TROPICAL SOIL AND CROP MANAGEMENT

Seedling Establishment and Grain Yield of Tropical Rice Sown in Puddled Soil

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ABSTRACT

Inconsistent seedling establishment constrains wider adoption of direct sowing of rice (*Oryza sativa* L.) in the tropics. Farmers broadcast pregerminated seeds onto the puddled soil surface. We hypothesize that if seeds were sown into the puddled soil rather than on the soil surface, then the establishment could be more consistent. For such below-surface sowing to be successful, however, the seedling must be able to withstand anoxic conditions. This study was conducted to clarify whether seedlings can be established by sowing below the surface in puddled soil and to analyze the difference in establishment among cultivars. Anoxia-tolerant cultivars, which had been selected from screening trials, were evaluated in flooded soil in a container in a temperature-controlled (29/21°C day/night) glass room under natural light and in the fields during the dry season at Los Baños and Muñoz, Philippines. In the container, pregerminated seeds of 12 cultivars were sown at the 25-mm depth in the soil with a water level of 30 mm. In the field, pregerminated seeds of 10 cultivars and calcium peroxide–coated seeds of two cultivars were drill-sown at Los Baños; pregerminated seeds of 12 cultivars were drill-sown and broadcast at Muñoz. Drill sowing was conducted 1 d after puddling, while broadcast sowing was done on the same day. The anoxia-tolerant cultivar outperformed the check cultivar in plant stand and seedling height and weight, hence producing more biomass. Plant stands at Los Baños were 80.5% for tolerant and 64.0% for check cultivars; those at Muñoz were 57.5 and 24.6% for drill sowing and 59.1 and 26.7% for broadcast sowing, respectively. Mean grain yield of short anoxia-tolerant cultivars was 6.9 t ha^{-1}, which was the same as that of check cultivars. It is concluded that the use of anoxia-tolerant cultivar can stabilize seedling establishment of rice plants sown in the puddled soil.

MANY RICE FARMERS in Asia are switching from transplanting to direct sowing because the latter requires less labor and time. Pregerminated seeds are broadcast onto the surface of puddled soil after drainage where seeds are placed in an aerobic condition. The wider adoption of direct sowing is constrained by inconsistent seedling establishment and increased weed infestation (Moody, 1993).

Inconsistent seedling establishment might be associated with the present practice of broadcasting pregerminated seeds on the soil surface. The seeds are often eaten by birds and rats, desiccated in dry parts of the field, or exposed to rain, sunshine, or wind. The physical condition of the soil surface changes in time after puddling. Thus, the environmental conditions of germinating seeds are heterogeneous as affected by soil types, intensity of puddling and leveling, water control, climate, and time of sowing. These problems could be lessened if plants are sown under the surface of puddled soil, although oxygen would be deficient (Yamauchi et al., 1993).

Rice (*Oryza sativa* L.) plants germinate and elongate their coleoptiles in anoxia (Alpi and Beevers, 1983). Oxygen is, however, required for the development of leaves and roots. In screening for rice cultivars that can establish seedlings from flooded soil (pregerminated seeds were sown 25 mm deep in soil with a water level of 30 to 50 mm), 2 to 8% of rice cultivars tested were superior in the establishment to the control semidwarf IR cultivars (Yamauchi et al., 1993). Such superior cultivars are tolerant to anoxic conditions, elongating their coleoptiles vigorously in N_2 gas at the expense of seed-reserved materials (Yamauchi et al., 1994; Yamauchi and Biswas, 1997). The tolerance is reduced by seed aging, suggesting that it is controlled not only by genetics but also seed vigor (Yamauchi and Tun Winn, 1996).

Although coating seeds with an oxygen release chemical (16% calcium peroxide; trade name Calper, Hodogaya Chemical Co., Tokyo) stabilizes seedling establishment in flooded soil (Yamada, 1952; Ota and Nakayama, 1970; Yamauchi and Chuong, 1995), the method requires resources and labor (i.e., purchase of the calcium peroxide and coating machine, and the labor for coating). The increase in seed weight and volume owing to the coating material reduces the efficiency of the sowing machine. We assume that the introduction of an anoxia-tolerant cultivar might be more advantageous than the use of Calper in terms of labor requirement and production cost.

There are two methods for sowing seeds in puddled soil. The first method uses a seeder designed for sowing seeds in puddled soil. Such a seeder was developed for the sowing of Calper-coated seeds and is commercially available; in addition, a new model was recently developed for sowing in puddled soil (Borlagdan et al., 1995). The other method is to sow the seeds just after puddling and leveling the field when the soil–water mixture is a suspension of dispersed soil particles in incomplete solution and broadcast-sown seeds can easily sink.

This paper aims to clarify the feasibility of sowing

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seeds under the surface of puddled soil in terms of seedling establishment in the tropics. The cultivars used were those selected after screenings for tolerance of seedling establishment in flooded soil (Yamauchi et al., 1993). They were first subjected to the study on seedling establishment in flooded soil in containers in a temperature-controlled glass room, then to the field study at two locations in the Philippines.

