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Full Length Research Paper

Efficacy and economics of different herbicides in aerobic rice system

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Aerobic rice system, the most promising irrigation water saving rice production technology, is highly impeded by severe weed pressure. Weed control through the use of same herbicide causes development of herbicide resistant weed biotypes and serious problem in weed management. This study was aimed at finding out herbicides with different mode of actions to suggest effective weed control herbicide technology in aerobic rice system. This study was conducted at Malaysian Agricultural Research and Development Institute (MARDI), Seberang Perai Station, Penang, Malaysia during off season 2008 (April – July 2008) and main season 2008-2009 (November 2008 – February 2009) to evaluate fourteen and eight combinations of different locally available herbicides, in the off season and main seasons, respectively. A weed free control and a weedy check treatment were also included in the both trials. The trial used a RCB design with three replications in the off season and four replications in the main season, respectively. Twenty one (21) weed species were found in the aerobic rice field but two species (*Eleusine indica* and *Digitaria ascendens*) appeared as dominant. Based on the weed control efficiency, weed index values and net benefit from economic analysis, it appeared that the herbicide combinations such as Propanil/Benthiocarb fb Bentazone/MCPA or Cyhalofop-butyl+Bensulfuron fb Bentazone/MCPA or Pendimethalin fb Cyhalofop-butyl+ Bensulfuron fb Bentazone/MCPA or Pretilachlor+Pendimethalin fb Bentazone/MCPA could be the possible alternative options for effective and economic weed control in rice under aerobic system towards avoiding development of herbicide resistance in weed. Manual weeding is not at all cost-effective. The selected herbicide combinations could be used in rotation for sustainable weed management and to run the aerobic rice system as a profitable business venture.

Key words: Herbicide combination, summed dominance ratio, weed control efficiency, weed index, rice yield.

INTRODUCTION

Rice (*Oryza sativa*), the staple food crop of the world, is generally grown by transplanting or wet direct seeding under lowland flooded irrigation system (Bouman and Tuong, 2000; Cantrell and Hettel, 2005). More than 45% of total fresh water is being used in Asia for rice production (Barker et al., 1999). Fresh water is becoming scarce not only in arid and drought prone areas but also in regions where rainfall is abundant. For example, about 20% of the 75 million hectares of Asia's irrigated rice area may experience severe water scarcity by 2025 (Tuong and Bouman, 2003). Under this situation, aerobic rice system has been evolved as a potential alternative to irrigated rice system to sustain rice productivity with less water input. In aerobic system, rice is grown by dry direct seeding on well-drained, non-puddled and nonsaturated soils (aerobic soils) without standing water (Bouman, 2003) with saving of about 50 to 60% total water

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Abbreviations: HGR, Height growth rate; **DAS,** days after sowing; **SPAD,** silicon photon activated diode; **fb,** followed by.

compared to lowland flood irrigated rice (Bouman et al., 2002; Wang et al., 2002). Despite its huge potential, the technology is highly impeded by high weed pressure with a broader spectrum compared to conventional puddle transplanting flood irrigated rice system (Balasuranmanian and Hill, 2002; Rao et al., 2007). In conventional transplanted system, weeds are suppressed by standing water and by transplanted rice seedlings, which have a “head start” over germinating weed seedlings. On the other hand, aerobic soil dry-tillage and alternate wetting and drying conditions are conducive for germination and growth of weeds causing grain yield loss of 50 to 91% (Rao et al., 2007). Thus, it appears that weed is the major constraint to aerobic rice production and therefore, success of this technology mostly depends on effective weed management.

The manual and mechanical weeding have rapidly been abandoned (De Datta, 1981; Merlier, 1983) due to technological and economic factors (Moody, 1991). Herbicide has become an attractive alternative to manual weeding due to its high efficacy and low cost. Most farmers in Malaysia are presently using herbicides as an effective tool in controlling weeds in wet direct seeded or transplanted rice (Karim et al., 2004). Flooding is also done to suppress weeds in the wet seeded or transplanted rice systems. The soil environment in aerobic rice system is different from lowland wet flooded rice system as because soil is always kept at aerobic condition and flooded or saturated soil is not allowed in this system. Therefore, the herbicides used in wetland flood irrigated system may not be equally effective in the aerobic system. Manual weeding could be used but this is not feasible due to increasing labour unavailability and cost. At this situation, herbicide could be the most practical, effective and economical means of weed control in aerobic soil. Pellerin and Webster (2004) reported that use of some pre-emergence herbicides such as pedimethalin, butachlor, thiobencarb, oxadiazon, oxyfluorfen and nitrofen alone or supplemented with hand weeding provided a fair degree of weed control. Application of these herbicides should be done during 0 to 5 days after sowing and adequate soil moisture is necessary at the time of application. In such situations post-emergence herbicides may be superior (Mahajan et al., 2009).

