Agronomic performance of tropical aerobic, irrigated, and traditional upland rice varieties in three hydrological environments at IRRI

G.N. Atlin, M. Laza, M. Amante, and H.R. Lafitte

The International Rice Research Insitute. DAPO 7777, Metro Manila, Philippines. Email g.atlin@cgiar.org

Abstract

Aerobic rice varieties are high-yield upland varieties distinguished from traditional upland rices adapted to low-input, subsistence-oriented management by their improved lodging resistance and higher harvest index. In the Asian tropics, aerobic varieties are usually medium-statured *indica* cultivars that are moderately drought-tolerant. Aerobic varieties may be useful where irrigated lowland production systems are failing due to water shortage, and in management intensification for drought-prone rainfed upland and lowland cropping systems. Little information is available on the yield potential, agronomic features, and hydrological adaptation of tropical Asian aerobic rice varieties. Improved and traditional varieties were therefore evaluated in multi-year irrigated lowland, non-stressed upland, and water-stressed upland environments at IRRI. Aerobic cultivars yielded 3.89 t ha^{-1} in favorable upland environments, outperforming improved upland and irrigated varieties by 100 and 30%, respectively. Aerobic cultivars are of intermediate height under favorable upland conditions and maintain HI of nearly 0.4, or about one-third higher than other cultivar types. Traditional upland cultivars, which are tall, lodging-prone, and have low HI, are not suitable for aerobic systems with yield targets of 2 t ha^{-1} or more. Aerobic rice cultivars offer a new approach to increasing productivity and reducing risk in Asian rainfed rice systems.

Media summary

Rice can be grown as a dryland “aerobic” crop, like maize, to save water and avoid drought. New aerobic rice varieties can produce yields of 4 t ha^{-1} or more in the tropics without flooding or transplanting.

Key Words

Aerobic rice, upland rice, water stress, traditional varieties, yield potential, harvest index.

Introduction

Upland rice is grown, usually as a low-input, subsistence crop, in unbunded, unpuddled fields, where no standing water is maintained and soils remain aerobic through the growing season. Yields average 1-2 t/ha in most regions. Intensification with traditional varieties is difficult because they are tall, low-tillering, and prone to lodging when grown in highly fertile soils. A new class of upland-adapted cultivars with improved lodging resistance, harvest index, and input responsiveness has been developed by breeding programs in China, Brazil, and the Philippines. They are referred to as aerobic rice varieties to differentiate them from traditional upland varieties for low-input systems. Aerobic rice management combines increased fertilizer use and input-responsive cultivars to generate high dry-land yields. Aerobic rice systems can greatly increase the productivity of traditional upland rice-based systems. Intensively managed aerobic rice is grown widely in Brazil as a result of the development of improved varieties. Aerobic rice varieties also offer water savings for water-short lowland production systems. Direct-seeded aerobic management eliminates water losses associated with puddling and reduces losses due to evaporation and percolation, reducing total irrigation requirements by 30-50% (Castaňeda *et al.,* 2002). This reduction is usually at the expense of some reduction in yield potential relative to fully irrigated systems (Bouman *et al.*, manuscript in preparation). In Northeast China, where irrigated lowland rice production is no longer possible due to water shortage, an aerobic rice system using specially-developed cultivars now occupies approximately 120,000 ha. There is little published information regarding characteristics of aerobic rice varieties for the Asian tropics, and their performance across a range of hydrological environments. This information is needed to guide aerobic rice breeding programs. The objectives of this report are therefore to:

Compare yields of aerobic rice cultivars with those of irrigated high-yield varieties (HYVs) and traditional upland varieties under a range of hydrological conditions;

Characterize some of the agronomic features of superior aerobic cultivars.

Methods

Four cultivar groups, consisting of three *indica* irrigated HYVs (IR 64, IR 72, and PSBRC 80), three predominantly *indica* aerobic rice varieties (IR55423-01, CT6510-24-1-2, and UPL RI-7), three short-duration, drought-tolerant upland varieties (Vandana, WAB 56-125, and IR 70358-84-1-1) of mixed *indica*, *japonica,* and *aus* background, and three traditional upland Philippine tropical *japonica* varieties (Azucena, Palawan, and Dinorado) were evaluated in 12 three-replicate randomized complete-block trials classified into three environment types:

Irrigated lowland fields established via transplantation at IRRI in the dry season, in which the trials experienced no water stress (2 trials);

Upland, high-fertility fields established via direct seeding at IRRI during the wet season, with soil maintained at or near field capacity via rainfall and occasional irrigation, and in which trials experienced little stress (3 trials).

