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Full Length Article

Competitive Ability of some Selected Rice Varieties against Weed under Aerobic Condition

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Abstract

Sustainable weed management strategy in aerobic rice cultivation system would be beneficial from both economic and environmental perspectives. Glass house and field experiments were conducted to evaluate competitive ability of five rice varieties, namely AERON 1, AERON 4, M9, MR211 and MR220-MCL2 against weeds under aerobic rice cultivation systems to select suitable varieties for cultivation in tropical Asia. Results revealed that AERON 1 had the lowest weed dry weight and weed density and the highest weed dry weight was recorded in MR211, both in glass house and field trials. Grasses were the most dominant weeds which occupied more than 60% of sum dominance ratio in which *Leptochloa chinensis* and *Echinochloa colona* were the most dominant weeds in glass house and field conditions, respectively. AERON 1 with characteristics of taller plant stature and short growth duration competed better with weed as compared to other varieties with shorter plant and longer growth duration. Weed competition had negative impact on rice plants. Lower weed dry weights and relative less yield loss was found in AERON 1 indicated its better weed suppressive and competitive ability against weeds. These results concluded that AERON 1 is the most competitive variety against weeds under aerobic rice cultivation systems.
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Keywords: Aerobic rice; Weed competition; Relative yield loss

Introduction

Rice is a crop of global importance and serves as the basis of life for half of the world's population, particularly in East and South East Asia. It is great source to nutritional calories, providing 35-80% of total calorie uptake (IRRI, 1997). Rice production needs to be increased by 50% or more above the current production level to meet the rising food demand.

In Asia, where about 60% of the world's population lives, food security is challenged by increasing food demand and threatened by declining water availability (Bouman and Tuong, 2000). Compared to other field crops, rice is most widely grown under irrigated condition which accounts for about 50% of the total amount of water diverted for irrigation, which in itself accounts for 80% of the amount of fresh water diverted (Guerra *et al.*, 1998; Farooq *et al.*, 2009). This is due to the high unproductive water losses by evaporation, surface run-off, and percolation. Producing one kilogram of unprocessed rice under irrigation is estimated to use between 1500 and 5000 L of water, depending on the local climate, soil type and rice variety (Tao *et al.*, 2006). The challenge thus facing national policy makers, irrigation authorities and farmers are how best to maintain and increase rice yields, while reducing total water use.

Water shortage is becoming severe in many rice-growing areas in the world, prompting the introduction of a water-saving aerobic rice production (Zhao *et al.*, 2007). This is an irrigated system in which rice is direct-seeded in dry soil and irrigation is applied to keep the soil sufficiently moist for crop growth but not saturated (Tuong and Bouman, 2003). This system differs from traditional upland rice production, which is completely dependent on rainfall and thus may experience severe drought stress from time to time (Zhao *et al.*, 2007). Compared with lowland rice, aerobic rice can reduce water use by as much as 50% while maintaining a moderately high yield (Tuong and Bouman, 2003).

However, direct-seeded aerobic rice is subjected to more severe weed infestations than transplanted lowland rice, because in aerobic rice systems, weeds germinate simultaneously with rice and there is no water layer to suppress weed growth (Moody, 1983). Weeds compete for nutrient, space, sunlight and consume the available moisture with crop plant resulting in crop yield reduction. Weeds in direct seeded rice may cause yield losses up to 35% (Oerke and Dehne, 2004).

Herbicides are now commonly used in controlling weeds. Although herbicides use alleviates the problem of weed infestation but, non-judicious use may bring other

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environmental problems such as chemical pollution (Labrada, 2003). Reduced dependence on herbicides may reduce the costs of crop production and retard the development of herbicide resistance in weeds (Lemerle *et al.,* 1996; De Vida, 2006). Recently, attention has shifted to integrate non-chemical methods of weeds control into the current farming systems to reduce herbicide use (Mcdonald, 2003), such as the development of competitive rice cultivars which provide a safe and environmentally benign tool for integrated weed management (Fischer *et al.,* 2001).

Plant to plant competition is common but not universal in natural ecosystems. However, weed-crop competition is abundant, natural and undesirable in agricultural plant communities (Zimdahl, 2004). Therefore, choosing a competitive crop can be a way to potentially suppress weed growth without sacrificing crop yield. However, crop cultivars often differ in competitive ability against weeds. Cultivars may also perform differently in different regions and growing conditions (Mason and Spaner, 2006). It is also important to note that the most competitive cultivars are not always the highest yielding cultivars. All these factors may influence the choice of crop cultivars for herbicide use reduction. Differences between rice cultivars in response to weed competition have been recognized (Suzuki *et al.,* 2002; Estorninos *et al.,* 2005; Zhao *et al.,* 2007). Since aerobic condition have lack of water to suppress weed, suitable competitive cultivars can be adopted to reduce the application of herbicide. However, study on competitive ability of rice varieties under aerobic condition in Malaysia is still scanty. The present study was undertaken to evaluate the competitive ability of several rice varieties against weeds under aerobic condition to select suitable rice varieties.

Materials and Methods

Experimental Site

The experiment was conducted in a glass house and repeated at experimental field at Malaysian Agriculture Research and Development Institute (MARDI), Pulau Pinang, Malaysia during January to April 2011 and May to September 2011. The local climate is hot-humid-tropic with plentiful rainfall.

Plant Material

Five rice varieties viz. two aerobic lines -AERON 1 and AERON 4, from International Rice Research Institute, IRRI and three low land rice varieties viz. M9, MR211 and MR220-MCL2, sourced from Malaysian Agriculture Research and Development Institute (MARDI) were used as the plant materials.

Experimental Design

The experiment was laid out in split plot design using four replications with weeding regime in main plot and five rice varieties in subplot. The weeding regimes were consisted of weedy and weed free condition.