Herbicide is the most effective and economic means of weed control, but inappropriate or wrong application may not only increase production cost and yield penalty but also may cause development of herbicide resistant weeds and environmental hazard (Karim et al., 2004). Repeated use of same herbicide in the same field had often led to the occurrence of herbicide resistant weeds (Kim, 1996) and therefore, selection of herbicides with different mode of actions is also necessary for alternate application to avoid development of herbicide resistance in weeds. Herbicide mixtures may help prevent resistance problem as well as shift in weed population (Wrubel and Gressel, 1994). Proprietary mixture or tank mixture of different herbicides could often be preferred because they require less time, cost and increase the spectrum of weed control (Ooi et al., 2000). So far, research findings are not sufficient to support weed specialists as well as farmers to select appropriate herbicides or herbicide combinations for weed control in aerobic rice under Malaysian context. Therefore, an evaluation of locally available herbicides in term of their efficacy and economic return is highly required for efficient and sustainable weed management in aerobic rice to cope with water scarcity and ensure food security under the potential global climate change scenario. Keeping all these in views, this study was carried out to evaluate the efficacy and economics of different herbicides and herbicide-combinations towards selecting the best alternative herbicides for aerobic rice system in tropical Asia, Malaysia in particular.

MATERIALS AND METHODS

Experimental details

Two field experiments were carried out at Malaysian Agricultural Research and Development Institute (MARDI) at Seberang Perai Station, Penang, Malaysia (N 05° 32.760’, E 100° 28.079’, elevation 17.4 to18.3 m) in the off season 2008 (April – July 2008) and main season 2008/2009 (November 2008 – February 2009). The soil belongs to Sogomana Series with average pH of 4.32. The organic matter (OM) content and cation exchange capacity (CEC) of the soil were 1.1% and 5.6 meq/100 g soil, respectively. The records from the Meteorological Department of Malaysia, Prai showed that the annual average rainfall during 2007 to 2009 ranged between 208 to 256 cm and the annual average minimum, maximum and mean temperatures were 25, 35 and 28°C, respectively. The off season and main season crops experienced the average temperature of 28.2 and 27.5°C, respectively during the growing season. The off season and main season crops received 448 and 381 cm rainfall, respectively in 54 and 38 occasions, respectively. An aerobic rice nursery line temporarily named as AERON001 (Aerobic Rice Observational Nursery) obtained from the International Rice Research Institute (IRRI), Los Banos, Manila, Philippines was used as planting material. The herbicides those were available in the local market and are used by the farmers for rice were selected for the study (Table 1).

The experiments in off season 2008 and main season 2008/2009 comprised a total of sixteen (Table 2) and ten (Table 3) herbicide treatments, respectively. The experiments were laid out in randomized complete block design with three and four replications in off and main seasons, respectively. The off season trial included 11 herbicides viz. two pre-emergence herbicides (Pretilachlor and Pendimethalin), six early post-emergence herbicides (Cyhalofop-butyl, Bispyribac-sodium, Propanil, Benthiocarb, Fenoxaprop-p-ethyl and Quinclorac) and two post-emergence herbicides (Bentazon and MCPA). The main season trial included only nine herbicides as two early post emergence herbicides (Fenoxaprop-p-ethyl and Quinclorac) were excluded because of their very poor performance in the off season trial. The herbicides were applied according to the experimental specification using 300 L of water per hectare with a Knapsack sprayer. Manual weeding was done according to the treatment adopted and weed free check plots were also kept weed free by manual weeding. Weedy check plot was also maintained, where no weeding operations were done.

Table 1. Trade name, active ingredients, chemical family, mode of action and manufactures of the herbicides used in the experiment.

Trade name	Active ingredient	Chemical family	Mode of action	Manufacturer
Sofit N300 (EC)	Pretilachlor (30% w/v)	Chloroacetamide	Inhibitor of synthesis of very long-chain fatty acids	Syngenta
Prowl	Pendimethalin (34% w/w)	Dinitroaniline	Microtubule assembly inhibitor	Behn Meyer
Clincher 100 (EC)	Cyhalofop-butyl (10.1% w/w)	Aryloxyphenoxy propionate	Acetyl CoA carboxylase (ACCase) inhibitor	Dow Agro Science
Londax (WP)	Bensulfuron-methyl (10% w/w)	Sulfonylurea	Acetolactate synthase (ALS) , also called Acetohydroxyacid synthase (AHAS) inhibitor, blocks branched chain amino acid biosynthesis	Du Pont
Nominee 100 (SC)	Bispyribac-sodium (9.7% w/w)	Pyrimidinlthio-benzoate	Acetolactate synthase (ALS) inhibitor, also called Acetohydroxyacid synthase (AHAS) inhibitor, blocks branched chain amino acid biosynthesis	ACM
Satunil (EC)	Propanil (20% w/w) /Thiobencarb (40% w/w)	Amide Thiocarbamate	Photosynthesis inhibitor at Photosystem II Inhibitor of lipid synthesis	ACM
Rumpas M (EC)	Fenoxaprop-p-ethyl (6.7% w/w) /safener	Aryloxyphenoxy propionate	Asetyl CoA carboxylase (ACCase) inhibitor	Bayer Crop Science
Facet (WP)	Quinclorac (50% w/w)	Quinaline carboxylic acid	Cell wall biosynthesis inhibitor	BASF
Basagran M60 aqueous solution	Bentazon (37.9% w/w) / MCPA (6.2% w/w)	Benzothiadiazole Phenoxy	Photosynthesis inhibitor at Photosystem II Synthetic auxins	Behn Meyer

ACM = Agricultural Chemical Marketing Sdn. Bhd, Malaysia.

