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Seeding method and rate influence on weed suppression in aerobic rice

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High weed pressure is amongst the major constraints to the extensive adoption of aerobic rice system as a water-wise technique. Towards developing a sustainable weed management strategy, seeding method and rate may substantially contribute to weed suppression and reduce herbicide use and weeding cost. A trough experiment was established at the Plant House of Universiti Putra Malaysia with two seeding methods, namely conventional broadcast seeding (CBS) and line seeding with east-west row orientation (REW). Three seeding rates were established at 200 (SR200), 300 (SR300) and 400 seeds m⁻² (SR400); and two weed control levels were established as weedy (W) and weed free (F) in a factorial RCBD with four replications. Twenty (20) weed species comprising eleven broadleaved, five grasses and four sedges were identified. Broadleaved weeds contributed more than 50% of the total dry matter. Weed density and dry weight decreased gradually with increased seeding rate, but were independent of methods. REW produced significantly higher grain yield compared with CBS. Among the seeding rates, SR300 produced the highest grain yield followed by SR200 and SR400. Weed free treatment performed better with a yield advantage of 23% over weedy treatment. Weed inflicted relative yield loss did not vary due to seeding methods or rates. Therefore, increasing seeding rate up to 300 seeds m⁻² may be worthwhile to reduce weed pressure without sacrificing rice yield.

Key words: Weed pressure, weed competitiveness, plant density, crop biomass, relative yield loss.

INTRODUCTION

Rice, the staple food for about half of the world population, has been cultivated conventionally in flooded conditions mostly for the availability of irrigation water and effective weed control (Bouman, 2003a). Unfortunately, a massive water crisis is foreseeable in the crop sector and the diminishing availability and high price of water has endangered the traditional way of rice production under flood irrigated conditions. It is projected that, 15 out of 75 million hectares of irrigated rice in Asia are likely to face severe water scarcity by 2025 (Tuong and Bouman, 2003) which may appear as a terrible

shock to the regional food security. Therefore, flood irrigated rice is no more the right choice and researchers should urgently pay considerable attention to find alternate ways of growing rice. Saturated soil culture (Borell et al., 1997; Juraimi et al., 2009a, 2010), alternate wetting and drying (Li, 2001; Tabbal et al., 2002), ground cover system (Lin et al., 2002), system of rice intensification (Stoop et al., 2002) and aerobic rice cultivation (Bouman, 2003b) are the rice production systems being developed so far to cope with the water scarcity. Amongst which aerobic rice is the most promising one in terms of water-saving (Tuong and Bouman, 2003; Zhao et al., 2006, Anwar et al., 2010).

In precise, aerobic rice system refers to growing direct seeded rice on non-puddled aerobic soil without standing water (Bouman, 2003b) and rice is managed intensively

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as an upland crop like wheat or maize. Aerobic rice is either rainfed or irrigated and soil water is maintained around field capacity in the root zone. This system eliminates surface runoff, percolation and evaporation losses (Singh and Chinnusamy, 2006) resulting in twice the water productivity of flood irrigated rice (Bouman et al., 2002; Wang et al., 2002). Apart from lower yield, aerobic rice experiences higher weed pressure (Balasubramanian and Hill, 2002) compared with flood irrigated rice mostly due to lack of 'head start' over weeds and absence of standing water layer to suppress weeds (Moody, 1983; Zhao et al., 2006). Weed is the major constraint in aerobic system and thus, yield losses is much higher in aerobic rice compared with other production systems (Balasubramanian and Hill, 2002). Therefore, developing a sustainable weed management approach has been a challenge for widespread adoption of aerobic rice technology.

Now a day, people are much bothered about the negative impact of using herbicides on environment and public health (Phuong et al., 2005). Apart from the fact that there are risks of developing resistant weed biotypes which resulted from the continuous use of herbicides (Fischer et al., 2000; Rahman et al., 2010), phytotoxicity (Begum, et al., 2008) and declination in soil microbial population (Ayansina and Osa, 2006). Even no herbicidal control has been found so effective against some vegetatively propagated weeds like purple nutsedge (*Cyperus rotundus* L.) (Juraimi et al., 2009b). On the contrary, hand weeding is highly labor-intensive (as much as 190 person-days/ ha) (Roder, 2001). Due to high wages as well as unavailability of labor during peak season, hand weeding is not an economically viable option for the farmers. Therefore, what is needed that adoption of all possible cultural practices in an integrated way to suppress weeds and reduce chemical dependence. Cultural approaches like seeding rate, seeding method, row spacing, etc. play significant role to determine the competitiveness of a crop with weeds for above-ground and belowground resources and hence, might influence weed management (Grichar et al., 2004; O'Donovan et al., 2001). Seeding density of a crop determines solar radiation interception, leaf area production, canopy coverage and biomass accumulation which have cumulative effect on its weed suppressive ability that is ultimately reflected in weed biomass.

High seeding density of a crop develops canopy rapidly and consequently, suppresses weeds more effectively and in contrast, reduced seeding rates result in sparse stands and encourage weed growth (Guillermo et al., 2009). Phuong et al. (2005) reported from their study with lowland rice that, higher seeding rates favor crop to compete with weeds and at the same time increase yield under weedy conditions. Ottis and Talbert (2005) opined that, seeding rate higher than recommendations can be suggested to compensate unforeseen biotic and abiotic stresses. Castin and Moody (1989) did not suggest

higher seeding rates for wet-seeded rice when herbicides are available for effective weed control. Guyer and Quadranti (1985), on the other hand, advocated for higher seeding rate only when no weed control or partial weed control is planned. Especially under aerobic conditions, it is often felt that there is a higher risk of poor seedling establishment associated with lower seeding rates. Zhao et al. (2007) emphasized on the combination of a weed suppressive rice cultivar with proper seeding rate for effective weed control in aerobic rice. They also reported that, under aerobic condition, seeding rate as high as 500 seeds/m² reduced weed growth and increased crop yield to some extent compared with a low seeding rate of 300 seeds/m². Phuong et al. (2005) confirmed seeding method influence of rice on weed growth and row seeding in east-west direction resulted in lowest rice yield loss under weedy condition. Planting uniformity also shows a positive impact on the competitive ability of a crop (Boyd et al., 2009). Weiner et al. (2001) emphasized on the combination of increased crop density and more uniform plating to enable crops to compete more efficiently with weeds. Karaye and Yakubu (2006) also confirmed planting density in terms of intra-row spacing effect of crop on weed growth.

In contrast, Krikland et al. (2000) reported from their study with different upland crops that, crop yield and weed growth were not influenced by higher seed rates up to 150% of recommended rate. Gibson et al. (2001) also observed no influence of rice seeding rate on weed growth in direct-seeded lowland rice. Several studies reveal that, high seed rate may bring about problems of mutual shading and intra-specific competition for below-ground resources. Despite improvement in weed management, higher seeding rate may exacerbate problems like lodging (Bond et al., 2005), insect and disease infestation (Tan et al., 2000) and rat damage (Castin and Moody, 1989) that harm crop yield. Moreover, economic benefit of using higher seeding rate should also be taken into account because cost of extra seed may be higher than the benefits in weed suppression (Nice et al., 2001) and therefore, high seed density should be reconsidered within the context of economic feasibility and compatibility with other aspects of cropping.

