the yield decline of continuous aerobic rice have to be developed before aerobic rice technology can be adopted in large areas in the tropics.

Keywords: Aerobic rice; Biomass production; Flooded rice; Grain yield; Yield decline

Rice production consumes about 30% of all freshwater used worldwide. Flood-irrigated rice uses two to three times more water than other cereal crops such as wheat and maize. In Asia, flood-irrigated rice consumes more than 45% of total freshwater used (Barker et al., 1999). However, scarcity of freshwater resource has threatened the production of the flood-irrigated rice crop (IWMI, 2000). By 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage (Tuong and Bouman, 2003).

Several technologies have been developed to reduce water loss and increase the water productivity of the rice crop. They are saturated soil culture (Borell et al., 1997), alternate wetting and drying (Li, 2001; Tabbal et al., 2002), ground cover systems (Lin et al., 2002) and system of rice intensification (Stoop et al., 2002). However, the fields are still kept flooded for some periods in most of these systems, so water losses remain high. Aerobic rice is high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is responsive to high inputs, can be rainfed or irrigated, and tolerates (occasional) flooding (Bouman and Tuong, 2001). In this paper, aerobic rice refers to rice crop grown in non-flooded and non-puddled lowland soil with supplemental irrigation. Aerobic rice promises substantial water savings by minimizing seepage and percolation and greatly reducing evaporation (Bouman et al., 2002).

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Experimentally growing high-yielding lowland rice varieties under aerobic conditions has shown great potential to save water, but with severe yield penalty. In the early 1970s, De Datta et al. (1973) tested the lowland variety IR20 in aerobic soil under furrow irrigation at IRRI. Water saving was 55% compared with flooded conditions, but the yield fell from about 8 t ha^{-1} under flooded conditions to 3.4 t ha^{-1} under aerobic conditions. There was limited information on the difference in crop performance between aerobic and flooded conditions when varieties that are adapted to aerobic conditions were used. Furthermore, physiological basis of yield gap between aerobic and flooded rice has not been studied extensively. Such information is vital for identifying the physiological and morphological traits to support the selection and breeding of high-yielding aerobic rice varieties.

In Brazil, it was reported that high yields could be sustained when aerobic rice is grown once in four crops, but not under continuous monocropping (Guimaraes and Stone, 2000). Rapid yield decline under continuous upland rice cropping has been documented in the Philippines (Ventura and Watanabe, 1978). Yield decline under monocropping of aerobic rice has also been reported by George et al. (2002). The causes of yield decline in the continuous aerobic rice system remain unclear. The buildup of soil-borne pathogens such as nematodes is a likely candidate (Ventura et al., 1981). Understanding the causes of yield decline and physiological processes responsible for the yield gap between aerobic and flood-irrigated rice will be useful for developing crop and resource management strategies to improve the grain yield and yield stability of aerobic rice. Because of the instability of grain yield in aerobic rice over seasons, the comparison between aerobic and flooded rice in crop performance has to be conducted in a long-term experiment.

In 2001, we established a long-term field experiment to compare the agronomic performance of aerobic and flooded rice using several varieties in both dry and wet seasons. The experiment has been going on for eight seasons. Our objectives were: (1) to compare crop performance between aerobic and flooded rice continuously over several seasons, and (2) to identify yield attributes responsible for yield gap between aerobic and flooded rice.

1. Materials and methods

The field experiment was conducted at the International Rice Research Institute (IRRI) farm at Los Baños, Laguna, Philippines (14°11′N, 121°15′E, 21 m asl) in both dry season (DS, January–May) and wet season (WS, June–October) from 2001 to 2004. The soil in the experiment site was Aquandic Epiaquoll with its chemical and physical properties listed in Table 1.

Three water management treatments were arranged in a randomized complete block design with four replicates. Plot size was 86 m^2. In the first six seasons (2001–2003), the three water treatments were aerobic rice in both DS and WS (T1), flooded rice in both DS and WS (T2), and aerobic in DS and flooded rice in WS (T3). Because one-season flooding in WS did not significantly change the performance of aerobic rice in DS, data of T3 from the first six seasons were not included in the comparison between aerobic and flooded rice. In 2004 DS, the flooded plots in previous six seasons (T2) were converted to aerobic plots while flooded plots only in WS (T3) became flooded. This change allowed a direct comparison between rice grown under aerobic conditions in the soil where flooded rice has been grown continuously in previous seasons (T2, first-season aerobic rice) and in the soil where aerobic rice has been grown continuously in previous six seasons (T1, seventh-season aerobic rice). In 2004 WS, T1 became eighth-season aerobic rice, T2 became second-season aerobic rice, and T3 remained as flooded rice.

Flooded plots were puddled and kept continuously flooded from transplanting until 2 weeks before harvest. Water depth was initially 2 cm and gradually increased to 5–10 cm at full crop development. The aerobic plots were dry-ploughed and harrowed but not puddled during land preparation. One day before transplanting, aerobic plots were soaked with irrigation water to facilitate transplanting. Transplanting was used for aerobic rice to keep seedling density constant across seasons. Afterward, aerobic plots were flash irrigated with about 5 cm water each time only when the soil moisture tension at 15 cm depth reached −30 kPa. Around flowering, the threshold for irrigation was reduced to −10 kPa to prevent spikelet sterility (O'Toole and Garrity, 1984). Irrigation outlets were fitted with 6-in. PVC pipes that served as delivery channel of water for each flooded and aerobic plot. The drainage system to prevent

Table 1
Initial soil characteristics of the field experiment conducted at the International Rice Research Institute (IRRI) farm in the Philippines

Parameter	Mean	S.D.
pH	6.4	0.1
Organic C (%)	1.5	0.1
Total N (%)	0.15	0.01
Available P-Olsen (mg kg^{-1})	9.0	4.2
Available K (meq 100 g^{-1})	0.97	0.14
Active Fe (%)	2.1	0.2
Active Mn (%)	0.14	0.01
Available Zn (mg kg^{-1})	1.6	0.4
Available Cu (mg kg^{-1})	0.18	0.03
Available B (mg kg^{-1})	6.0	0.2
Exch. K (meq 100 g^{-1})	1.1	0.2
Exch. Na (meq 100 g^{-1})	1.4	0.1
Exch. Ca (meq 100 g^{-1})	21.7	0.6
Exch. Mg (meq 100 g^{-1})	13.6	0.3
Exch. Al (meq 100 g^{-1})	Nil	
EC (dS m^{-1})	0.62	0.12
CEC (meq 100 g^{-1})	37.4	1.3
Clay (%)	59.0	2.1
Silt (%)	30.8	1.4
Sand (%)	10.2	1.1

Soil samples were taken 2 days before transplanting in the dry season of 2001.