Methodology

The glass house study, a total of 40 troughs (0.75 m×0.57 m = 0.43 m^2) was filled with prepared dry soils up to trough surface to prevent ponding. Dry rice seeds were drill-seeded by hand in each trough in three rows with an inter-row spacing of 25 cm and within-row spacing of 20 cm. Each spot consisted of seven seeds and thinned to five seedlings at 7 days after emergence. Hand weeding was carried out to keep the weed-free treatments weed free. For field experiment, the soil was dry-ploughed twice, harrowed and leveled to prevent from ponding. Organic manure at the rate of 8 t $ha^{-1}$was applied before second ploughing. Similar to glass house study, dry rice seeds were drill-seeded by hand in each plot (4 m × 4 m = 16 m^2) in three rows with similar inter-row and within-row spacing. Each spot consisted of seven seeds and thinned to five seedlings at 7 days after emergence. 'Pretilachlor' herbicide (0.50 kg a.i. ha^{-1}) was sprayed 2 days after sowing and Benthiocarb/Propanil (0.9 kg ai/ha) at 10 days after sowing followed by manual weeding throughout the growing season to control weeds in weed-free treatments. Troughs and field plots were fertilized at the rate of 180, 54 and 76.5 kg ha^{-1} N, P_2O_5 and K_2O respectively and were irrigated when necessary to keep the soil moisture around field capacity throughout the growing period. Different intercultural operations and plant protection measures were conducted following standard practices.

Crop and Weed Data Measurements

Data for plant height at 25 days after sowing (DAS), 50 DAS, and harvesting were recorded. The tiller numbers were counted manually following the same intervals. The leaf chlorophyll content of fully expanded healthy leaves was measured at 10 days interval starting from two weeks after sowing (MINOLTA™ SPAD-502, Minolta camera Co., Osaka, Japan). Plant height, tiller number and SPAD value were determined from six (glass house) and sixteen (field) randomly selected hills from each plot. Days to 50% flowering and days to maturity were recorded when 50% of plants started to flower and more than 80% grains turned to yellow color, respectively. At maturity, number of productive tiller per hill, panicle per meter square and grain yield were recorded. Yield components such as number of spikelet's per panicle, number of filled grains per panicle, sterility percentage and thousand grain weights were determined. The relative yield loss (%) was calculated using the formula of Haefele *et al.* (2004):

$$\text{Relative yield loss} = \frac{\text{Weed free yield} - \text{weedy yield}}{\text{Weed free yield}} \times 100$$

Weed sampling in glass house was carried out only at harvest from weedy trough where weeds from the whole trough were uprooted. In field, weed sampling were carried out at 25 DAS, 50 DAS and at harvest. Weeds were uprooted in a sampling area of 1 m^2 by using 0.5 m x 0.5 m quadrant. Weeds were cleaned, separated into species and sundried, counted and oven dried at 70°C for 72 h to record dry weights. The major or dominant weed species were determined from the sum dominance ratio (SDR). SDR value was expressed as a percentage, which was computed using the equation of Janiya and Moody (1989).

Statistical Analysis

All data were analysed using the Analysis of Variance (ANOVA) technique and the mean separation was done with the Least Significant Difference (LSD) test at 5% probability level using the computerized Statistical Analysis System Software (SAS, 2003).

Results

Weed Composition (DMR)

Sixteen types of weed species were identified in glass house experiment (Table 1). The weed flora dominantly consisted of grasses (75.84%) followed by sedges (18.08%) and then broadleaves (6.08%). The most dominant weed species were *Leptochloa chinensis* (64.1%), *Fimbristylis miliacea* (14.76%), *Echinochloa colona* (10.26%), *Ludwigia hyssopifolia* (4.96%) and *Cyperus iria* (3.15%).

In field, grasses were dominating population (96.16%) followed by broadleaves (3.84%) (Table 2). No sedge weed was recorded. The major weeds infesting the aerobic field were *E. colona* (61.08%), *Eleusine indica* (31.91%), *Panicum maximum* (2.4%) and *Mimosa invisa* (1.76%).

Weed Dry Weight and Weed Density

In glass house condition, weed dry weight and weed density were significantly affected by rice varieties (Fig. 1). The minimum weed dry weight was produced by AERON 1 (559.7 g m^{-2}) followed by AERON 4 (583.2 g m^{-2}), while the maximum weed dry weight was produced by MR 220CL2 (934.5 g m^{-2}). Similar pattern was observed in weed density, where AERON 1 produced the lowest weed density (491.5 m^{-2}), followed by AERON 4 (501.6 m^{-2}). The highest weed density was observed in MR 220CL2 (783.0 m^{-2}).

In field condition, weed dry weight was significantly affected by rice varieties but not weed density (Fig. 2). Weed dry weights ranged between 99.4 to 438.6 g m^{-2}. The minimum weed dry weight was produced by AERON 1 (184.3 g m^{-2}) followed by AERON 4 (204.2 g m^{-2}). The maximum was produced by MR211 (327.7 g m^{-2}) but did not differ significantly with MR 220CL2 (270.8 g m^{-2}) and M9 (273.0 g m^{-2}). Similar pattern was observed in weed density in which AERON 1 produced the lowest weed density (176.5 m^{-2}), while the highest (235.7 m^{-2}) was in MR211. On average, number of weeds per meter square was 226.12 m^{-2} in field condition (Fig. 2).