Role of seeding method and rate in reducing weed pressure in rice especially under aerobic conditions still remains as a germane research issue and therefore, a better understanding is necessary before integrating seeding method and rate as viable components in sustainable weed management strategy for aerobic rice. To the best of our knowledge, a very few studies have so far been conducted with aerobic rice addressing this issue. This research was therefore, initiated to elucidate the role of seeding method and rate on suppressing weeds and to find out suitable seeding method and rate to reduce yield loss due to weed competition and thus to contribute to develop integrated weed management

strategy in aerobic rice.

MATERIALS AND METHODS

Experimental site and soil

A trough (made of fiber glass of size 50 × 50 × 40 cm³) experiment was carried out in the Plant House, Universiti Putra Malaysia (3°02' N, 101°42' E, 31 m above sea level), Malaysia during October to December 2009. The local climate is hot-humid-tropic with plentiful rainfall. During the experimental period, monthly average maximum and minimum temperature and relative humidity ranged from 33 to 33.5°C, 23.4 to 23.6°C and 93.5 to 95.2%, respectively, while rainfall, evaporation and sunshine hours ranged from 5.3 to 11.1 mm/day, 3.52 to 4.65 mm/day and 4.65 to 6.20 h/day, respectively. The troughs were filled with the soil of Serdang series having clayey texture (39.51% sand, 9.03% silt and 51.35% clay) with pH 4.8 , 2.6% organic carbon, 1.24 g/cc bulk density and CEC of 19.53 me/100 g soil. Soil nutrient status was 0.21% total N, 21 ppm available P, 104 ppm available K, 32 ppm Ca and 32 ppm Mg. At field capacity, soil water retention was 31.18% (wet basis) and 45.31% (dry basis).

Plant material

AERON 1 (Aerobic Rice Observation Nursery), a rice germplasm developed by International Rice Research Institute (IRRI), the Philippines for growing especially under aerobic soil conditions was used as the plant material in this study. The seeds were collected from Malaysian Agriculture Research and Development Institute (MARDI), Seberang Perai, 13200 Kepala Batas, Pulau Pinang, Malaysia.

Experimental design and treatments

The experiment was organized in a randomized complete block design with four replicates. Treatments comprised two seeding methods: conventional broadcast seeding (CBS) and row seeding in east-west direction (REW); three seeding rates: 200 (SR200), 300 (SR300) and 400 seeds m⁻² (SR400) and two weed control levels: weedy (W) and weed free (F).

Crop husbandry

Dry rice seeds were sown at 2 to 3 cm depth in troughs containing non-puddle and non-saturated soil. Troughs were irrigated as necessary to maintain around field capacity (-33 kPa or -1/3 bar of hydraulic head or suction pressure) throughout the growing period. In weedy treatment, weeds were allowed to grow up to 6 week after sowing (WAS) and in weed-free treatment, weed-free condition was maintained throughout the growing season by hand weeding. Before seeding, each trough was initially fertilized with triple super phosphate (TSP) and muriate of potash (MP) at 100 kg P/ha and 100 kg K/ha, respectively; urea as a source of N was top dressed thrice each at 50 kg N/ha at 2, 4 and 6 weeks after seeding. Different intercultural operations and plant protection measures were conducted following standard practices (MARDI, 2002).

Data collection procedure

Several vegetative and physiological traits along with the yield components and yield of rice in both weedy and weed-free

conditions were investigated for the better understanding of the role of seeding method and seed rates to suppress weeds and to produce yield under aerobic soil conditions.

Rice stand density (SD₁₅) was counted at 15 days after seeding (DAS). Plant height, distance from ground level to the tip of the panicle, were measured in cm from 5 randomly selected plants at harvest (PH_H). To study the growth pattern, height growth rate (HGR), increase in plant height per day (cm/day) was also calculated based on the height measured at different growth stages. HGR_{E-PI}, HGR_{PI-HG} and HGR_{HG-H} represent height growth rates between emergence and panicle initiation, panicle initiation and heading and heading and harvesting, respectively. Leaf area was measured at panicle initiation and heading stages by leaf area meter (Licor, Model LI- 3100 Area Meter, LI-COR Inc. Lincoln, Nebraska, USA). Flag leaf area at heading stage was also measured. Leaf area index (LAI) was calculated by the following formula:

$$\text{LAI} = \text{Leaf area of sample plants (cm}^2\text{)} / \text{Area of land covered by the sample plants (cm}^2\text{)}$$

Crop growth rate (CGR) was measured at different growth stages using the formula given below:

$$\text{CGR (g/m}^2\text{/day)} = (W_2 - W_1) / (T_2 - T_1)$$

Where, T₁ is the day of starting; T₂ is the day of final count; W₁ is the dry weight at T₁ and W₂ is the dry weight at T₂.

Panicles from each trough were counted and converted to panicles/m² (PN). At maturity, 10 panicles from each replicate were randomly collected and hand-threshed; filled grains were separated from unfilled grains and counted to calculate average grains /panicle (filled grains + unfilled grains), filled grains/panicle (FGN) and grain filling percentage (GF) (filled grains / (filled grains + unfilled grains) × 100). Filled grains were weighed in g to measure thousand-seed weight (TSW). Panicle length (PL) was measured in cm. Grain yield (GY) was calculated after harvesting the whole trough and transformed to Mg/ha. Panicle weight, thousand-seed weight and grain yield were adjusted to 14% moisture content. Aboveground crop biomass (ACB) was obtained from the total dry matter of straw, rachis, filled grains and unfilled grains and expressed as g/m². Harvest index (HI) was calculated as the percentage of grain yield to the above ground total biomass in weight. Relative yield loss (RYL) due to weed was calculated as:

$$\text{Relative yield loss (\%)} = 100((\text{weed free yield} - \text{weedy yield}) / \text{weed free yield});$$

Where, weed-free yield refers to rice grain yield at 14% moisture content grown under weed-free conditions; weedy yield refers to rice grain yield at 14% moisture content grown under weedy conditions.

Flowering (DF) and maturity dates (DUR) were recorded when 50% plants of a trough started to flower and more than 80% grains turned golden yellow color, respectively. Relative chlorophyll content or greenness of leaves was measured at panicle initiation (SPAD_{PI}) and at heading stage (SPAD_{HG}) using portable chlorophyll meter or SPAD meter (MINOLTA™ SPAD-502, Minolta camera Co., Osaka, Japan). Reading was taken from the youngest fully expanded leaf or flag leaf (if applicable). Ten leaf SPAD readings were taken and then averaged to have mean SPAD reading for each replicate.