MATERIALS AND METHODS

Seeds

The International Rice Germplasm Center (IRGC) at IRRI supplied the seeds of CO25 (IRGC accession number 3697, origin India) and ASD1 (6267, India); International Network for the Genetic Evaluation of Rice, IRRI, IR41996-50-2-1-3, IR52341-60-1-2-1, IR50363-61-1-2-2, IR31802-48-2-2-2 (all Philippines), RP1125-3-2-1 (India), 7909-TR16-1-1 (Turkey), BR736-20-3-1 and BR1870-67-1-3 (Bangladesh); Plant Breeding, Genetics and Biochemistry Division, IRRI, IR72; and Central Research Farm, IRRI, PSBRc4. These seeds were produced during the 1992 wet season at Los Baños, Philippines, except that seeds of IR41996-50-2-1-3 were produced at PhilRice, Muñoz, Philippines. IR72 and PSBRc4 were check cultivars; the others were anoxic-tolerant.

Seeds with a specific gravity of more than 1.06 were selected by pouring the seeds into a sodium chloride solution (specific gravity 1.06). Seeds that precipitated were collected, washed with water, and dried at 50°C. Seed dormancy was broken by keeping the seeds at 50°C for 5 d (Jennings and de Jesus, 1964).

Seeds were pregerminated by soaking in water for 24 h followed by 14-h incubation at room temperature. Calper-coated seeds were prepared during the incubation. The amount of Calper used was two times the seed dry weight.

Seedling Growth in Container in a Temperature-Controlled Glass Room

Seeds of 12 cultivars used for the field experiments were evaluated in containers in a temperature-controlled (29/21°C day/night) glass room under natural light in a phytotron. Pregerminated seeds were sown at 25-mm depth with a water level of 30 mm in plastic containers (70 by 40 by 15 cm). One container represented one replication. The design was a randomized complete block with four replications. The soil used was the same as the one used for the screenings (Yamauchi et al., 1993). Seventeen seeds per plot represented a cultivar.

Field Experiments

Field experiments were conducted at IRRI, Los Baños (14°11′ N, 121°15′ E) and PhilRice, Muñoz (15°45′ N, 120°56′ E), during the 1993 dry season. Soil properties of the field at Los Baños were pH of 6.5, organic C of 20.7 g kg^{-1}, total N of 2.25 g kg^{-1}, and Olsen P of 11 mg kg^{-1}. Exchangeable bases were K at 0.60 cmol kg^{-1}, Ca at 22.70 cmol kg^{-1}, Mg at 14.90 cmol kg^{-1}, and Na at 0.17 cmol kg^{-1}. Total exchangeable bases were 38.37 cmol kg^{-1}; cation exchange capacity was 42.3 cmol$_c$ kg^{-1}. Available Zn was 4.2 mg kg^{-1}. The soil had a clay texture. The field used for drill sowing at Muñoz had the following soil properties: pH of 6.6, organic C of 11.9 g kg^{-1}, total N of 0.7 g kg^{-1}, and Olsen P of 5.3 mg kg^{-1}; exchangeable bases K at 0.01 cmol kg^{-1}, Ca at 12.21 cmol kg^{-1}, and Na at 0.23 cmol kg^{-1}; available Zn at 1.4 mg kg^{-1}; and heavy clay texture. The soil properties for the broadcast-sown field at Muñoz were pH of 6.1, organic C of 30.0 g kg^{-1}, total N of 1.3 g kg^{-1}, and Olsen P of 7.0 mg kg^{-1}; K at 0.08 cmol kg^{-1}, Ca at 11.54 cmol kg^{-1}, and Na at 0.25 cmol kg^{-1}; available Zn at 1.7 mg kg^{-1}; and heavy clay texture.

The experiment was laid out in a randomized complete block design with four replications. Three experiments were conducted: performance of 10 cultivars and calcium peroxide–coated seeds of two cultivars were tested by drill sowing at Los Baños, and 12 cultivars at Muñoz by drill and broadcast sowing. The lands were plowed, flooded, and then puddled with hand tractor or water buffalo, following common land preparation practices at IRRI and PhilRice. After puddling, the land surface was leveled by pulling wooden planks. The field was drained.

The size of a plot was 3 by 11 m at Los Baños and 3.4 by 14 m for drill sowing and 3.4 by 7.4 m for broadcast sowing at Muñoz. Sowing was done on 20 Jan. 1993 at Los Baños and 27 and 28 Jan. 1993 for drill and broadcast sowing at Muñoz, respectively.

A two-row direct sowing machine developed for the sowing of Calper-coated seeds into the flooded soil Gonbe (OH-192, product of Mukai Kogyo Co., Osaka, Japan) was used. The seeder was operated 1 d after puddling. The seed rate was estimated by measuring the difference in the number of seeds before and left after sowing. The total number of seeds sown in four plots of replications was estimated and the seed rate calculated.

The seed rate for broadcast sowing at Muñoz was 232 m^{-2}. Sowing was done on the day of puddling. The sown field was occasionally submerged and drained to protect seedlings from freshwater snails (*Pomacea* spp.). The field was flooded from when we applied first fertilizer (15 to 16 d after sowing) until harvest.