Upland fields at IRRI established via direct-seeding in the dry season, with irrigation timed to result in moderate to severe stress between irrigations (7 trials).

The cultivars are part of a larger set of 44 varieties tested under a range of management conditions from 2000-2003. Only those varieties that could be characterized unambiguously as belonging to one of the four categories listed above are discussed in this report. Trials were conducted at the IRRI Experiment Station, Los Banos, Philippines, where annual average rainfall was 2100 mm in 1979-2002. The soil is an Andaqueptic Haplaquol with pH of 6.5. The vapor pressure deficit in the period from 60 days after sowing to harvest was 0.75 kPa in the dry season experiments, compared to 0.50 kPa in the wet season. Free water was not present within 1 m of the soil surface during the dry season. In the wet season, free water was present within 0.3 m of the surface during periods of high rainfall, but usually fell below 0.5 m for several extended periods. Wet season trials experienced little water stress, but dry season upland trials were always under moderate to severe stress. Irrigation and fertility management details are presented in Table 1 (yields in that table refer to the whole 44-variety set).

Table 1. Description of trial environments.

Season	Year	N-P_2O_5-K_2O	Hydrology	Establishment method	Irrigation method	Trial mean yield (t/ha)
			Irrigated lowlands			
Dry	2001	60-60-60	Lowland	Transplanting	Continuous flood	2.70
Dry	2002	120-30-30	Lowland	Transplanting	Continuous flood	2.82
			Non-stressed upland			

Wet	2001	130-100-100	Upland	Direct seeding	Rainfed	2.33
Wet	2002	60-60-60	Upland	Direct seeding	Rainfed	2.15
Wet	2003	105-28-28	Upland	Direct seeding	Rainfed	2.80
				Stressed upland		
Dry	2002	110-60-60	Upland	Direct seeding	Sprinkler twice weekly	0.91
Dry	2001	160-40-40	Upland	Direct seeding	Sprinkler twice weekly	1.36
Dry	2001	0-40-40	Upland	Direct seeding	Sprinkler twice weekly	0.90
Dry	2003	90-60-60	Upland	Direct seeding	Basin once every 10 days	1.07
Dry	2002	90-60-60	Upland	Direct seeding	Sprinkler once weekly	0.55
Dry	2002	0-0-0	Upland	Direct seeding	Sprinkler once weekly	0.36
Dry	2002	70-30-30	Upland	Direct seeding	Sprinkler once weekly	0.49

Weeds were controlled though a combination of early season herbicide applications and manual weeding. Chemical insect control was used as required. A severe infestation of mole crickets damaged seedlings in the DS 2002 trials. Plot size ranged from 4.5 to 7.5 m^2. The entire plot was harvested for grain yield. Yields given are for air-dried paddy, at approximately 12% moisture content. Harvest index and panicle number were determined from a 0.25 m^2 sample.

To estimate cultivar and group means within environment types, a mixed model was used in which cultivar types were considered fixed effects, while trials, replicates, and cultivars nested within the four cultivar groups were considered random factors. The REML algorithm of the SAS MIXED procedure (SAS Institute, 1992) was used for the analysis.

Results

There were significant differences in yield among cultivar groups in all three environments (Table 2). Variation among cultivars within groups for yield was not significant (not shown). The irrigated HYVs and aerobic types both yielded approximately 4 t ha^{-1} under lowland conditions. In the non-stress upland environment, aerobic varieties significantly outyielded all other types, surpassing the irrigated HYVs by over 30% and the traditional upland tropical *japonicas* by over 100%. Aerobic types also outyielded HYVs and traditional *japonicas* under severe upland stress conditions, and were as productive as highly drought-tolerant, short-duration varieties. The advantage of short-duration, drought-tolerant types was evident only under conditions of extreme stress. They were the lowest-yielding group in the other environments. The aerobic group combined responsiveness with a high degree of tolerance to water stress.