In weedy treatments, weed growth was visually rated (WR) at 6 WAS on a 1 to 9 scale, with 1 as the minimum weed growth and 9 as the maximum. Weed biomass was clipped at the ground level; weed species were identified, counted species wise and finally, each species were separately oven dried at 70°C to constant

Table 1. Dominant weed species with family name, type, relative density (RD), relative dry weight (RDW) and summed dominance ratio (SDR) (averaged over all weedy troughs).

Scientific name	Family name	Weed type	RD (%)	RDW (%)	SDR (%)
<i>Echinochloa colona</i> (L.) Link	Poaceae	Grass	20.84	15.58	18.21
<i>Physalis heterophylla</i> Nees	Solanaceae	Broadleaf	11.23	20.45	15.84
<i>Cleome ruidosperma</i> DC	Capparidaceae	Broadleaf	12.17	13.07	12.62
<i>Cyperus iria</i> L.	Cyperaceae	Sedge	14.69	10.27	12.48
<i>Cyperus rotundus</i> L.	Cyperaceae	Sedge	11.85	7.33	09.59
<i>Cyperus sphacelatus</i> Rottb.	Cyperaceae	Sedge	5.38	7.16	6.27
<i>Jussiaea linifolia</i> Vahl	Onagraceae	Broadleaf	2.09	2.95	2.52
<i>Eleusine indica</i> (L.) Gaertn.	Poaceae	Grass	2.65	2.37	2.51
<i>Scoparia dulcis</i> L.	Scrophulariaceae	Broadleaf	2.0	2.15	2.07
<i>Hyptis brevipes</i> Poit	Lamiaceae	Broadleaf	1.84	2.09	1.96
<i>Phyllanthus niruri</i> L.	Euphorbiaceae	Broadleaf	2.26	1.64	1.95
<i>Euphorbia hirta</i> L.	Euphorbiaceae	Broadleaf	2.15	1.38	1.77
<i>Cyperus difformis</i> L.	Cyperaceae	Sedge	1.35	2.14	1.75
<i>Fimbristylis miliacea</i> (L.) Vahl	Cyperaceae	Sedge	1.42	2.01	1.71
<i>Digitaria ciliaris</i> (Retz.) Koel	Poaceae	Grass	1.45	1.94	1.69
<i>Axonopus compressus</i> (Sw.) Beauv	Poaceae	Grass	1.56	1.81	1.68
<i>Amaranthus viridus</i> L.	Amaranthaceae	Broadleaf	1.45	1.86	1.65
<i>Borreria setidens</i> (Miq.) Bold.	Rubiaceae	Broadleaf	1.05	1.56	1.31
<i>Paspalum conjugatum</i> Bergius	Poaceae	Grass	1.01	1.60	1.30
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Grass	1.56	0.64	1.1

weight. Weed density (WD) and weed dry weight (WDW) were calculated and expressed as no/m² and g/m², respectively. To identify dominant weed species, 2-factor summed dominance ratio (SDR) expressed as percentage was computed as per the following equation (Janiya and Moody, 1989):

SDR of a weed species = (Relative density (RD) + Relative dry weight (RDW)) / 2

Where, RD (%) = (Density of a given weed species/ Total weed density) × 100; RDW (%) = (Dry weight of a given weed species/ Total weed dry weight) × 100.

Relative contribution of different weed groups (broad-leaved, grasses and sedges) to the weed vegetation in terms of RD and RDW were also calculated. To study weed homogeneity that is, similarity in occurrence of weed species between treatments, Sorenson's index of similarity was calculated using the following formula:

$$S = 2J / (A + B) \times 100$$

Where, S is the index of association between treatment A and B; J is the number of weed species common in both treatment A and B; A is the number of weed species present in treatment A and B is the number of weed species present in treatment B.

Statistical analysis

All data were subjected to analysis of variance (ANOVA) conducted using statistical analysis system (SAS 9.1) (SAS, 2003). Significant

differences among means were adjudged using Fisher's protected least significant differences (LSD) test at p = 0.05.

RESULTS

Composition and dominance of weed flora

Twenty (20) weed species from ten different families were identified in weedy troughs comprising nine broad-leaved, six grasses and five sedges (Table 1). *Echinochloa colona* (L.) Link, *Physalis heterophylla* Nees, *Cleome ruidosperma* D., *Cyperus iria* L. and *Cyperus rotundus* L. existed in preponderance based on their summed dominance ratio (SDR); while other fifteen (15) were found to lesser extent jointly contributing only 31% to the weed community. Maximum relative density and relative dry weight were recorded with *E. colona* (L.) Link and *P. heterophylla* Nees, respectively. Broad-leaved weeds shared about 49% of the total dry matter and 37% of total density followed by sedges (27 and 35%, respectively) and grasses (24 and 29%, respectively) (Figure 1). Sorenson's index of similarity among different treatments (data not shown) ranged from 76.39 to 92.13%, indicating good homogeneity of weed composition (Bonham, 1989) among the experimental troughs.

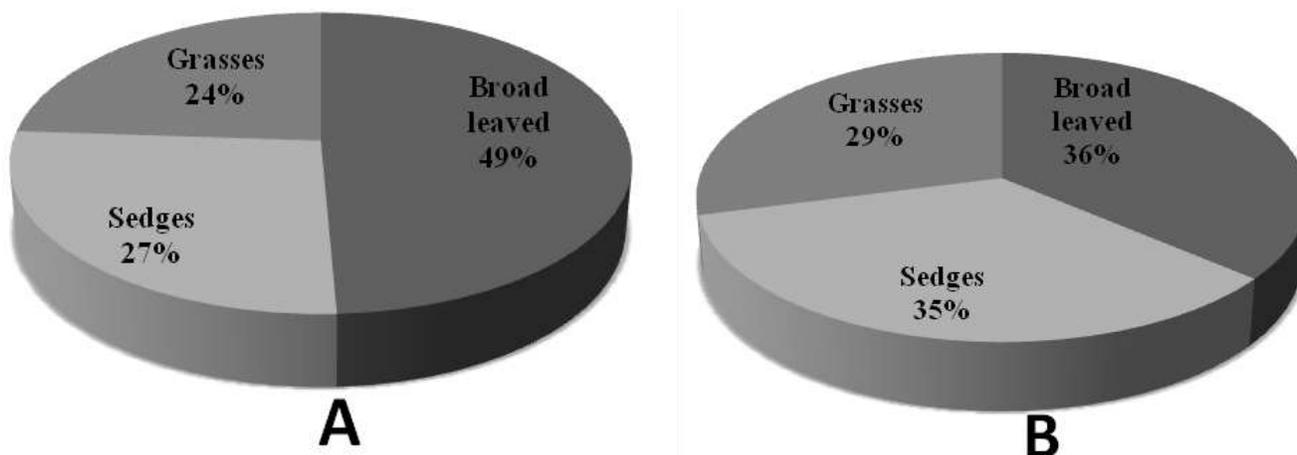


Figure 1. Relative dry weight (A) and relative density (B) of different weed groups.