The fields were kept weed-free. The herbicide quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) was applied 13 d after sowing at 0.3 kg a.i. ha^{-1} for drill-sown plants at Los Baños and Muñoz, and pretilachlor (a chloroacetanilide herbicide) 2 d after sowing at 0.3 kg a.i. ha^{-1} for broadcast-sown plants at Muñoz. When necessary, weeds were removed by hand.

Fertilizer was broadcast at the following rates and combinations: 50 kg ha^{-1} N, 22 kg ha^{-1} P, and 42 kg ha^{-1} K at 16 d followed by 30, 30, and 50 kg ha^{-1} N at 33, 48, and 65 d after sowing, respectively, at Los Baños. The same rates and combinations of fertilizers were applied at 16, 30, 48, and 65 d for drill sowing, and 15, 29, 47, and 64 d for broadcast sowing at Muñoz.

Seed Germination Analysis

Germination and rate of germination were measured at room temperature (Krishnasamy and Seshu, 1989), with germination (%) calculated as the number of germinated seeds at 7 d divided by the number of seeds subjected for germination, times 100, and the rate of germination calculated as the number of germinated seeds at 2 d divided by the number of germinated seeds at 7 d.

Analysis of Plant Growth

The characters of seedling establishment were measured 14 d after sowing for the container experiments in the temperature-controlled glass room, and 12 d for the field experiments. Plant stand (%) was defined as the number of established seedlings divided by the number of sown seeds, times 100. Seedling establishment was indicated by the appearance of the first leaf. For the container experiment, the number of

Table 1. Seed germination and seedling establishment of rice in flooded soil. Germinated seeds were sown at 25 mm depth in flooded soil with 25 mm water level in a temperature-controlled (29/21°C day/night) glass room in a phytotron.

Cultivar	Germination	Germination rate	Plant stand	Seedling height	Seedling wt.
	%		%	mm	mg seedling^{-1}
IR72	98.3ab†	0.98a	23.5c	43d	2.0f
PSBRc4	90.0b	0.41c	21.6c	89cd	4.4f
IR41996-50-2-1-3	99.3a	0.99a	82.3a	210ab	12.0bc
IR31802-48-2-2-2	100	0.99a	67.7ab	109c	5.3ef
BR736-20-3-1	100	0.98a	72.1ab	171bc	10.1cd
IR50363-61-1-2-2	99.3a	1.00	64.7ab	120c	6.2ef
IR52341-60-1-2-1	97.8ab	1.00	50.0b	107c	5.5ef
RP1125-3-2-1	100	1.00	73.5ab	151bc	9.5cde
CO25	100	1.00	72.1ab	236a	15.3ab
ASD1	100	1.00	76.5ab	250a	17.0a
7909-TR16-1-1	80.0c	0.73b	76.5ab	244a	15.2ab
BR1870-67-1-3	98.3ab	0.90a	64.7ab	167bc	10.2cd

† Within columns, means followed by a common letter are not significantly different at the 0.05 level. Germination (100%) and germination rate (1.00) having no letters indicate no variation among the replications of measurement.

established plants out of the 17 seeds sown and the height and weight (dried at 80°C) of established seedlings were measured. In the field experiments, six pieces of rectangular frames (0.1 by 1.0 m or 0.2 by 1.0 m) were used per plot for counting the number of established seedlings. Seedling height and weight were measured from 20 plants collected from a plot. Biomass was estimated by calculating the product of seedling number and weight.

Sowing depth was estimated by the length of the white portion on a plant stem (white due to no light exposure below the soil surface). We measured the length between the seed and the portion of a plant stem where the color changes from white to green.

Grain yield was measured from the harvest area of 7.2 m^2 $plot^{-1}$ at Los Baños and 5.0 m^2 $plot^{-1}$ at Muñoz. The moisture content was adjusted at 14% for the yield presentation. Plant growth was analyzed by collecting plants from 0.9 m^2 and 0.5-m^2 per plot at Los Baños and Muñoz, respectively.

Statistical analysis was conducted with IRRISTAT (IRRI, 1992; Gomez and Gomez, 1984).

Soil Redox Potential and Hardness

A platinum electrode (PTS-2019C, TOA Electronics, Tokyo) was inserted 20 mm deep into the soil to measure redox potential. A crust hardness meter (DIK-5560, Daikirika, Tokyo) assembled with a spring (9.8 N for 40-mm contraction) and a cone (8 mm diam., 50 mm long) was used to measure soil hardness. The number of points measured in a replication was two to six and mean of a field (four replications) was calculated.

Climatic Data

IRRI supplied the climatic data at Los Baños and Muñoz. The daily means of climatic data from the date of sowing to 12 d after sowing were as follows, for drill sowing at Los Baños and for drill and broadcast sowing at Muñoz, respectively: rainfall, 1.0, 0.0, and 0.0 mm; irradiation, 14.9, 20.2, and 20.3 MJ m^{-2}; evaporation, 3.9, 5.7, and 5.8 mm; and temperature, 24.2, 23.9, and 24.0°C. Maximum temperatures during this period were 27.1, 27.6, and 27.7°C for the same three respective sites, and the minimums were 24.2, 23.9, and 24.0°C.

