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Yield of aerobic rice in rainfed lowlands of the Philippines as affected by nitrogen management and row spacing

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ABSTRACT

Management practices need to be developed for aerobic rice, a system in which rice is grown under nonflooded conditions in nonsaturated soil. We evaluated the effects of amount and timing of fertilizer nitrogen (N) application and of row spacing on the yield of aerobic rice under rainfed conditions in the 2004 and 2005 wet seasons in 3 and 2 locations, respectively, in Central Luzon, Philippines. N timing and management were also evaluated under irrigated conditions at one location in the dry season in 2005. Yields were 3.1–4.9 t ha^{-1} with 60–150 kg ha^{-1} of applied N. Yields increased with N rate, up to rates of 60–150 kg ha^{-1} depending on site and season, but at rates beyond 90 kg ha^{-1} the risk of lodging increased, especially in the wet season. Yields were similar for different splits of N over time, and the regional practice for lowland rice of three to four splits can also be used for aerobic rice. Yields were similar for row spacings ranging from 25 to 35 cm. Although the number of panicles per square meter was significantly higher at 25-cm spacing than at 35-cm spacing, this difference was compensated for by significantly more spikelets per panicle at 35-cm spacing, while spikelet fertility and grain weight were similar for all row spacings. Lodging and bending resistance of stems were not affected by row spacing. The results suggest that a row spacing of 35 cm can be used to enable easier weeding between the rows, and allows for mechanized field operations in which tire tracks do not damage the crops.

1. Introduction

Aerobic rice is a relatively new cropping system in which rice is grown under nonflooded, nonpuddled, and nonsaturated soil conditions (Bouman, 2001). Because aerobic rice needs less water at the field level than conventional lowland rice, the system is targeted at relatively water-short irrigated or rainfed lowland environments. To achieve high yields under aerobic soil conditions, new varieties are required that combine the drought-resistant characteristics of upland varieties with the high-yielding characteristics of lowland varieties (Lafitte et al., 2002). In northern (temperate) China, breeders have been breeding "aerobic rice" varieties since the mid-eighties and have developed varieties with an estimated yield potential of around 6 t ha^{-1} using about half the amount of water required for lowland rice (Wang et al., 2002; Yang et al., 2005; Bouman et al., 2006). The development of aerobic rice for the tropics is of relatively recent origin. Using improved upland rice varieties, George et al. (2002) reported yields of 1.5–7.4 t ha^{-1} under aerobic conditions in the Philippines but with 2500–4500 mm of annual rainfall. The yields over 6 t ha^{-1} occurred only in the first 2 years of cultivation after non-rice crops, and most yields were in the 2–3 t ha^{-1} range. Atlin et al. (2006) reported aerobic rice yields of 3–4 t ha^{-1} using recently developed varieties in farmers' fields in rainfed uplands in the Philippines. Though the amount of rainfall was not reported, the conditions of the trials were described as "well watered". Bouman et al. (2005) and Peng et al. (2006) quantified yield and water use of the recently released upland rice variety Apo under irrigated conditions. In the dry season, yields were 4–5.7 t ha^{-1}, with 744–924 mm of total water (rain plus irrigation); in the wet season, yields were 3.5–4.2 t ha^{-1} with 922–1301 mm of water, compared with typical inputs for puddled transplanted rice of 1500–2000 mm in this region. Based on these early results, Atlin et al. (2006) and Bouman et al. (2005) suggested that the system of aerobic rice could be an attractive option for farmers in rainfed lowlands with limited or erratic distribution of rainfall.

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In 2003, research began on aerobic rice in rainfed lowlands in the Philippines (Lampayan et al., 2004). The first objective was to derive management recommendations for nitrogen (N) fertilizer in terms of timing and distribution within the season. In the wet season of the Philippines, heavy winds frequently cause lodging in rice (Tabbal et al., 2002), and N fertilization should be balanced between maximizing yield and minimizing the risk of lodging. The second objective was to optimize row spacing. Rice that is not permanently flooded tends to have more weed growth and a broader weed spectrum than rice that is permanently flooded (Mortimer and Hill, 1999). To limit the use of herbicides and (labor-intensive) manual weed removal in aerobic rice, mechanical interrow cultivation is a promising alternative. Wider spacing between the rows is needed to avoid damage to the crop caused by the tractor wheels. However, wide row spacing may result in yield loss compared with a narrow row spacing. Moreover, during participatory field observations with farmers, it was suggested that row spacing may have an effect on lodging resistance. Therefore, field experiments were undertaken to study the interactive effects of fertilizer-N application and row spacing on yield and lodging resistance of aerobic rice. Here, we report on the results of field experiments conducted in 2004 and 2005 in the Philippines.