Table 2. Main effect of seeding methods and seeding rates on weed rating (1 to 9 scale) and relative yield loss (%) of aerobic rice germplasm AERON1.

Treatment	Weed rating	Relative yield loss (%)
Seeding method[#]		
CBS	4.58	21.90
REW	4.33	21.74
LSD	0.501	5.06
Seeding rate^{##}		
200 seeds/ m ²	5.62 ^a	24.37
300 seeds/ m ²	4.38 ^b	20.78
400 seeds/ m ²	3.38 ^c	20.30
LSD	0.623	6.20

CBS, Conventional broadcast seeding; REW, row seeding in east-west direction. [#] Data pooled across three seeding rates; ^{##} data pooled across two seeding methods. Within a column for each factor, means sharing same alphabets are not significantly different at P = 0.05 probability level according to least significant difference (LSD) test.

Weed pressure and relative yield loss

No considerable differences regarding weed rating, dry weight and density were found between seeding methods, although, values for all those parameters were numerically higher in CBS than in REW (Table 2; Figures 2 and 3). Weed rating, dry weight and density remarkably varied among the seeding rates and decreased gradually with increased seeding rate. Rating of weed vegetation was lowest (3.38) for SR400 and highest (5.62) for SR200, while intermediate (4.38) for SR300. Like weed rating, dry weight and density of weeds also followed the same trend. Weed suppression in terms of both dry matter and density was enhanced due to increase in seeding rate. In SR200, weed dry weight was 29 and 71% higher compared with those in SR300 and SR400,

respectively. Weed density, on the other hand, was reduced by 25 and 44% in SR300 and SR400, respectively compared with SR200. Two-factor SDR of individual weed species was not significantly affected by seeding method or rate (data not shown). Weed inflicted relative yield loss was not significantly influenced by seeding method or rate (Table 2). However, on average, weeds reduced rice grain yield by 22%.

Rice seedling stand establishment

Rice seedling stand counted at 15 DAS was significantly affected by seeding method and seedling rate, but not by weeding regime (Table 3). Seedling density in REW was higher than that in CBS (255 versus 245 seedlings/m²).

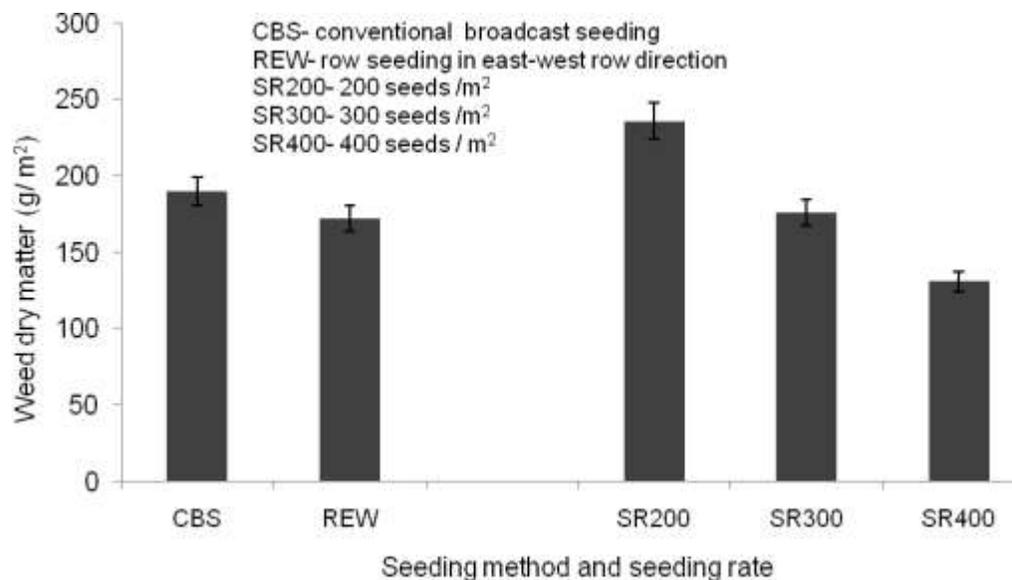


Figure 2. Weed dry matter as influenced by rice seeding method and seeding rate.

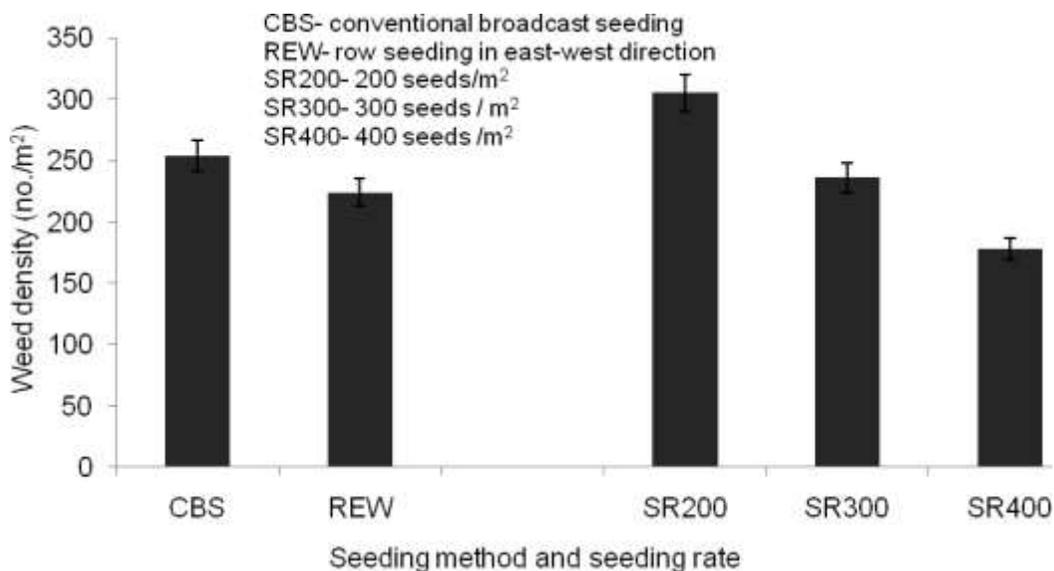


Figure 3. Weed density as influenced by rice seeding method and seeding rate.

Among the seedling rates, SR200 had the lowest seedling density of only 170 seedlings/m². Increasing seedling rate to SR300 and SR400, increased density to 258 and 322 seedlings/m², respectively.