Table 1: Sum dominance ratio (SDR) based on different weed species in aerobic rice cultivation under glass house condition

Species	Family name	Weed type	SDR (%)
Leptochloa chinensis (L.) Nees	Poaceae	Grass	64.12
Fimbristylis miliacea (L.) Vahl.	Cyperaceae	Sedge	14.76
Echinochloa colona (L.) Link	Poaceae	Grass	10.26
Ludwigia hyssopifolia (G. Don)	Onagraceae	Broadleaf	4.94
Cyperusiria (L.)	Cyperaceae	Sedge	3.15
Monochoria vaginalis (Burm.)	Pontaderiaceae	Broadleaf	0.89
Eleusineindica (L.) gaertn.	Poaceae	Grass	0.69
Echinochloa crus-galli (L.) Beauv	Poaceae	Grass	0.67
Hedyotis corymbosa (L.) Lam.	Rubiaceae	Broadleaf	0.21
Ischaemum rugosum Salisb	Poaceae	Grass	0.12
Cyperus compactus Retz.	Cyperaceae	Sedge	0.07
Cyperus difformis L.	Cyperaceae	Sedge	0.07
Lindernia sp.	Linderniaceae	Broadleaf	0.04
*Cyperuspilosus*Vahl.	Cyperaceae	Sedge	0.02
Calopogonium mucunoides Desv.	Leguminosae	Broadleaf	0.01
Cyperuscompressus L.	Cyperaceae	Sedge	0.01

Table 2: Sum dominance ratio (SDR) based of different weed species in aerobic rice cultivation under field condition

Weed Species	Family name	Weed type	SDR (%)
Echinochloa colona (L.) Link	Poaceae	Grass	61.08
Eleusine india (L.) gaertn.	Poaceae	Grass	31.91
Panicum maximum Jacq.	Poaceae	Grass	2.41
Mimosa invisa Colla	Leguminosae	Broadleaf	1.76
Melochia corchorifolia L.	Malvaceae	Broadleaf	0.78
Cleome rutidosperma DC.	Cleomaceae	Broadleaf	0.52
Digitaria adcendens (Kunth) Henrard	Poaceae	Grass	0.47
Euphorbia heterophylla L.	Euphorbiaceae	Broadleaf	0.41
Leptochloa chinensis (L.) Nees	Poaceae	Grass	0.26
Ipomeatriloba	Convolvulaceae	Broadleaf	0.14
Calopogonium mucunoides Desv.	Leguminosae	Broadleaf	0.11
Ludwigia hyssopifolia (G. Don) Exell	Onagraceae	Broadleaf	0.06
Paspalum conjugatum P.J. Bergius	Poaceae	Grass	0.04
Ageratum conyzoides(L.) L.	Compositae	Broadleaf	0.03
*Portulaca oleracea*L.	Portulacaceae	Broadleaf	0.02
Phyllanthus niruri L.	Phyllanthaceae	Broadleaf	0.02

Rice Plant Height

In glass house condition, all rice varieties exhibited significant differences in plant height at all sampling dates (Table 3) however, interaction between rice varieties and weeding regime was not significant.

At 25 DAS, plant height in weedy condition was higher than weed free condition. AERON 1 appeared the tallest plant (67.0 cm), while MR211 produced the shortest (42.8 cm). Plant height of AERON 4 was significantly shorter than AERON 1 (57.49 cm) but taller than the others. Height of M9 variety was at par with MR 220CL2, which 49.5 cm and 43.9 cm, respectively. On contrary, at 50 DAS and at harvest plant height in weed free condition was significantly taller than weedy condition. During harvest, AERON 4 produced

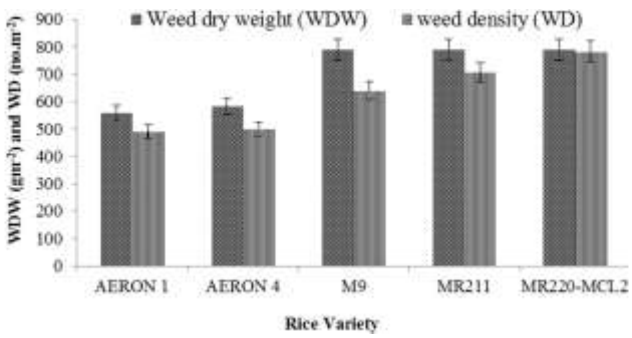

Fig. 1: Weed dry weight and weed density under glass house condition

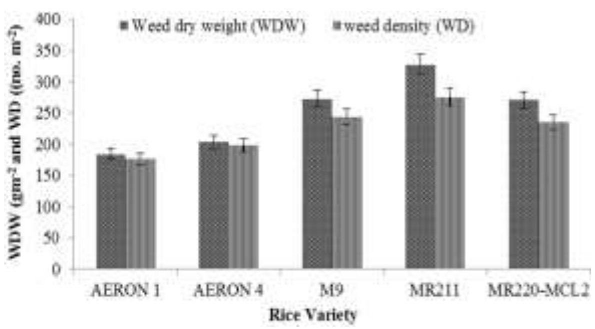

Fig. 2: Weed dry weight and weed density under field condition

the tallest plant (122.2 cm), closely followed by AERON 1 (120.2 cm). MR211 gave the shortest plant height (82.8 cm) which was at par with MR 220CL2 (85.19 cm) and M9 variety produced intermediate height of 94.5 cm. At harvest, plant height ranged from 23 to 136.8 cm.

In field condition, plant height was significantly different between five rice varieties but not among weeding regime (Table 4). Interaction between weeding regime and rice varieties were not significant. At 25 DAS, AERON 1 appeared to be the tallest plant (53.0 cm). MR211 as the shortest plant but not significantly different from M9 (35.8 cm) and MR 220CL2 (36.6 cm). At 50 DAS, similar pattern was observed as at 25 DAS, where AERON 1 produced the tallest plant (106.0 cm) while MR 211 produced the shortest plant (38.6 cm) which at par with MR 220CL2 (68.6 cm). AERON 4 (95.1 cm) grew significantly taller than M9 (75.5 cm). At harvest, AERON 1 also produced significantly taller plant which on average (113.5 cm) closely followed by AERON 4 (113.3 cm) and MR211 produced significantly shorter plant (78.0 cm) where height of M9 did not differ significantly with MR 220CL2.