RESULTS

Germination and rate of germination of the seeds were 98 to 100% and 0.90 to 1.00, respectively, and there were no significant differences among the cultivars except 7909-TR16-1-1 and PSBRc4 (Table 1). The cultivars 7909-TR16-1-1 and PSBRc4 showed lower germination and rate of germination than the other cultivars. In the container experiment, the tolerant cultivar outperformed the checks, IR72 and PSBRc4 (Table 1). The tolerant cultivar showed a plant stand of 50 to 82%, while the checks had only 22 to 24%. The tolerant cultivars ASD1, CO25, 7909-TR16-1-1, and IR41996-50-2-1-3 were taller and heavier than the others. The plant stand in the container closely correlated with that in the screening trials (data not shown), with a coefficient of simple linear correlation of 0.93 (significant at the 0.01 probability level).

Soil redox potential at sowing, and 1 and 2 d after sowing was higher at Muñoz (244, 255, and 265 mV for drill-sown fields; 107 and 125 mV [no measurement at 2 d] for broadcast-sown fields) than at Los Baños (32, 82, and 126 mV). Drill-sown seeds were deeper than the broadcast-sown: 3.7 mm at Los Baños and 2.3 mm at Muñoz for drill sowing, and 0.5 mm for broadcast sowing at Muñoz. Soil hardness 12 d after sowing was 23 kPa at Los Baños, and 255 kPa for drill sowing and 4 kPa for broadcast sowing at Muñoz.

The seed rate of drill sowing was not consistent among the cultivars (Tables 2 and 3), ranging from 157 m^{-2} for the Calper-coated seeds of IR41996-50-2-1-3 to 348 m^{-2} for PSBRc4 at Los Baños and from 125 m^{-2} for 7909-TR16-1-1 to 363 m^{-2} for BR736-20-3-1 at Muñoz. The mean of seed rates at Los Baños (251 seeds m^{-2}, excluding Calper-coated seeds) was almost the same as that at Muñoz (252 seeds m^{-2}, excluding 7909-TR16-1-1 and BR1870-67-1-3). Since the seed rate was determined by the amount of seeds loaded to a belt in the seeder, the rate was affected by the size of pregerminated seeds. Calper coating lowered the seed rate, due to the increased seed size. The low seed rate of 7909-TR16-1-1 might be due to its large seed size, which was indicated by large single-seed weight (32.7 mg). The single-seed weight of the other cultivars ranged from 20.6 to 26.8 mg.

At Los Baños, only PSBRc4 showed low plant stand (34.5%); the other cultivars, including IR72, established well (63.1–98.3%) (Table 2). The seedling number ranged from 120 for PSBRc4 to 265 m^{-2} for IR72. Coating seeds of IR72 and IR41996-50-2-1-3 with Calper did not significantly increase the plant stand, seedling height, or weight.

Table 2. Rice crop establishment 12 d after drill sowing at Los Baños, Philippines, during the 1993 dry season.

Cultivar and group†	Seed rate	Seedling no.	Plant stand	Seedling height	Seedling wt.	Biomass
	no. m^{-2}		%	mm	mg $seedling^{-1}$	g m^{-2}
IR72	283	265a‡	93.5ab	97d	9.1de	2.43bcd
PSBRc4	348	120h	34.5e	85e	7.9e	0.95e
IR41996-50-2-1-3	217	168defg	77.1abcd	125b	12.3bc	2.02cd
IR31802-48-2-2-2	208	205bcd	98.3a	108c	10.6cd	2.18cd
BR736-20-3-1	281	250ab	88.9abc	107c	12.0bc	2.99ab
IR50363-61-1-2-2	199	170defg	85.2abc	111c	12.4bc	2.09cd
IR52341-60-1-2-1	241	152efgh	63.1d	106c	12.0bc	1.83d
RP1125-3-2-1	219	196cde	89.4abc	109c	11.3cd	2.22cd
CO25	298	219bc	73.6bcd	142a	15.9a	3.52a
ASD1	214	147fgh	68.6cd	135a	17.8a	2.57bc
IR41996-50-2-1-3 + Calper	157	138gh	91.6ab	133ab	13.8b	1.87d
IR72 + Calper	222	194cdef	87.5abc	104cd	9.4de	1.81d
Checks	316	192A‡	64.0B	91C	8.5C	1.69C
Short, tolerant	228	190A	83.7A	111B	11.8B	2.22B
Tall, tolerant	256	183A	71.1B	138A	16.9A	3.05A

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

Seedling height and weight of PSBRc4 and IR72 were lower than those of the tolerant cultivars. Biomass of PSBRc4 was much smaller than the other cultivars due to the small seedling number and weight. IR72 had as much biomass as the other tolerant cultivars except CO25. CO25 had large seedling number and weight, resulting in the largest biomass among the tested cultivars 12 d after sowing.