Plant height and height growth rate

Seeding rate and weeding regime exerted significant influence on plant height at harvest and height growth rates at different growth stages (Table 3). Nevertheless,

seeding method influence was insignificant, numerical values were found higher with REW compared with CBS for all the cases. Increasing seeding rates significantly decreased plant height. By harvest time, plant height recorded with SR200, SR300 and SR400 were 98, 94 and 91 cm, respectively. Weed competition reduced rice plant height and weed free treatment attained 11% more height compared with weedy treatment at harvest (100 versus 89 cm). Height growth rate declined with the advancement of growth stages (Table 3) and like plant height it also showed a decreasing trend with the

Table 3. Main effect of seeding methods, seeding rates and weeding regimes on SPAD value, leaf area index (LAI), flag leaf area, days to flowering (DF) and days to maturity (DUR) of rice germplasm AERON1

Treatment	SD ₁₅	PH _H	HGR _{E-PI}	HGR _{PI-HG}	HGR _{HG-H}	CGR _{E-PI}	CGR _{PI-HG}	CGR _{HG-H}
Seeding method[#]								
CBS	245.5 ^b	94.38	2.21	2.02	0.13	6.91	3.95 ^b	3.09 ^b
REW	255.3 ^a	95.02	2.23	2.03	0.13	7.09	4.27 ^a	3.31 ^a
LSD	8.25	3.50	0.03	0.03	0.016	0.285	0.18	0.18
Seeding rate^{##}								
SR 200	170.2 ^c	98.5 ^a	2.21 ^a	2.14 ^a	0.15 ^a	5.03 ^c	4.22 ^b	3.13 ^b
SR 300	258.4 ^b	94.49 ^{ab}	2.19 ^a	2.02 ^b	0.17 ^a	7.15 ^b	4.77 ^a	3.99 ^a
SR400	322.5 ^a	91.10 ^b	2.14 ^b	1.92 ^c	0.08 ^b	8.83 ^a	3.36 ^c	2.49 ^c
LSD	10.11	4.29	0.04	0.03	0.02	0.349	0.23	0.22
Weeding regime^{###}								
Weed free	251.81	100.29 ^a	2.23 ^a	2.13 ^a	0.16 ^a	8.24 ^a	4.47 ^a	3.61 ^a
Weedy	248.91	89.11 ^b	2.13 ^b	1.92 ^b	0.11 ^b	5.76 ^b	3.79 ^b	2.80 ^b
Reduction (%)	-	11.15	4.48	9.86	31.25	30.18	15.21	22.44
LSD	8.25	3.50	0.03	0.03	0.01	0.285	0.18	0.18

SD₁₅ Indicate rice stand density at 15 days after seeding; PH_H indicates plant height at harvest; HGR_{E-PI}, HGR_{PI-HG} and HGR_{HG-H} indicate height growth rate between emergence and panicle initiation, panicle initiation and heading, heading and harvesting, respectively; CGR_{E-PI}, CGR_{PI-HG}, CGR_{HG-H} indicate crop growth rate between emergence and panicle initiation, panicle initiation and heading, heading and harvesting, respectively. CBS and REW stand for conventional broadcast seeding and row seeding in east-west direction, respectively; SR200, SR300 and SR400 indicate 200, 300 and 400 seeds m⁻², respectively. [#] Data pooled across three seeding rates and two weeding regimes; ^{##} Data pooled across two seeding methods and two weeding regimes; ^{###} Data pooled across two seeding methods and three seeding rates. Within a column for each factor, means sharing same alphabets are not significantly different at P = 0.05 probability level according to least significant difference (LSD) test.

increase in seeding rate. Among the seeding rates, SR200 had the highest height growth rates at all the stages (2.21, 2.14 and 0.15 cm/day for HGR_{E-PI}, HGR_{PI-HG} and HGR_{HG-H}, respectively), while SR400 had the lowest values (2.15, 1.92 and 0.08 cm /day for HGR_{E-PI}, HGR_{PI-HG} and HGR_{HG-H}, respectively). Weed competition resulted in 4.5, 10 and 31% decrease in height growth rate for HGR_{E-PI}, HGR_{PI-HG} and HGR_{HG-H}, respectively.

Crop growth rate

Seeding method, seeding rate and weeding regime produced significant effect on crop growth rate of AERON 1 (Table 3). REW performed better than CBS in terms of crop growth rate. CGR_{PI-HG} and CGR_{HG-H} were found higher in REW than in CBS (4.27 versus 3.95 and 3.31 versus 3.09 g/m²/day, respectively), while CGR_{E-PI} was found unaffected. Amongst the seedling rates, SR400 had the highest CGR_{E-PI} (9 g/m²/day) followed by SR300 (7 g/m²/day) and SR200 (5 g/m²/day). SR300, on the other hand, had the highest CGR_{PI-HG} (4.77 g/m²/day) and CGR_{HG-H} (3.99 g/m²/day), while SR400 had the lowest CGR_{PI-HG} (3.36 g/m²/day) and CGR_{HG-H} (2.49 g/m²/day). Rationally, weed free condition maintained higher crop growth rate than weedy condition. Weed competition

reduced CGR_{E-PI}, CGR_{PI-HG} and CGR_{HG-H} by 30, 15 and 22%, respectively.

Relative chlorophyll content (SPAD)

Results reveal that, seeding method failed to influence SPAD value but seeding rate and weeding regime significantly affected the same (Table 4). Both the seeding methods maintained SPAD values of 34 and 35 at panicle initiation and heading stages, respectively. SR200 and SR300 had statistically similar SPAD_{PI} (34.5 and 36, respectively) and SPAD_{HG} (36.5 and 36.7, respectively) values. SPAD_{PI} and SPAD_{HG} were recorded as 31.5 and 32, respectively with SR400 indicating that, seed rate higher than 300/m² had adverse effect on SPAD value irrespective of growth stages. Reasonably, weedy treatment showed lower SPAD value than weed free treatment. Crop-weed competition resulted in 10 and 11% reduction in SPAD_{PI} and SPAD_{HG}, respectively.

Leaf area index and flag leaf area

Leaf area index and flag leaf area responded significantly to seeding rate and weeding regime but not to seeding

Table 4. Main effect of seeding methods, seeding rates and weeding regimes on plant height (cm) and height growth rate (cm/day) and crop growth rate of rice germplasm AERON1.

Treatment	SPAD _{PI}	SPAD _{HG}	LAI _{PI}	LAI _{HG}	Flag leaf area (cm ²)	DF	DUR
Seeding method[#]							
CBS	34.00	35.07	5.35	8.27	44.70	54.00	82.66
REW	33.84	36.0	5.51	8.15	44.21	53.79	82.41
LSD	1.38	1.18	0.20	0.18	1.80	0.41	0.44
Seeding rate^{##}							
SR 200	34.55 ^a	36.45 ^a	3.84 ^c	6.42 ^c	47.71 ^a	52.25 ^b	80.87 ^b
SR 300	36.01 ^a	36.73 ^a	5.40 ^b	8.80 ^b	44.09 ^b	52.50 ^b	80.93 ^b
SR400	31.55 ^b	31.91 ^b	7.05 ^a	9.43 ^a	41.56 ^c	56.93 ^a	85.81 ^a
LSD	1.69	1.44	0.24	0.22	2.21	0.50	0.53
Weeding regime^{###}							
Weed free	35.74 ^a	37.04 ^a	5.79 ^a	8.78 ^a	47.84 ^a	53.70	82.54
Weedy	32.33 ^b	33.02 ^b	5.07 ^b	7.65 ^b	41.07 ^b	54.08	82.50
Reduction (%)	9.54	10.85	12.44	12.87	14.15	-	-
LSD	1.38	1.18	0.20	0.18	1.80	0.41	0.44