Tiller Number

In glass house, weed competition reduced the number of tillers of all rice varieties. Mean tiller number in weed free condition increased growth duration except AERON varieties (Table 5). However, in weedy condition, the number of tiller increased from 25 DAS to 50 DAS, and thereafter decreased at harvest. At 25 DAS, MR211 produced the highest number of tillers (337 tillers m^{-2}) followed by M9 (319.6 tillers m^{-2}) and MR 220CL2 (291.7 tillers m^{-2}) whereas AERON 1 produced the lowest number of tillers (195 tillers m^{-2}) followed by AERON 4 (220 tillers m^{-2}). At 50 DAS in weedy condition, there was no difference in tiller number. At maturity, M9 produced the highest number of tiller (389 tiller m^{-2}) followed by MR211 (376 tillers m^{-2}) and MR 220CL2 (337 tillers m^{-2}). AERON 1 produced the lowest number (234 tillers m^{-2}), followed by AERON 4 (230 tillers m^{-2}) (Table 6).

At 25 DAS, M9 produced the highest number tillers (292.5 tillers m^{-2}) and AERON 4 produced the lowest number of tillers (220 tillers m^{-2}). AERON 1, MR211 and MR 220CL2 did not differ significantly in tiller number from each other. However, in weed free condition, there was no significant difference in tiller number detected among rice varieties. No difference was observed in tiller number among five rice varieties At 50 DAS, whereas at harvest, differences were detected in tiller number only for weeding regimes but not for rice varieties. M9 produced the highest tiller number (339 tiller m^{-2}), followed by MR211 (323 tillers m^{-2}) and MR 220CL2 (308 tillers m^{-2}). AERON varieties produced almost the similar number of tillers (287 tiller m^{-2}).

Chlorophyll Contents

In glass house, average SPAD values in weed free condition were significantly higher compared to weedy conditions at 30 and 90 DAS, but not at 60 DAS (Table 7). Interaction effect between weeding regimes and rice varieties were not significant at all observational dates. SPAD values varied between 28.2 to 42.2.

At 30 DAS, MR211 had the highest (41.3) while M9 had the lowest SPAD value (35.5). The average SPAD value (39.6) produced by AERON followed by AERON4 (38.6) and MR 220CL2 (38.6) but at 60 DAS, AERON 4 produced the highest average SPAD value (40.0), but did not show significant value between AERON 1 (39.7) and MR211 (39.4). M9 gave the lowest SPAD value (35.2) but not significantly different with MR 220 CL2. At 90 DAS, AERON 1 produced the highest SPAD value (37.3) but not significantly different with AERON 4 (37.1). MR 220CL2 gave the lowest value (32.1) but did not differ significantly with M9 and MR211.

Under field condition, SPAD values significantly differed between rice varieties but not between weeding regimes (Table 8). SPAD value in weedy condition was significantly lower than value in weed free condition at 30 and 60 DAS but not during at 90 DAS, which ranged from 29.3 to 40.4. At 60 DAS, AERON 4 gave significantly higher SPAD value (39.7) and was comparable with AERON 1 (37.9), while M9 gave the lowest value (35.8). Whereas during harvest; AERON 4 also gave highest SPAD value (37.6) but did not differ significantly with AERON 1 (36.4). MR 220CL2 gave significantly lower SPAD value

Table 3: Plant height of different rice varieties under weedy (W) and weed-free (WF) conditions in glass house

Rice variety	Plant height at 25 DAS			Plant height at 50 DAS			Plant height at harvest		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	68.11 a	66.12 a	67.09 a	114.71 a	119.01 a	116.80 a	118.11 a	123.21 a	120.23 a
AERON 4	59.30 b	55.53 b	57.49 b	99.21 b	114.43 a	106.81 b	117.83 a	126.52 a	122.21 a
M9	50.71 c	48.40 c	49.54 c	78.40 c	90.40 b	84.40 c	86.10 b	102.93 b	94.52 b
MR211	42.45 d	43.25 c	42.84 d	68.54 c	75.74 c	72.14 d	75.15 b	87.64 c	82.85 c
MR 220CL2	43.40 d	44.52 c	43.94 c	76.01 c	81.02 c	78.53 c	80.32 b	90.12 c	85.19 c

Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 4: Plant height of different rice varieties under weedy and weed-free conditions in field

Treatment	Plant height at 25 DAS			Plant height at 50 DAS			Plant height at harvest		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	55.13 a	50.91 a	53.02 a	101.31 a	110.61 a	106.02 a	110.02 a	117.04 a	113.51 a
AERON 4	45.31 b	43.32 ab	44.32 b	92.56 a	97.75 b	95.13 b	108.53 a	118.11 a	113.34 a
M9	38.60 cd	33.03 bc	35.81c	74.41 b	76.63 c	75.51 c	92.71 b	105.13 b	98.91 b
MR211	35.13 d	29.73 c	32.43 c	58.52 c	60.71 d	58.62 d	77.08 c	96.12 c	78.06 c
MR 220CL2	40.71 bc	32.61 bc	36.60 c	67.73 b	69.45 c	68.65 d	90.53 b	79.17 c	93.35 b

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 5: Tillering ability of different rice varieties under weedy and weed-free conditions in glass house

Treatment	Tiller number at 25 DAS			Tiller number at 50 DAS			Tiller number at harvest		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	175.83 c	215.06 b	195.42 b	190.08 a	299.33 b	244.65 b	171.74 b	291.31 b	234.76 b
AERON 4	191.81 bc	248.32 b	220.04 b	228.86 a	329.30 b	279.12 b	178.31 b	309.63 b	240.62 b
M9	250.14 ab	375.07 a	312.65 a	297.73 a	482.10 a	389.90 a	284.25 a	494.34 a	389.21 a
MR211	258.35 a	415.80 a	337.11 a	272.35 a	423.65 a	362.93 a	256.71 a	475.87 a	376.23 a
MR 220CL2	211.72 a-c	371.76 a	291.73 a	239.90 a	467.10 a	353.56 a	205.03 b	470.03 a	337.5 a
Mean	217.52 B	325.24 A		245.71 B	406.33 A		223.22 B	408.23 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 6: Tillering ability of different rice varieties under weedy and weed-free conditions in field