Table 2. Mean yield (t /ha) of irrigated, aerobic, traditional upland, and highly drought tolerant upland cultivar groups in three hydrological environments.

Variety type	Environment type		
	Irrigated lowland	Non-stressed upland	Water-stressed upland
Aerobic	4.06	3.89	1.08
Irrigated	4.07	2.94	0.73
Tradition lowland	2.29	1.89	0.57
Drought tolerant	1.71	1.58	1.06
$LSD_{.05}$	*0.80*	*0.99*	*0.31*

The superiority of aerobic cultivars under upland conditions appears to be a function of their higher harvest index (HI) under aerobic conditions (Table 3). Both aerobic and irrigated varieties achieved HI of over 45% in lowland environments, but the HI of irrigated varieties declined in upland environments, whereas that of aerobic varieties remained relatively high. Only in severely water-stressed environment was HI of aerobic varieties exceeded by the drought-tolerant group, which retained higher levels of grain-set under extreme stress. However, their low biomass production in (Table 4) resulted in lower yields in all other environments.

Table 3. Mean harvest index of irrigated, aerobic, traditional upland, and highly drought tolerant upland varieties in three hydrological environments.

Variety type	Environment type		
	Irrigated lowland	Non-stressed upland	Water-stressed upland
Aerobic	0.47	0.36	0.22
Irrigated lowland	0.46	0.29	0.19
Traditional upland	0.34	0.23	0.13
Drought tolerant	0.39	0.26	0.30
$LSD_{.05}$	*0.09*	*0.06*	*0.05*

Table 4. Mean biomass production (t/ha) of irrigated, aerobic, improved upland, traditional upland, and highly drought tolerant upland varieties in three hydrological environments.

Variety type	Environment type		
	Irrigated lowland	Non-stressed upland	Water-stressed upland
Aerobic	13.40	13.03	9.82
Irrigated lowland	14.40	12.57	8.64
Traditional upland	12.74	11.06	8.23
Drought tolerant	9.44	8.70	7.26
$LSD_{.05}$	*1.28*	*2.28*	*1.03*

Other features of the aerobic rice cultivars included intermediate plant height and panicle number under favorable upland conditions relative to irrigated and traditional upland varieties. The aerobic varieties had a mean height of approximately 111 cm (data not shown) compared to means of 91 cm and 149 cm for irrigated and traditional upland varieties, respectively. The semi-dwarf stature of irrigated varieties appears to be detrimental to aerobic adaptation. Aerobic varieties had significantly more panicles than the traditional upland varieties, but 100-150 fewer than irrigated lowland types (Table 5). Selection for increased panicle number may be a promising avenue for increasing aerobic rice grain yield.

Table 5. Mean number of productive tillers/m^2 of irrigated, aerobic, improved upland, traditional upland, and highly drought tolerant upland varieties in three hydrological environments: Los Banos, Philippines.

Variety type	Environment type		
	Irrigated lowland	Non-stressed upland	Water-stressed upland
Aerobic	240	306	383
Irrigated lowland	354	469	492
Traditional upland	182	209	223
Drought tolerant	265	335	377
$LSD_{.05}$	*68*	*41*	*62*

Conclusion

In general, these results indicate that the main feature distinguishing aerobic rice varieties from other cultivar types is their ability to retain both high biomass production and harvest index under both favorable and stressful upland conditions. Traditional varieties and HYVs produced as much biomass but partitioned less of it to grain under upland management. Remarkably, traditional Philippine upland varieties were lower-yielding than irrigated HYVs under even the most stressful upland conditions. Because aerobic rice is seeded directly in dry soil, without accumulation of standing water, vigorous early growth and extensive tillering is needed to compete with weeds. Moderate drought tolerance is also needed, because aerobic rice systems are likely to evolve in rainfed areas or areas with limited and unreliable irrigation. The results of this study indicate that these traits are most likely to be found in varieties with a high proportion of *indica* germplasm. Traditional Philippine tropical *japonica* varieties are low-tillering, drought-susceptible, and have low HI; they are therefore unlikely to have the yield potential or early vegetative vigor needed for intensively-managed upland systems. High-yielding cultivars that have emerged from Asian breeding programs for the favorable uplands often have a high proportion of their germplasm derived from elite tropical irrigated varieties, usually IR 8 and its relatives (Atlin and Lafitte, 2002).

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