For drill sowing at Muñoz, plant stand was high for CO25, ASD1, and IR41996-50-2-1-3 and low for PSBRc4 and IR72 (Table 3). The seedling number ranged from 40 for PSBRc4 to 236 m^{-2} for CO25. Seedling was tallest for CO25 and ASD1 among the cultivars tested. ASD1 had the heaviest seedling weight. Biomass was largest in CO25 and ASD1, and smallest in PSBRc4 among the cultivars.

For broadcast sowing at Muñoz, we found the same difference among the cultivars in plant stand, seedling height, and weight as in drill sowing, CO25 and ASD1 being the best and PSBRc4 being the worst among the cultivars (Table 4). The seedling number ranged from 49 m^{-2} for PSBRc4 to 210 m^{-2} for CO25. Because the seed rate in broadcast sowing was constant among the cultivars, the biomass reflected the performance in plant stand and seedling weight of a cultivar.

Seedling growth was better at Los Baños than at Muñoz when we compared the height and weight of established seedlings of cultivars common to the two locations (Tables 2–4). The difference between drill and broadcast sowing at Muñoz was smaller than the difference between the two locations. The results suggest that seedling establishment is controlled more by the conditions of the locations than by the sowing methods.

Seedling height or weight in an experiment correlated to that in another experiment, while plant stand did not (Table 5). Seedling height and weight measured in the container in a temperature-controlled glass room significantly correlated with those measured in drill and broadcast sowing at Los Baños and Muñoz. On the other hand, plant stand in the container did not correlate with that at Los Baños but did at Muñoz. Plant stand at Los Baños did not correlate with that at Muñoz.

Grain yield, biomass, panicle-to-shoot dry weight ratio, and productivity were higher at Los Baños than at Muñoz (Tables 6–8). Highest grain yields were obtained from IR72 (8.4 t ha^{-1}) at Los Baños and from IR52341-

Table 3. Rice crop establishment 12 d after drill sowing at Muñoz, Philippines, during the 1993 dry season.

Cultivar and group†	Seed rate	Seedling no.	Plant stand	Seedling height	Seedling wt.	Biomass
	no. m^{-2}		%	mm	mg $seedling^{-1}$	g m^{-2}
IR72	249	86de‡	34.3e	75e	7.6cd	0.64de
PSBRc4	268	40f	14.9f	64f	6.0e	0.26f
IR41996-50-2-1-3	202	134bc	66.4abc	93b	9.2b	1.22bc
IR31802-48-2-2-2	274	142b	51.7cde	79de	6.7de	0.95cd
BR736-20-3-1	363	195a	53.6cd	86bcd	7.8c	1.49b
IR50363-61-1-2-2	211	126bcd	59.6bc	77e	7.2cd	0.90cd
IR52341-60-1-2-1	180	89cde	49.7cde	83cde	8.0c	0.70de
RP1125-3-2-1	202	107bcd	53.0cd	87bc	9.4b	1.01cd
CO25	302	236a	78.2a	108a	9.7b	2.29a
ASD1	272	198a	72.8ab	105a	11.0a	2.17a
7909-TR16-1-1	125	51ef	40.5de	81cde	7.7cd	0.39ef
BR1870-67-1-3	277	136bc	49.0cde	76e	7.4cd	1.01cd
Checks	259	63C‡	24.6C	70C	6.8C	0.45C
Short, tolerant	229	132B	55.6B	84B	8.0B	1.04B
Tall, tolerant	287	217A	75.5A	107A	10.4A	2.23A

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

Table 4. Rice crop establishment 12 d after broadcast sowing at 232 seed m^{-2} at Muñoz, Philippines, during the 1993 dry season.

Cultivar and group†	Seedling no.	Plant stand	Seedling height	Seedling wt.	Biomass
	no. m^{-2}	%	mm	mg seedling^{-1}	g m^{-2}
IR72	76cde‡	32.6cde	79e	8.1fg	0.62de
PSBRc4	49e	20.8e	72f	7.4g	0.36e
IR41996-50-2-1-3	116bcd	50.0bcd	97b	10.6d	1.19bcd
IR31802-48-2-2-2	139b	59.7b	87cd	10.3d	1.43b
BR736-20-3-1	134bc	57.8bc	86d	10.1de	1.37bc
IR50363-61-1-2-2	162ab	69.9ab	85d	9.9de	1.59b
IR52341-60-1-2-1	134bc	57.6bc	88cd	9.8de	1.31bcd
RP1125-3-2-1	123bc	53.0bc	97b	11.9c	1.47b
CO25	210a	90.4a	118a	13.9b	2.77a
ASD1	168ab	72.6ab	115a	15.2a	2.59a
7909-TR16-1-1	63de	27.0de	93bc	11.1cd	0.69cde
BR1870-67-1-3	123bc	52.7bc	78ef	8.9ef	1.08bcd
Checks	63C‡	26.7C	76C	7.7C	0.49C
Short, tolerant	135B	58.0B	90B	10.4B	1.39B
Tall, tolerant	189A	81.5A	117A	14.5A	2.68A