Treatment	Tiller number at 25 DAS			Tiller number at 50 DAS			Tiller number at harvest		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	204.21 ab	277.61 a	240.93 bc	238.85 a	306.93 a	275.51 a	247.08 a	326.41 bc	287.16 b
AERON 4	191.93 b	250.94 a	220.91 c	245.52 a	312.34 a	276.23 a	254.53 a	321.32 c	287.92 b
M9	259.01 a	326.01 a	292.56 a	258.43 a	360.61 a	309.50 a	267.21 a	411.80 a	339.50 a
MR211	243.73 ab	320.32 a	282.02 ab	250.42 a	338.03 a	294.22 a	259.25 a	388.42 ab	323.61 ab
MR 220CL2	245.80 ab	289.77 a	267.81 a-c	247.94 a	340.80 a	294.44 a	262.82 a	360.43 a-c	308.66 ab
Mean	228.75 B	292.93 A		248.22 B	331.71 A		257.14 B	361.61 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 7: SPAD values of different rice varieties under weedy and weed-free conditions in glass house

Treatment	SPAD Value at 30 DAS			SPAD Value at 60 DAS			SPAD Value at 90 DAS		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	38.52 ab	40.82 ab	39.62 b	38.83 ab	40.71 a	39.74 a	34.81 a	39.83 a	37.31 a
AERON 4	37.23 bc	40.07 bc	38.66 b	39.71 a	40.47 a	40.02 a	34.13 ab	40.10 a	37.13 ab
M9	35.15 c	35.72 d	35.57 c	35.04 b	35.33 b	35.21 b	31.52 a-c	37.51 ab	34.52 bc
MR211	40.42 a	42.21 a	41.31 a	38.63 ab	40.22 a	39.44 a	29.84 bc	38.34 a	33.91 c
MR 220CL2	38.07 a	39.25 c	38.65 b	35.55 b	36.91 b	36.18 b	28.23 c	35.92 b	32.41 c
Mean	37.88 B	39.73 A		37.56 A	38.75 A		31.73 B	38.34 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

(31.5) and at par with MR211 (32.2) and M9 (33.1).

Rice Phenology

Total growth duration to maturity of five varieties ranged from 82.5 to 104.8 days after seeding (DAS). AERON 1 and AERON 4 showed earliest flowering of about 59 DAS and matured at 83 DAS, while M9 varieties took the longest duration for flowering (80 DAS) and matured by 103 DAS.

MR211 and MR 220CL2 did not show significant difference from one another which gave flowering at 75 DAS and matured after 100 DAS.

In field condition, also there were significant differences in days to flowering and maturity between weeding regime and rice varieties (Table 10). Days to flowering differed significantly between weedy and weed free conditions; plants in weedy condition flowered and matured earlier than plants in weed free condition. AERON 1 variety showed earliest flowering days (57.8 DAS) followed by AERON 4 (59.0 DAS).

In general, plants in weedy conditions flowered and matured earlier than plant in weed free conditions. This might be due to high weed pressure. Days to 50% flowering and days to maturity varied between glass house and field conditions could be attributed to differences in weather and temperature in experimental condition, implying that in field, the plants were exposed to higher water stress as compared to glass house. The differences in phenology also could be influenced by aerobic conditions as aerobic cultivation resulted in a delay in heading time. Thus early maturing varieties had an advantage on weed competition rather than delay maturing varieties as shorter growth duration can minimize the effect of weed competition.

Yield Components

In glass house condition, number of panicles m^{-2} ranged from 127 to 472. Variety M9 produced the highest number of panicles (297 m^{-2}) followed by MR 220CL2 (265 panicles m^{-2}), while AERON 1 produced the lowest number panicles (214 m^{-2}), which was comparable to AERON 4 (220 panicles m^{-2}) and MR211 (250 panicles m^{-2}) (Table 9). In field condition, number of panicle m^{-2} ranged between 167 to 447. M9 produced the highest number of panicle (292 panicles m^{-2}) followed by MR 220CL2 (274.2 panicles m^{-2}), while MR211 produced the lowest (233 panicles m^{-2}) and did not differ significantly with AERON 4 (254 panicles m^{-2}) and AERON 1 (252 panicles m^{-2}) (Table 10).

In the glass house, filled grains/panicle ranged from 41 to 113 (Table 11). The highest filled grain per panicle was produced by AERON 1 (88 filled grains panicle^{-1}) and followed by AERON 4 (81 filled grains panicle^{-1}) whereas M9 produced only 67 filled grains panicle^{-1} and did not differ significantly with MR 220CL2 (73.3 filled grains panicle^{-1}) and MR211 (64.5 filled grains panicle^{-1}). The range of sterility percentage was from 11.3 to 69.3 (Table 11). MR211 had the highest sterility percentage (44.4), followed by MR 220CL2 (41.2%) and M9 (37.0%) while AERON 1 had the lowest sterility percentage (20.7) followed by AERON 4 (34.4%). Thousand grain weights ranged from 19.6 g to 29.6 g (Table 11). AERON 4 had the highest thousand grain weight (29.6 g), followed by AERON 1 (28.6 g), while it was the lowest in MR 220CL2 (22.1 g) and was at par with MR211 (22.8 g).

In field experiment, filled grain/panicle produced ranged from 52 to 111 grains (Table 12). The highest filled grain per panicle was recorded in AERON 1 (90 filled grains panicle^{-1}) followed by AERON 4 (86 filled grains panicle^{-1}) and M9 (79 grains panicle^{-1}). MR 220CL2 produced 77.2 filled grains per panicle and MR211 produced the lowest one (63 grains panicle^{-1}). The percentage of sterility was significantly higher in weedy conditions as compared to weed free conditions (Table 12). Sterility was highest for MR211 (43.9%) followed by M9 (38.0%) and MR 220CL2 (35.0%). AERON 1 had the lowest fertility percentage (25.9%). AERON 4 had the highest thousand grain weight (29.6 g), followed by AERON 1 (28.1 g and M9 (25.4 g); while MR211 had the lowest (24.2 g) and was at par with MR 220CL2 (24.3 g).