2. Materials and methods

We conducted two field experiments at three locations in Central Luzon. The first experiment studied the interaction of amount of N application and row spacing (N × RS), and was conducted in the wet seasons (June–October) of 2004 and 2005: (i) on a loamy sand soil (78% sand; 5% clay) at the village of Dapdap (15°40′N, 120°33′E) in Tarlac Province and (ii) on a clay soil (23% sand; 58% clay) at the experimental station of the National Soil and Water Resources Research and Development Center – Bureau of Soils and Water Management at San Ildefonso (15°04′N, 120°57′E) in Bulacan Province. The second experiment studied the interaction of N splits and row spacing (NS × RS). This experiment was conducted on a loam soil (37% sand; 17% clay) at the experiment station of PhilRice at Muñoz (15°39′N, 120°54′E) in Nueva Ecija Province, in the wet season of 2004 and the dry season of 2005 using irrigation. The 20-year (1986–2005) average annual rainfall is 1600 mm in Tarlac, 2017 mm in Bulacan, and 2000 mm in Nueva Ecija, with 80–90% of the rain falling between May and October in all provinces. In Dapdap, the site was previously used by farmers and cropped with lowland rice in the rainy season and left fallow in the dry season. At San Ildefonso, the site was previously cropped with lowland rice in the rainy season and upland crops in the dry season. At Muñoz, the site was planted first with rice in the 2004 dry season after a long fallow for several years.

2.1. Experimental layout

All experiments were laid out in a split-plot design with N as the main factor and row spacing as a sub-factor, with four replicates, and split-plot sizes of 4 m × 8 m. In the N-amount by row spacing experiment at Dapdap and San Ildefonso, five N amounts were used: 0 (N_0), 60 (N_{60}), 90 (N_{90}), 120 (N_{120}), and 150 kg N ha^{-1} (N_{150}). The N fertilizer was applied as urea by side-dressing each plant row in three splits over time: 30% at 10–14 days after emergence (DAE), 40% at 30–35 DAE, and 30% at 45–50 DAE. In the N-split by row spacing experiment at Muñoz, a total fixed rate of 100 kg N ha^{-1} was applied in five different split applications: 0-30-30-30-10 (NS_1), 0-20-50-30-0 (NS_2), 0-20-30-50-0 (NS_3), 23-23-29-25-0 (NS_4), and 18-0-29-43-10 (NS_5) kg ha^{-1} at 0 DAE (basal), 10–14 DAE, 30–35 DAE, 45–50 DAE, and 60 DAE. Three row spacings were used in both experiments: 25 cm (RS_{25}), 30 cm (RS_{30}), and 35 cm (RS_{35}).

Table 1
Monthly rainfall (mm) in 2004 and 2005 in the experimental sites in Dapdap, San Ildefonso and Muñoz, Philippines.

Month	Dapdap[a]		San Ildefonso[a]		Muñoz[b]	
	2004	2005	2004	2005	2004	2005
January	1	0	4	2	1	0
February	9	0	11	3	1	0
March	9	3	77	34	1	18
April	35	54	20	57	37	2
May	191	92	231	197	208	106
June	380	191	235	281	287	256
July	261	128	491	247	447	95
August	306	155	453	184	668	335
September	187	412	203	248	223	190
October	126	197	73	270	99	400
November	110	44	270	90	157	49
December	98	27	63	129	82	61
Total	1713	1302	2129	1742	2212	1513

[a] N-amount by row spacing (N × RS) experiment.
[b] N-split by row spacing (NS × RS) experiment.

In all experiments, the land was dry ploughed and harrowed 3 weeks before the onset of the rains. All main plots were bunded to avoid movement of fertilizer-N across plots. All plots received 20 kg ha^{-1} $ZnSO_4$ and 60 kg ha^{-1} of P and K in two equal splits as a basal application (broadcast before sowing) and topdressing 30–35 DAE. Dry seeds of variety Apo (PSBRc 9) were sown manually at 60 kg ha^{-1} in slits of 2–3-cm depth created using a wooden dented harrow (locally known as lithao). The seeds were covered with soil to promote seed–soil contact and to protect them from birds. Sowing and harvest dates are given in Table 1. Weeds were controlled by the application of butachlor at the recommended rate 2 days after sowing, and followed by interrow cultivation using lithao at 15–25 DAE. The experiments in the wet season were purely rainfed, whereas the crop at Muñoz in the dry season of 2005 received flush irrigations during the growing season (amounts of about 2-cm depth during the first 4 weeks of crop growth, and of 4 cm thereafter).

2.2. Measurements

Plant height was measured weekly from the four permanent sample plants in each plot. Measurement was done from the base of plant to the tip of the longest leaf or panicle of the plant. At Dapdap and Muñoz, two adjacent 50-cm row length plant samples were taken outside of the central final harvest area of each subplot at mid-tillering, panicle initiation, flowering, and physiological maturity to determine total dry crop biomass and leaf area index (LAI). Dry biomass was determined after oven-drying at 70 °C to constant weight. The LAI was determined using a Licor LI 3100 area meter. At San Ildefonso, samples were taken only at physiological maturity to determine biomass. To characterize lodging resistance, we measured stem resistance to bending at all sites at panicle initiation, flowering, and physiological maturity using the methodology described by Tabbal et al. (2002). We used a push-gauge to push a 10-cm row section of plants to a 45° angle from the vertical at 10-cm height from the base. The measured force was standardized by dividing by number of stems in the 10-cm row section. At maturity, plants from 6-m^2 area in the center of each subplot were harvested for determination of yield, whereas 4 row samples of 0.5 m each located at the corners outside of the harvest area were taken for determination of final aboveground biomass, yield components (panicle density, number of spikelets per panicle, 1000-grain weight, and percentage filled spikelets). Grain yield was expressed at 14% moisture content. The percentage lodged area in each subplot was estimated visually at the time of harvest.