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

60-1-2-1 (9.8 t ha^{-1}) and IR72 (7.7 t ha^{-1}) by drill and broadcast sowing at Muñoz, respectively. The low grain yield of CO25 and ASD1 was caused by lodging at maturity at both locations. There were significant inverse correlations between grain yield and plant height at maturity (correlation coefficient $r = -0.71$ for drill sowing and $r = -0.80$ for broadcast sowing at Muñoz, significant at the 0.01 level). The difference in growth duration between the locations and between the drill and broadcast sowings was little. Productivity, which is defined here as the daily grain yield (grain yield divided by number of days from sowing to maturity), was high with IR72, IR50363-61-1-2-2, and IR52341-60-1-2-1 at Los Baños; with IR52341-60-1-2-1 with drill sowing; and with IR72, IR41996-50-2-1-3, IR50363-61-1-2-2, and IR52341-60-1-2-1 with broadcast sowing at Muñoz. The simple linear correlation analyses clarified that high grain yield was associated more with large panicle-to-shoot weight ratio than biomass in the three experiments: the correlation coefficient was 0.67 to 0.71 (significant at the 0.05 level) for panicle-to-shoot weight ratio and 0.43 to 0.62 (not significant) for shoot weight.

The cultivar that showed poor seedling establishment caught up with the other cultivar with good seedling establishment in terms of biomass at maturity. Although PSBRc4 at Los Baños, and PSBRc4 and IR72 at Muñoz had low biomass due to low seedling weight and small seedling number at 12 d after sowing (11 to 28% of the biomass of the best performer), their biomass was more than that of most others at maturity (69 to 84% of the best performer). The characters of seedling establishment (i.e., plant stand, seedling number, height, weight, and biomass) did not correlate with the grain yield.

There was a significant correlation between the heights at seedling establishment and harvesting time. The coefficient of simple linear correlation was 0.81 for drill sowing and 0.80 for broadcast sowing at Muñoz (significant at the 0.01 level). The exception was IR41996-50-2-1-3, which was tall at seedling establishment stage but short at maturity stage.

DISCUSSION

The anoxia-tolerant cultivars CO25 and ASD1 were tall and lodged at maturity; the others did not. We calculated the characters of seedling establishment and grain yield by classifying the cultivars common to the three field experiments into checks, tolerant cultivars that are short at maturity, and tolerant cultivars that are tall, so that the three field experiments can be compared (Tables 2–4, 6–8). The short tolerant cultivars were superior over the checks in plant stand, seedling height and weight, and biomass.

The short tolerant cultivars produced as much grain as the checks in drill sowing at Los Baños (Table 6) and Muñoz (Table 7). Although the grain yield of short

Table 5. Coefficient of simple linear correlation between the characters in different experiments at seedling establishment of rice.

Location and sowing method	Plant stand	Seedling height	Seedling wt.
	Correlation with the characters in container in a temperature-controlled glass room		
Los Baños, drill sowing	0.41NS	0.89**	0.89**
Muñoz, drill sowing	0.87**	0.90**	0.86**
Muñoz, broadcast sowing	0.73*	0.89**	0.91**
	Correlation with the characters at Los Baños with drill sowing		
Muñoz, drill sowing	0.37NS	0.96**	0.84**
Muñoz, broadcast sowing	0.30NS	0.96**	0.94**
	Correlation with the characters at Muñoz with drill sowing		
Muñoz, broadcast sowing	0.91**	0.98**	0.89**

The characters of 10 cultivars commonly used in the experiments (IR72, PSBRc4, IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, RP1125-3-2-1, CO25, and ASD1) were used for the analysis.

Table 6. Grain yield, biomass, and panicle–shoot weight ratio of drill-sown rice plants at Los Baños, Philippines, during the 1993 dry season.

Cultivar and group†	Grain yield	Biomass	Panicle–shoot ratio	Growth duration	Productivity
	t ha^{-1}	g m^{-2}		d	kg ha^{-1} d^{-1}
IR72	8.42a‡	1480a	0.55c	112	75.0a
PSBRc4	6.59d	1180cd	0.53cd	106	62.3bc
IR41996-50-2-1-3	6.91cd	1230bcd	0.53cd	98	70.5ab
IR31802-48-2-2-2	7.85abc	1190cd	0.56bc	110	71.3ab
BR736-20-3-1	7.90abc	1400abc	0.53cd	110	71.5ab
IR50363-61-1-2-2	8.18a	1440ab	0.58ab	105	77.8a
IR52341-60-1-2-1	8.39a	1310abcd	0.61a	105	80.0a
RP1125-3-2-1	6.37d	1450ab	0.50d	112	56.8c
CO25	4.42e	1290abcd	0.41e	112	39.5d
ASD1	4.75e	1100d	0.43e	100	47.5d
IR41996-50-2-1-3 + Calper	7.15bcd	1230bcd	0.54c	98	73.0a
IR72 + Calper	8.11ab	1530a	0.53cd	112	72.5a
Checks	7.50A‡	1330A	0.54A	109	68.6A
Short, tolerant	7.60A	1340A	0.55A	107	71.3A
Tall, tolerant	4.58B	1190B	0.42B	106	43.5B

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

tolerant cultivars was lower than that of the checks in broadcast sowing at Muñoz (Table 8), the biomass and panicle-to-shoot ratios were the same between the short tolerant cultivars and the checks, suggesting that the former may have the potential to produce as much grain as the latter. The grain yield of tall tolerant cultivars was lower than that of the checks and the short tolerant cultivars. Thus, we may conclude that the use of anoxia-tolerant cultivar with short height improves seedling establishment without sacrificing grain yield in these irrigated conditions.