SPAD_{PI} and SPAD_{HG} indicate relative leaf chlorophyll content at panicle initiation and heading stages, respectively; LAI_{PI} and LAI_{HG}, indicate leaf area index at panicle initiation and heading stages, respectively; DF and DUR, indicate days to flowering and days to maturity, respectively. CBS and REW stand for conventional broadcast seeding and row seeding in east-west direction, respectively; SR200, SR300 and SR400 indicate 200, 300 and 400 seeds m⁻², respectively. [#] Data pooled across three seeding rates and two weeding regimes; ^{##} data pooled across two seeding methods and two weeding regimes; ^{###} data pooled across two seeding methods and three seeding rates. Within a column for each factor, means sharing same alphabets are not significantly different at P = 0.05 probability level according to least significant difference (LSD) test.

method (Table 4). Leaf area index increased gradually with increased seeding rate at both panicle initiation and heading stages. SR300 and SR400, respectively, had 40 and 84% more LAI_{PI} than that of SR200. Compared with SR200, LAI_{HG} was increased by 37 and 47% due to increased seeding rates of SR300 and SR400, respectively. Weed competition which showed adverse effect on leaf area index resulted in 13 and 14% reduction in LAI_{PI} and LAI_{HG}, respectively. Unlike leaf area index, flag leaf area showed a declining trend with increased seeding rate. Among the seeding rates, SR200 had the highest flag leaf area of 47.71 cm². Increasing seeding rate to SR300 and SR400, decreased flag leaf area by 8 and 13%, respectively compared with SR200. Reduction in flag leaf area because of weeds was calculated as high as 14%.

Days to flowering and maturity

Days to flowering and total growth duration were not significantly affected by seeding method and weeding regime, but seeding rate exerted significant influence on those parameters (Table 4). Irrespective of seeding methods, it took 54 days to flower and 83 days to mature. Both SR200 and SR300 required 53 days for flowering and consequently, matured by 81 days without any significant differences between them. SR400, on the

other hand, took 4 days more to flower and 5 days more to get matured compared with SR200 and SR300. Weed free and weedy treatments required same duration for flowering and maturity (54 and 83 days, respectively).

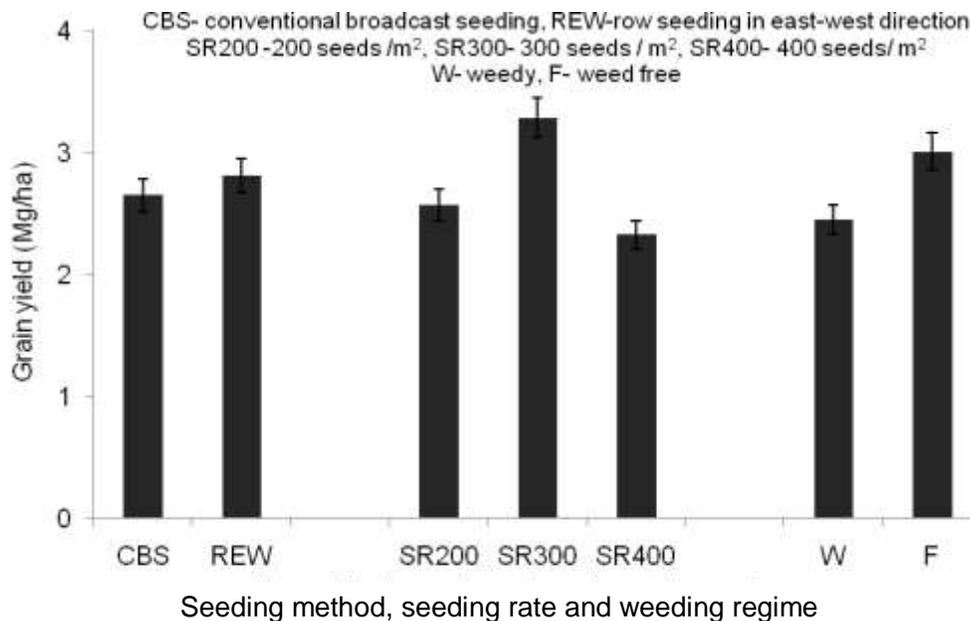
Yield attributes and yield

Seeding method, seeding rate and weeding regime caused significant effect on yield attributes and yield of AERON1, but PN and FGN were not influenced by seeding method (Table 5). REW performed consistently better than CBS. GF and TSW, respectively were 5.5% and 0.3 g higher in REW compared with CBS which resulted in a yield advantage of 7% (2.66 versus 2.48 Mg/ha). PL also was found 2% higher in REW than in CBS. The differences in PN among the three seeding rates were very clear: SR400>SR300>SR200. SR400 had 43 more panicles /m² than SR300 and 124 more panicles /m² than SR200. No significant differences between SR200 and SR300, regarding FGN, GF and PL were noticed. SR400 had 3 and 34% less FGN than SR200 and SR300, respectively, whilst GF was recorded 17 and 15% lower with SR400 compared with SR200 and SR300, respectively. TSW followed a decreasing trend with increased seed rate: SR200>SR300>SR400. On an average, an increase of 100 seeds /m² reduced TSW by 5%. SR 300 topped the list of grain yield (3.03 Mg/ha)

Table 5. Main effect of seeding methods, seeding rates and weeding regimes on yield attributes of rice germplasm AERON1.

Treatment	PN (number)	FGN (number)	GF (%)	TSW (g)	PL (cm)	HI (%)
Seeding method[#]						
CBS	228.21	50.83	66.94 ^b	22.82 ^b	19.34 ^b	37.48
REW	227.29	53.58	72.38 ^a	23.11 ^a	19.76 ^a	38.48
LSD	9.39	3.08	3.434	0.21	0.13	1.67
Seeding rate^{##}						
SR 200	159.81 ^c	59.90 ^a	74.79 ^a	24.85 ^a	20.10 ^a	38.33 ^a
SR 300	240.44 ^b	56.93 ^a	72.53 ^a	24.53 ^b	19.96 ^a	39.92 ^a
SR400	283.00 ^a	39.75 ^b	61.68 ^b	19.52 ^c	18.58 ^b	35.68 ^b
LSD	11.5	3.77	4.201	0.26	0.16	2.05
Weeding regime^{###}						
Weed free	245.92 ^a	55.21 ^a	74.92 ^a	23.58 ^a	20.03 ^a	40.67 ^a
Weedy	209.58 ^b	49.20 ^b	64.40 ^b	22.35 ^b	19.06 ^b	35.29 ^b
Reduction (%)	14.78	10.87	14.04	5.22	4.99	13.23
LSD	10.06	3.08	3.434	0.21	0.13	1.67

PN, FGN, GF, TSW, PL and HI indicate panicles/m², filled grains/panicle, filled grain %, thousand seed weight, panicle length and harvest index, respectively. CBS and REW stand for conventional broadcast seeding and row seeding in east-west direction, respectively; SR200, SR300 and SR400 indicate 200, 300 and 400 seeds m⁻², respectively. [#]Data pooled across three seeding rates and two weeding regimes; ^{##}data pooled across two seeding methods and two weeding regimes; ^{###} data pooled across two seeding methods and three seeding rates. Within a column for each factor, means sharing same alphabets are not significantly different at P = 0.05 probability level according to least significant difference (LSD) test.