Grain Yield and Relative Yield Loss

Grain yields significantly varied between weeding regimes and rice varieties. However, interactions between weeding regime and rice varieties were not significant. In glass house condition, grain yield ranged from 0.50 to 3.69 t ha^{-1} (Table 13). The mean grain yields in weedy and weed free condition were 0.86 t/ha and 2.50 t ha^{-1}, respectively. AERON 1 produced the highest grain yield (2.02 t ha^{-1}) under weed free conditions, while the lowest grain yield was produced by MR211 (1.33 t/h t ha^{-1}), which was comparable to M9 (1.60 t ha^{-1}) and MR 220CL2 (1.62 t ha^{-1}). Relative yield loss was the lowest for AERON 1 (57.1%), followed by AERON 4 (62.2%) and the highest relative yield loss was recorded for MR211 (74.8%), closely followed by M9 (71.1%) and MR 220CL2 (67%).

In field condition, grain average yields of all varieties in weedy and weed free conditions were 0.82 and 2.23 t ha^{-1}, respectively (Table 14). AERON 1 produced the highest grain yield (2.16 t ha^{-1}) under weed free constitutions, but was not significantly different with AERON 4 (1.63 t ha^{-1} a), M9 (1.51 t ha^{-1}) and MR 220CL2 (1.50 t ha^{-1}) while MR211 produced the lowest grain yield (1.18 t ha^{-1}). Similar pattern of relative yield loss were observed among varieties. The lowest relative yield loss was in AERON 1 (53.1%) and the highest was in MR211 (70.9%). Data revealed that grain yield in glass house condition was higher than field condition. This could be due to controlled condition in glass house and for that the plants in field conditions experienced more water stress.

Discussion

Weed management in rice is very important especially in aerobic condition. The weed flora and density involved in the competition varied according to the season. The summed dominance ratio (SDR) is more informative than any single measure reflecting the contribution of a species in the community (Bhagat *et al.,* 1999). Different weed species were observed in glass house and field conditions. The differences could be attributed to different soil moisture,

Table 8: SPAD values of different rice varieties under weedy and weed-free conditions in field

Treatment	SPAD Value at 30 DAS			SPAD Value at 60 DAS			SPAD Value at 90 DAS		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	38.81 ab	39.84 ab	39.31 a	36.25 b	39.82 b	37.95 ab	34.71 a	38.29 a	36.43 a
AERON 4	38.63 ab	40.02 ab	39.32 a	39.30 a	40.11 a	39.72 a	33.35 a	38.84 a	37.61 a
M9	33.71 c	34.21 c	33.95 c	35.57 b	36.14 c	35.88 c	30.46 b	34.13 b	33.15 b
MR211	39.50 a	40.40 a	39.96 a	36.23 b	37.93 bc	37.16 bc	30.64 b	35.64 ab	32.26 b
MR 220CL2	36.95 b	38.16 b	37.53 b	36.75 ab	39.02 ab	37.83 c	29.33 b	33.77 b	31.57 b
Mean	37.55 A	38.53 A		36.84 B	38.61 A		32.15 A	36.12 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 9: Phenology and panicle number of different rice varieties under weedy and weed-free conditions in glass house

Treatment	Days to 50% flowering			Days to Maturity			No. panicle m^{-2}		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	57.84 c	59.05 c	59.15 c	82.94 b	82.55 b	82.65 b	154.86 a	268.04 b	214.35 c
AERON 4	59.01 c	59.51 c	59.41 c	83.52 b	84.31 b	83.92 b	160.55 b	284.81 b	219.62 c
M9	80.81 a	81.32 a	80.90 a	101.85 a	104.80 a	103.34 a	198.92 a	395.40 a	297.20 a
MR211	75.33 b	76.54 b	75.81 b	103.02 a	104.03 a	103.51 a	166.03 ab	333.16 ab	249.53 bc
MR 220CL2	73.55 b	75.56 b	74.93 b	100.57 a	101.34 a	100.90 a	153.84 b	376.03 a	264.90 ab
Mean	69.36 A	70.43 A		94.36 A	95.41 A		166.72 B	331.43 A	

W and WF indicated weedy and weed free, respectively, DAS: Day after sowing
[#]Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 10: Phenology and panicle number of different rice varieties under weedy and weed-free conditions in field

Treatment	Days to 50% flowering			Days to Maturity			No. panicle m^{-2}		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	58.85 c	62.85 c	60.85 c	88.35 d	90.56 d	89.45 e	218.08 a	287.32 b	252.63 bc
AERON 4	62.31 c	66.52 c	64.42 c	94.52 c	94.55 c	94.53 d	223.91 a	282.83 b	253.31 bc
M9	55.82 a	90.83 a	89.61 a	115.81 ab	119.32 b	117.51 b	221.83a	362.41 b	292.10 a
MR211	86.03 ab	87.37 a	86.65 a	118.50 a	120.13 a	120.13 a	194.46 a	271.65 b	233.02 c
MR 220CL2	80.57 b	81.54 b	81.07 b	114.05 b	116.04 c	116.07 c	231.11 a	317.22 ab	274.21 ab
Mean	75.28 B	77.82 A		106.21 B	108.80A		217.93 B	304.21 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
[#]Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 11: Filled grain per panicle, sterility percentage and thousand grain weights of different rice varieties under weedy and weed-free conditions in glass house