The potential of grain yield with anoxia-tolerant cultivars sown in puddled soil should be assessed with the optimum seedling number per unit land area and fertilizer management, particularly N. Hiraoka et al. (1992) reported that grain yield of direct-sown rice plants increased as the seedling number increased up to 150, but it leveled off when it was more than 180 m^{-2}. In this study, the seedling number was from 89 to 170 m^{-2}, with a mean of 153 m^{-2} for the anoxia-tolerant cultivars. Although IR41996-50-2-1-3 and IR52341-60-1-2-1 produced high grain yield (8.2 and 9.8 t ha^{-1}) in drill sowing at Muñoz, their seedling numbers were below the optimum (134 and 89 m^{-2}) (Tables 3 and 7). Besides, Schnier et al. (1990) demonstrated that direct-sown rice plants had a higher demand for N fertilizer than the transplanted ones. The rate and time of N application in the present study were not those tuned to direct-sown plants.

When seedling establishment is defined as biomass production at the early stage, it can be expressed as Biomass (g m^{-2}) = Seed Rate (no. m^{-2}) × Plant Stand (%) × Seedling Weight (g seedling^{-1}). Seed rate is determined by the cultural practice; seedling weight could be controlled by genetics. Plant stand seems to be the most difficult to control and to predict among these characters, being determined by seed environmental conditions, genetics, seed source, and cultural practice.

The plant stand of anoxia-tolerant and the local check cultivars has also been tested in the deltas of the Mekong River (Chau and Yamauchi, 1994) and Red River (Yamauchi et al., 1995) in Vietnam and Yezin and Kyaukse in Myanmar (Tun Winn et al., 1997). In each experiment, five to seven tolerant cultivars and two local checks were tested. Plant stand differed between the locations, which also occurred in the present study. The interaction in the plant stand between cultivar performance and location was analyzed (Fig. 1). Location was

Table 7. Grain yield, biomass, and panicle–shoot weight ratio of drill-sown rice plants at Muñoz, Philippines, during the 1993 dry season.

Cultivar and group†	Grain yield	Biomass	Panicle–shoot ratio	Plant height	Growth duration	Productivity
	t ha^{-1}	g m^{-2}		cm	d	kg ha^{-1} d^{-1}
IR72	6.96bc‡	880bc	0.48c	88ef	113	62.0cd
PSBRc4	5.57cd	1070abc	0.52ab	81f	105	53.0d
IR41996-50-2-1-3	8.24b	1170ab	0.53a	84ef	98	84.3ab
IR31802-48-2-2-2	7.39b	1070abc	0.48bc	87ef	105	70.3bc
BR736-20-3-1	4.06de	860bc	0.37d	114c	113	35.8e
IR50363-61-1-2-2	7.29b	940bc	0.53a	88ef	105	69.3bc
IR52341-60-1-2-1	9.83a	1070abc	0.53a	88ef	105	93.5a
RP1125-3-2-1	4.58de	1010abc	0.39d	91def	126	36.3e
CO25	3.83e	1270a	0.31e	150a	113	34.0e
ASD1	1.72f	970abc	0.30e	133b	103	16.8f
7909-TR16-1-1	3.93e	840c	0.49abc	102d	82	48.3de
BR1870-67-1-3	7.47b	1080abc	0.48c	96de	105	71.3bc
Checks	6.27A‡	977A	0.50A	84B	109	57.5A
Short, tolerant	6.90A	1020A	0.47B	92B	109	64.9A
Tall, tolerant	2.77B	1120A	0.30C	142A	108	25.4B

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

Table 8. Grain yield, biomass, and panicle–shoot weight ratio of broadcast-sown rice plants at Muñoz, Philippines, during the 1993 dry season.

Cultivar and group†	Grain yield	Biomass	Panicle–shoot ratio	Plant height	Growth duration	Productivity
	t ha^{-1}	g m^{-2}		cm	d	kg ha^{-1} d^{-1}
IR72	7.65a‡	1190bc	0.50cd	85e	112	68.3a
PSBRc4	6.08b	1210bc	0.51cd	98cd	104	58.5b
IR41996-50-2-1-3	7.13a	1110bc	0.53bc	89de	97	73.5a
IR31802-48-2-2-2	5.27bc	1320ab	0.52cd	91de	104	50.8bcd
BR736-20-3-1	5.06bc	1120bc	0.46ef	106c	112	45.0de
IR50363-61-1-2-2	7.14a	1500a	0.55ab	98cd	104	68.8a
IR52341-60-1-2-1	7.42a	1490a	0.57a	91de	104	71.3a
RP1125-3-2-1	4.88c	980c	0.45f	105c	125	36.0e
CO25	2.67e	1110bc	0.27h	168a	112	23.8f
ASD1	1.40f	1080bc	0.34g	131b	102	13.5g
7909-TR16-1-1	3.81d	1070bc	0.49de	105c	81	47.0cde
BR1870-67-1-3	5.75bc	1270abc	0.49d	99cd	104	55.5bc
Checks	6.86A‡	1200AB	0.50A	91B	108	63.4A
Short, tolerant	6.15B	1250A	0.51A	97B	108	57.6B
Tall, tolerant	2.03C	1100B	0.30B	149A	107	18.9C