**Figure 4.** Grain yield of AERON1 as influenced by seeding method, seeding rate and weeding regime.

which was 23% higher than SR200 (2.46 Mg/ha) and 45% higher than SR400 (2.23 Mg/ha) (Figure 4). Weed free treatment consistently obtained higher values regarding yield attributes and yield as well compared with

weedy treatment. Weed competition decreased PN, FGN, GF and TSW by 15, 11, 14 and 5%, respectively. On the other hand, grain yield reduction because of weed was calculated as high as 30% (3.01 versus 2.12 Mg/ha). In

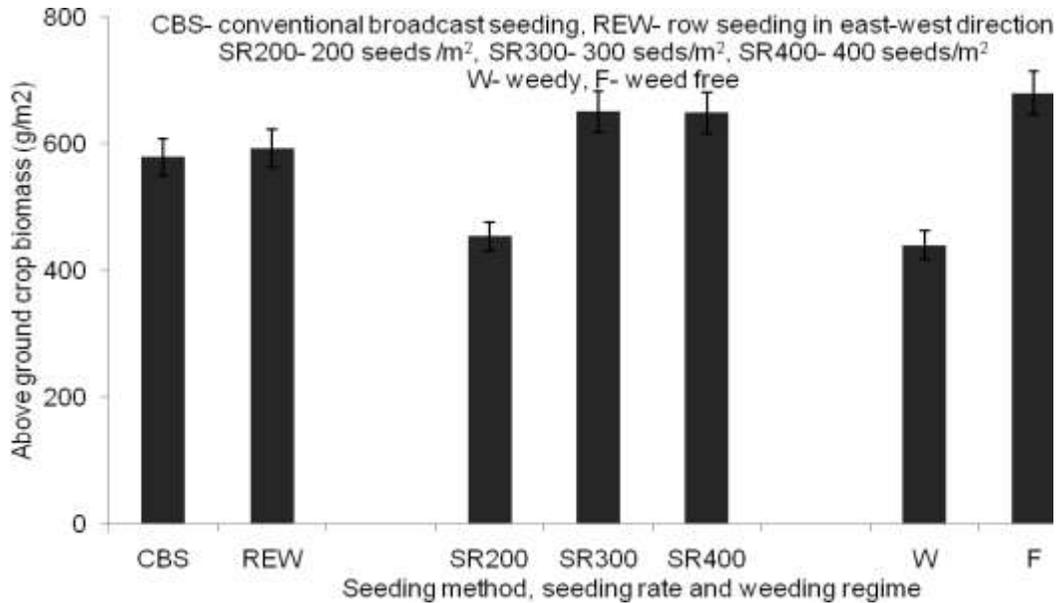


Figure 5. Above ground crop biomass of AERON1 as affected by seeding method, seeding rate and weeding regime.

producing biomass, no significant difference was found between CBS and REW (Figure 5). Biomass production was increased with increased seeding rate up to SR300. SR300 and SR400 produced statistically similar biomass which was 15% more than that produced by SR200. Aboveground rice biomass production was reduced by 35% due to weed competition.

DISCUSSION

Weed is the most terrible competitor of rice, and especially under aerobic soil conditions weed management has been a huge challenge for the farmers and researchers as well. Despite the high efficacy and profitability, emerging problems with herbicide resistant weed biotypes and environmental hazard trigger the need for less reliance on herbicide. Manipulation of management practices like seeding method and rate for improving crop competitiveness against weeds may make the rice production system more sustainable through minimizing herbicide dependence (Mohler, 1996).

Rice seedling density was found higher in REW than in CBS, indicating that row seeding requires less seed and ensures better crop establishment compared with broadcast seeding. Balasubramanian (1999) and Phuong et al. (2005) also observed better seedling establishment in row seeding than in conventional broadcast seeding. At the highest seeding rate, emergence percentage was lower compared with that of the lower seed rates (85 versus 80%). Higher emergence in lower seed rates may have been partially due to reduced intra-specific

competition. Poor emergence in highest seed rate, on the other hand, was probably due to increased competition among neighboring plants that reduced seed emergence resulted in poor seedling density. Based on our findings, higher seed rate may reduce emergence efficiency, while lower seed rate may allow for efficient seedling emergence. These findings buttressed those of Ottis and Talbert (2005) and Payman and Singh (2008) who found that, higher seed rate reduced emergence efficiency resulted in poor seedling establishment.

In our study, weed dry weight and density rating remained statistically at par with both the seeding methods which indicate that, seeding method had no influence on weed vegetation. Boyd et al. (2009) also found no significant differences in weed emergence due to varying seeding rates of rye. Contrary to our findings, Phuong et al. (2005) reported significant differences in weed density and dry weight between broadcasting and row seeding methods and found higher weed density and dry weight as well in broadcasting method than in row seeding method. The conflicting findings reported in these studies may result from the differential weed pressure and weed suppressive ability of the rice varieties used in these studies. Unlike seeding method, seeding rate exhibited significant influence on weed pressure; both weed density and dry weight decreased with increasing seeding rate. Similar to other research findings (Nice et al., 2001; Phuong et al., 2005), ours confirms that reduced plant density may provide a congenial environment for weed growth and may enhance the survival and fecundity of weeds. In case of lower seeding rate, weeds always have a better chance to germinate, grow and develop a vigorous population.

There might be a couple of reasons why increased seed rate reduced weed pressure. Mahajan et al. (2010) reported that, higher seeding rate can keep the weed flora under check through smothering effect. Guillermo et al. (2009) opined that, higher plant densities might have a competitive advantage over weeds due to fast canopy development. Mohler (1996), on the other hand, revealed that higher seeding rate provides a competitive advantage to crop over weeds because crop plants will grab limited resources at a faster rate. Weiner et al. (2001) discoursed that due to increased crop population, crop fraction of the total plant biomass (crop + weed) is increased which results in higher weed suppression. However, increased seeding rate may not be able to increase the weed competitiveness of a crop due to greater intra-specific competition between crop plants especially under stressful environmental conditions rather may intensify the negative impact of higher intra-specific competition (Zimdahl, 1983; Krikland et al., 2000). The circumstantial evidences suggest that, increased seeding rate of rice might have some positive effect on weed suppression. Guillermo et al. (2009) recommended that the farmers having difficulties in managing weeds should avoid lower seeding rates to improve the consistency of weed management.