Treatment	Filled grain per panicle (no.)			Sterility percentage			Thousand grain weight (g)		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	71.30 a	104.50 a	87.91 a	25.95 b	15.54 b	20.74 c	27.44 a	29.75 a	28.64 a
AERON 4	64.06 a	97.84 b	80.95 ab	38.40 ab	30.41 a	34.41 b	28.61 a	30.51 a	29.61 a
M9	55.55 a	79.01 cd	67.32 c	38.33 ab	35.66 a	37.03 ab	25.33 b	26.12 b	25.71 b
MR211	55.38 a	73.85 d	64.57 c	51.61 a	37.10 a	44.40 a	21.72 c	22.66 c	22.16 c
MR 220CL2	60.12 a	86.52 bc	73.31 bc	45.64 a	36.63 a	41.23 ab	22.51 c	23.13 c	22.82 c
Mean	61.29 B	88.36 A		40.04 A	31.08 B		25.14 B	26.43 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

Table 12: Filled grain per panicle, sterility percentage and thousand grain weights of different rice varieties under weedy and weed-free conditions in field

Treatment	Filled grain per panicle (no.)			Sterility percentage			Thousand grain weight (g)		
	W	WF	Mean	W	WF	Mean	W	WF	Mean
AERON 1	86.50 a	94.31 a	90.44 a	27.65 c	24.21 c	25.96 d	28.05 a	28.23 b	28.13 b
AERON 4	81.75 a	89.35 ab	85.52 ab	33.31 bc	24.91 bc	30.62 cd	29.01 a	30.31 a	29.60 a
M9	69.32 ab	89.52 ab	79.41 ab	43.34 ab	32.83 ab	38.01 ab	24.71 b	26.12 c	25.41 c
MR211	48.55 b	77.34 b	62.93 c	51.30 a	34.60 a	43.91 a	23.75 b	24.85 d	24.25 d
MR 220CL2	72.91 a	81.63 ab	77.21 b	36.42 bc	33.61 ab	35.07 bc	23.82 b	24.92 d	24.32 d
Mean	71.88 B	86.43 A		38.46 A	31.05 B		25.86 B	26.84 A	

W and WF indicated weedy and weed free, respectively, DAS = Day after sowing
Means followed by same letter within a column are not significantly different at $P \leq 0.05$ (LSD)

temperature, and source of irrigation. Grasses were dominant where *L. chinensis* and *E. colona* showed more than 60% SDR in glass house and field condition, respectively. Jaya Suria *et al.* (2011) stated that grassy weeds constituted about 80% of total weed community in aerobic rice. Bhagat *et al.* (1999) reported that the dominance of *L. chinensis* and *E. colona* species were favored by saturated and below saturated conditions. The high weed pressure in the aerobic rice field may be related to dry soil tillage (favorable soil moisture level during sowing) and alternate wetting and drying conditions during crop growth period which are conducive to germination and growth of weeds (Rao *et al.,* 2007).

Biomass accumulation is a good measure of competitive success, because it reflects resource capture under the interference of neighbors (Fernando *et al.,* 2006). The higher planting density increases crop fraction of the total biomass, which results in higher weed suppression (Weiner *et al.,* 2001). The weed dry weight was significantly higher in glass house as compared to field condition due to the differences in dominant weed size. *L. chinensis* (were taller than rice plants at maturity) had a higher weed biomass as compared to *E. colona*, which had almost the same height with semi-dwarf rice.

Weeds suppressive ability is determined by assessing weed biomass or weed seeds in plots under weedy conditions (Zhao *et al.,* 2006). Lower weed biomass indicated that the rice variety was greater ability in suppressing weed and vice versa. In this study, lower weed dry weight and weed density were observed for AERON 1, while the highest was observed for MR211. It might be related to their plant characteristics which was taller (AERON 1) and shorter (MR211) compared to other varieties. Ekeleme *et al.* (2007) stated that plant height was negatively and significantly correlated with weed biomass, thus indicated that plant height played a positive role in weed suppression.

Plant in weedy condition was taller than in weed free condition at 25 DAS. It might be due to competition of rice with weeds for light. Page *et al.* (2010) documented an increase in plant height in weedy treatment during early seedling development. At 50 DAS and at harvest in weedy condition, there was severe competition among weeds and plants that might cause slightly shorter plants than in weed free condition. The advantage of a taller plant is perhaps an increase in the ability to compete with weeds but a taller plant is more susceptible to lodging and less responsive to nitrogen (Yoshida, 1981). Even though AERON varieties are tall-stature plants, they are responsive to nitrogen, as they are purposively developed as aerobic rice. M9, MR211 and MR 220CL2 varieties produced shorter plant height, because of their genetic makeup and partly could be related to water stress. According to Janiya and Moody (1991), the reduced water condition significantly reduced the height of rice plant but enhanced weed emergence. From the visual assessment of rice growth and development, this study suggested that plant height is important in determining the competitive ability of crop. Garrity *et al.* (1992) reported that correlation between plant height and competitive ability and the minimum plant height needed to adequately suppress weeds was approximately 100 to 115 cm. Saito *et al.* (2010) also suggested that plant height is the key characteristic for weed suppressive ability in upland conditions. In other crops such as field pea and soybean, plant height was the trait that was most strongly associated with competitiveness (Jannink *et al.,* 2000; Mcdonald, 2003). Contrarily, Fischer *et al.* (2001) reported no correlation between heights of upland semi-dwarf cultivars.