† Checks = IR72 and PSBRc4; short, tolerant = IR41996-50-2-1-3, IR31802-48-2-2-2, BR736-20-3-1, IR50363-61-1-2-2, IR52341-60-1-2-1, and RP1125-3-2-1; tall, tolerant = CO25 and ASD1.

‡ Within columns, means followed by a common lowercase or uppercase letter are not significantly different at the 0.05 level.

presented in the *x*-axis by the use of plant stand of the better check cultivar. In the *y*-axis, plant stand of the best tolerant cultivars and the mean of tolerant cultivars were presented. The regression curve of plant stand of the best cultivar indicated that the use of such a cultivar had a plant stand of more than 80%, even when the plant stand of the local best check cultivar was only 20%. Thus, the use of the tolerant cultivar is useful in stabilization of plant stand.

Plant stand and seedling height and weight were lower in drill sowing at Muñoz than at Los Baños, suggesting that seedling growth was hampered more at Muñoz. The environmental conditions responsible for the difference between the locations may include climate and soil. Because temperature, rainfall, and cultural practices at Los Baños and Muñoz were not much different, the soil conditions (not only chemical and physical properties but also biological factors) might be most responsible for the difference in the performance of seedling establishment.

It is known that seedling growth is inhibited at low redox potential (Ponnamperuma, 1978). In pots, the difference in redox potential among the soil types is related to the difference in plant stand in flooded soil (Yamauchi, 1997). However, soil redox potential might not be the responsible factor in the present study, because the redox potential at Los Baños was lower than that at Muñoz. Neither was soil hardness responsible, because the difference in soil hardness between the Los Baños and drill-sown fields at Muñoz was similar to the difference between drill- and broadcast-sown fields at Muñoz. Further studies are needed to identify the factors responsible for the difference in seedling growth between locations and then to define the conditions in which sowing pregerminated seeds of anoxia-tolerant cultivars under the puddled soil surface may be suitable.

TeKrony and Egli (1991) reviewed the literatures and concluded that seed vigor and grain yield are not related in crops harvested at maturity. This is true in the present study where the characters of seedling establishment did not correlate with the grain yield. Although the biomass was poor for PSBRc4 at Los Baños and Muñoz and for IR72 at Muñoz at the early stage, they grew vigorously thereafter, resulting in high grain yield. The vigorous growth could be expected only when the field is managed intensively to prevent weed infestation as was done in the present study.

Under an extensive rice production system, the poor biomass induced by inferior seedling establishment might increase weed infestation, leading to low grain yield. In such a system, we need a cultivar with high weed competitiveness along with anoxia tolerance. The cultivar IR41996-50-2-1-3 would be advantageous not only in weed competitiveness but also in achieving high grain yield, because it is tall at the early stage and short at harvest time. Thus, there might be anoxia-tolerant cultivars suitable for extensive production.

CONCLUSION

Rice plants can be sown under the surface of puddled soil in the tropics. Although seedling establishment of check cultivars varies between the locations, that of

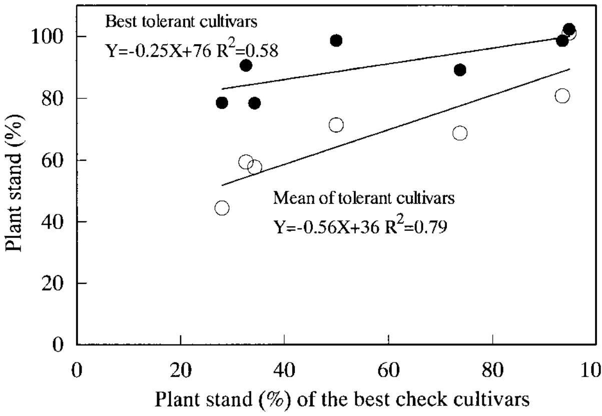

Fig. 1. Plant stand of the anoxia-tolerant rice cultivar vs. the local check cultivar in the tropics (data from 7 experiments, 6 locations). Each experiment involved 2 check cultivars and 5 to 10 tolerant cultivars. In the *x*-axis, plant stand of the better check cultivar is shown, indicating the character associated with the locations. The *y*-axis indicates the plant stand of the best anoxia-tolerant cultivars and mean of the tolerant cultivars tested.

the cultivars with anoxia tolerance is superior and less variable. Further study is needed, however, to identify the factors responsible for the difference in seedling establishment between locations.

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