Plant height at harvest and height growth rate at different stages was significantly higher for SR200 and SR300, than those in SR400. Taller plants at lower seed rates is conflicting to general perception; the reasoning might be due to less intra-specific competition for nutrients at lower seeding rates which allowed the plants to attain more height when compared with higher seeding rates. With the advancement of growth stages the reduction in height growth rate at SR400 when compared with SR200 and SR300 was increased which might be the resultant effect of increased intra-specific competition for resources at later stages. Similarly, higher plant height and height growth rate were observed at weed free condition when compared with weedy condition, which might be the outcome of higher inter-specific interference in the presence of weeds. No significant changes in plant height and height growth rate due to seeding methods indicate that, intra-specific competition for plant resources remains the same in CBS and REW.

Leaf area index is the efficiency of photosynthetic process and photosynthetic surface (Lockhart and Wiseman, 1988) and thus, it is an important determinant of plant productivity. The differences in LAI at both panicle initiation and heading stages due to seeding rates were very clear SR400>SR300>SR200. Increased LAI with increasing seeding rate has also been reported in aerobic rice by Zhao et al. (2007). Crop growth rate calculated during the period from emergence to panicle initiation was found to be increased with increased seeding rate, while in the later stages, CGR increased up to SR300 and thereafter declined. Up to initiation of panicle, crop (even at the highest seeding rate) did not

experience much intra-specific competition to affect dry matter accumulation resulting increased CGR with increased seeding rate. After panicle initiation, photosynthetically active radiation (PAR) was more efficiently intercepted by the canopy due to reduced mutual leaf shading at lower seeding rates resulting in higher dry matter accumulation and higher CGR as well (Mahajan et al., 2010).

SPAD (silicon photon activated diode) value is proportional to the amount of chlorophyll present in leaf and a linear relationship exists between SPAD value and leaf nitrogen concentration. Thus, higher SPAD value indicates healthier plant. In this study, seeding methods did not influence SPAD value, but seeding rate did. At both the sampling dates, SPAD value remained unchanged up to SR300 and thereafter declined which clearly indicates that, higher seed rates caused dilution. This study findings confirm the earlier perception that, plants at higher density suffer from hidden hunger of nitrogen due to more intra-specific competition causing dilution that is reflected in SPAD values and ultimately in yield. This finding supports study with aerobic rice (Mahajan et al., 2010); where SPAD values at flowering stage were lower at higher seeding rates. Higher SPAD values in weed free treatment compared with weedy check was undoubtedly the consequence of higher inter-specific competition for nitrogen.

Though, grain yield was affected but weed inflicted relative yield loss was not influenced by seeding method or rate. This indicate that, irrespective of seeding methods or rates, difference between weed free yield and weedy yield is directly proportionate to the weed free yield that is, the higher the weed free yield the higher the absolute yield loss due to weed, resulting in constant relative yield loss. In contrast to our findings, Phuong et al. (2005), under direct-seeded lowland rice observed significant differences in relative yield losses due to seeding methods and rates. The contradictory findings might be due to the differential cultivars and seed rates used in these studies and variation in weed pressure resulted from varying rice ecosystems.

Rice grain yield is the function of panicles /m², filled grains/panicle and 1000-grain weight. In our study, row seeding in east-west orientation out yielded broadcast seeding which was mostly the outcome of higher grain filling percentage and higher 1000-grain weight. Our results are in conformity with the findings of Phuong et al. (2005) who also found superiority of east-west row orientation over broadcast seeding in terms of yield. Yield differences in seeding methods are mostly due to the variation in solar radiation interception. Light transmission through the canopy is affected by row orientation (Tournebize and Sinoquet, 1995). More light transmission occurs in east-west row orientation than in north-south row orientation (Jaya et al., 2001). Moreover, Sinoquet and Bonhomme (1992) recorded higher within-canopy temperature in east-west row orientation due to more

direct penetration of radiation. Grain yield in this study, was increased with the increasing seeding rate up to 300 seeds /m² and thereafter, declined. In the highest seeding rate of 400 seeds /m², highest number of panicles/ m² was accompanied by lowest filled grains/panicle and 1000-grain weight resulting in lowest grain yield. On the contrary, lowest number of panicles/ m² was compensated by higher number of grains/panicle and higher 1000-grain weight in 300 seeds /m², producing the highest yield. Our results closely resembles those reported by many researchers (Zhao et al., 2007; Lin et al., 2009; Mahajan et al., 2010). Contrary to our findings, Ottis and Talbert (2005) and Payman and Singh (2008) did not observe any significant yield differences among the seeding rates. Linghe and Michael (2000), on the other hand, revealed lack of increased grain yield with increased seeding density of rice. The conflicting findings reported might be due to the variation in seed rate and canopy architecture of rice genotypes used in different studies. However, in case of early maturing genotypes, close spacing is congenial to achieve higher yield because insufficient vegetative growth is the main hurdle to achieve maximum yield at conventional spacing (Yoshida, 1978). As reported by Wells and Faw (1978), rice yield is limited under dense populations due to reduced light interception and CO₂ accumulation. Baloch et al. (2002) also opined that, under increased plant density, intra- specific competition for light and nutrient leads to reduction in grain yield. Mahajan et al. (2010) discoursed that increased rice plant density, beyond the optimal, might lead to high dilution effect resulting in lower yield. On the other hand, lower yield at less-than-optimal densities is probably due to the inability to intercept maximum available light due to poor stand establishment. In fact, intra-specific competition due to different seeding densities may vary in their intensity and compensatory growth of individual plant, when grown at lower densities, results in similar grain yield over a broad range of densities, a phenomenon known as the law of constant final yield (Bond et al., 2005). Weedy check produced 23% lower yield compared when weed free condition which confirms that, weed is a crucial yield-limiting factor in aerobic rice and weed management should be properly addressed to make aerobic rice cultivation a profitable business venture.

Conclusion

Weed is the major impediment to widespread adoption of aerobic rice technology. Risks of environmental hazard of chemical weed control and scarcity along with high wages of labor required for hand weeding trigger the need of an environment-friendly and less labor-intensive weed management strategy for aerobic rice through integration of all possible agronomic practices. This study implies exploitation of seeding rate has a decisive role to play in minimizing weed pressure and thus, open the

pave for reducing herbicide use in aerobic rice. Therefore, it can be incorporated as a vital tool to design a sustainable weed management package for aerobic rice. Increasing seeding rate up to 300 seeds m⁻² may be worthwhile to reduce weed pressure without sacrificing rice yield under the experimental conditions. Despite no influence on weed suppression, row sowing in east-west direction is desirable from yield view point. In addition, rice yield is influenced by weed dry matter rather than by weed density. Therefore, before making decision regarding seeding rate as a tool for weed suppression, weed competitiveness of the rice cultivar, weed pressure and dominant weed species of the site must be taken into account.

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