Tillering ability plays a vital role in determining rice grain yield. Too few tillers result fewer panicle, but excessive tillers enhance high tiller mortality, small panicle, poor grain filling and consequent reduction in grain yield (Peng *et al.,* 1994). In general, tiller number in weedy condition was significantly lesser as compared to weed free condition at all observational dates. Results indicated that weeds negatively influenced the tillering ability of rice varieties. These results are in accordance with Ashraf *et al.* (2006) who reported weed population reduced the number of tillers. Tiller number increased from 25 to 50 DAS, but decreased during harvest. The decrease in the number of tillers per plant was attributed to the death of some of the late appearance of tillers as a result of their failure in competition for light and nutrients (Fageria *et al.,* 1997) with weeds. Another explanation for this effect is that during the panicle initiation stage of crop growth period, competition for assimilates exists between developing panicle and young

Table 13: Grain yield and relative yield loss of different rice varieties due to weed competition under glass house condition

Treatment	Yield (t ha^{-1})			RYL (%)
	Weedy	Weed free	Mean	
AERON 1	1.22 a	2.80 a	2.02 a	57.15
AERON 4	1.01 ab	2.66 ab	1.83 ab	62.21
M9	0.72 bc	2.49 ab	1.60 bc	71.10
MR211	0.5 4c	2.12 b	1.33 c	74.82
MR 220CL2	0.80 bc	2.43 ab	1.62 bc	67.00
Mean	0.86 B	2.50 A		18.16
LSD			0.26	

Means followed by same letter within a column are not significantly different at P=0.05 probability based on Least Significant Difference (LSD)

Table 14: Grain yield and relative yield loss of different rice varieties due to weed competition under field conditions

Treatment	Yield (t ha^{-1})			RYL (%)
	Weedy	Weed free	Mean	
AERON 1	1.15 a	2.44 a	1.79 a	53.14
AERON 4	0.92 ab	2.33 ab	1.62 a	60.52
M9	0.75 bc	2.28 ab	1.51 a	67.11
MR211	0.53 c	1.83 c	1.18 b	70.90
MR 220CL2	0.77 bc	2.24 ab	1.50 a	65.62
Mean	0.82 B	2.23 A		18.16
LSD			0.30	

Means followed by same letter within a column are not significantly different at P=0.05 probability based on Least Significant Difference (LSD) tillers. Eventually, growth of many young tillers is suppressed, and they may senesce without producing panicle (Dofing and Karlsson, 1993; Sandeep *et al.*, 2002). This study suggested that tillering ability is not significantly important for weed competitiveness because there was no significant difference in tillering ability in rice varieties.

The chlorophyll content indicates the need of a nitrogen top dressing that would result greater agronomic efficiency of nitrogen fertilizer than commonly pre-application of nitrogen (Hussain *et al.,* 2000). Chlorophyll content in rice leaves mostly varied among varieties. On average, AERON varieties produced higher SPAD values as compared to M9, MR211 and MR 220MCL2. The higher SPAD value indicated that healthier plant received enough nutrients for growth and development especially nitrogen. Weed competition reduced the uptake of nitrogen by rice resulting in lower SPAD value. Turner and Jund (1994) recognized that SPAD values are influenced by plant growth stage, cultivar, leaf thickness, plant population and soil or climate factor. Balasubramanian *et al.* (2007) also noted variations in SPAD values for weed-competitiveness under aerobic condition.

Yield components, when considered as a whole, manifest loss in grain yield among cultivars (Deihimfard *et al.*, 2006). In this study, the number of panicles/m^2, number of filled grains/panicle and 1000 grain weight were severely reduced by weed competition. Competition with weed had reduced the panicle length which indirectly reduced the number of filled grains/panicle. Sharma *et al.* (1977) stated that in direct seeded rice, the number of panicles/m^2 was significantly affected by competition of grasses, sedges and broadleaves. In general, AERON 1 and AERON 4 produced the highest 1000 grain weight and filled grain per panicle and the lowest sterility percentage, while MR211 produced the lowest values. This could be attributed to aerobic condition as water plays an important role during grain filling.

Weeds caused severe reductions to yields than to vegetative growth traits, such as height, tillering and biomass (Munene *et al.*, 2008). Rice yield is drastically reduced as a consequence of increased weed infestations due to limited water supply (Becker and Johnson, 1999). The ranking of relative yield loss among rice varieties were consistent in both conditions. However, relative yield loss in glass house was higher than in field condition. The changing trend in relative yield loss had been influenced by difference in weed dominance and weed composition along with soil moisture and climate factors in both conditions. The most dominant weed in glass house was *L. chinensis*, however in field condition was dominated by *E. colona*. In term of size, *L. chinensis* was taller than *E. colona*. This means that *L. chinensis* was more competitive and had greater negative impact on grain yield as compared to *E. colona*. While all weed species present contributed to yield losses, the contribution from both grasses and sedges was more significant than that of broadleaved weeds (Zoschke, 1991).

This study found that even though some of the varieties could produce higher panicle/m^2, but still lower in grain yield as compared to the varieties that produced lower panicle/m^2 but produced greater grain yield. This could be attributed by yield components which lower in filled grains per panicle and lighter in thousand grain weight and higher in sterility percentage indirectly produced lower grain yield. Anwar *et al.* (2012) stated that prolonged weed competition resulted in lower biomass accumulation and lesser panicles/m^2, grains/panicle and thousand grain weight which ultimately translated into lower grain yield. Similar results found by Sunyob *et al.* (2012) where weedy plots had significantly lesser yields than the weed free plots for aerobic rice. Weed tolerance is the ability to maintain high yield despite weed competition (Jannink *et al.,* 2000). In this study, AERON 1 showed the highest weed tolerance by producing the lowest relative yield loss, followed by AERON 4. M9 and MR220-MCL2 showed intermediate tolerant to weeds, even though AERON 1 did not produced standard level of yield. Competitive ability has been linked to lower yield potential for some crop species (Callaway, 1992; Jannink *et al.,* 2000).

Conclusion

In aerobic condition, grasses were mostly dominant weeds which occupied more than 60 percent of sum dominance ratio in which *L. chinensis* and *E. colona* were the most dominant weed in glass house and field conditions, respectively. This study concluded that due to different varietal characteristics, rice varieties varied in their performance against weed under aerobic rice cultivation. AERON 1 with characteristics of taller plant and short growth duration competed better with weed as compared to shorter plant and longer growth duration (MR211). Weed competition had negative impact on rice plants. Lower weed dry weight and relative yield loss in AERON 1 indicated its better weed suppressive ability and tolerance against weeds.

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