The plot size was 5 x 5 m in both the seasons. Rice seeds were hand sown on the field at 25 x 20 cm spacing allocating 10 seeds per hill, that is seed rate of about 60 kg ha^{-1}. Before laying out the experiment and seed sowing, the land was well pre-pared by dry-ploughing followed by harrowing. The field was incorporated with organic manure at 8 t ha^{-1} during land preparation. The initial soil samples from 5 randomly selected spots were taken for soil analysis before manuring. Fertilizers were applied according to the Interim Fertilizer Rate Recommended for Aerobic Rice at 180 N : 54 P_2O_5 : 76.5 K_20 kg ha^{-1} (Azmi Man, pers. Comm.). NPK Blue granules (N, P_2O_5,K_20 at 12:12:17) were applied in the plots at 5 days after emergence (DAE) at 450 kg ha^{-1}. This was followed by the application of urea at 274 kg ha^{-1} in three splits (42% at 18 DAE, 42% at 30 DAE and 16% at 42 DAE). The field was irrigated using water sprinkler system to maintain soil moisture at field capacity condition. Three units of jet fill tensiometers of 30 cm body-length were installed at random spots in the field to monitor soil suction value or subsurface water tension of an aerobic system on a regular basis. Accumulated air in the tensiometers was removed by pushing the jet fill reservoir button. TREBON 10 EC (etofenprox 10%) and SCORE 25 EC (difeoconazole 25%) were used to control

Table 2. Herbicide treatments in the off season 2008 (season I).

Label	Treatment	Rate of application	Time of application
T1	Pretilachlor fb. manual weeding	0.5 kg ai ha^{-1}	1 DAS fb. 43 DAS
T2	Pretilachlor fb. Bentazon/MCPA	0.5 kg ai ha^{-1} fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 43 DAS
T3	Cyhalofop-butyl + Bensulfuron fb. manual weeding	0.1 kg ai ha^{-1} + 0.06 kg ai ha^{-1}	10 DAS fb. 43 DAS
T4	Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.1 kg ai ha^{-1} + 0.06 kg ai ha^{-1} fb. 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T5	Bispyribac-sodium fb. Manual Weeding	0.03 kg ai ha^{-1}	10 DAS fb. 43 DAS
T6	Bispyribac-sodium fb. Bentazon/MCPA	0.03 kg ai ha^{-1} fb 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T7	Propanil / Benthiocarb fb. Manual Weeding	1.2/2.4 kg ai ha^{-1}	10 DAS fb. 43 DAS
T8	Propanil / Benthiocarb fb. Bentazon/MCPA	1.2/2.4 kg ai ha^{-1} fb 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T9	Fenoxaprop-p-ethyl/safener fb. Manual Weeding	0.06 kg ai ha^{-1}	10 DAS fb. 43 DAS
T10	Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA	0.06 fb. 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T11	Quinclorac fb. Manual Weeding	0.25 kg ai ha^{-1}	10 DAS fb. 43 DAS
T12	Quinclorac fb. Bentazon/MCPA	0.25 fb. 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T13	Pendimethalin fb. Manual Weeding	1 .0 kg ai ha^{-1}	10 DAS fb. 43 DAS
T14	Pendimethalin fb. Bentazon/MCPA	1.0 kg ai ha^{-1} fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 43 DAS
T15	Weed free check		10 DAS to 74 DAS
T16	Weedy check		Up to harvest

/ Means that the herbicides were formulated as a proprietary mixture, + means that the herbicides were tank-mixed and applied at the same time, DAS = days after sowing, fb = followed by.

leaf folder and leaf blast respectively, whenever necessary.

Data collection

Sixteen rice hills were selected (four hill at a spot x four spots) and tagged from each plot to measure plant height (cm) at 30, 60 and 75 DAS. Tiller number was also counted from these plants. The leaf chlorophyll content was quantified by using a chlorophyll meter (Minolta SPAD 502) at every 10 day intervals from the day of sowing until harvest. Crop injury score using a scale of 1 to 10 were evaluated at 7 and 14 days after each herbicide application. The time of 50% heading was also recorded. Weed from randomly selected spots were collected by a 50 x 50 cm quadrate from each plots for measuring weeds density and dry weight at 30, 60 and 75 days after sowing (DAS) following procedure described by Bhagat et al. (1999). The collected weeds were separated into different species and all biomass was weighed after drying the weeds in an electric oven for 72 h at 80°C. At harvest, yield components were observed on 16 hills by taking four hills from a randomly selected spot with four replicates per plot. The number of panicles m^{-2}, number of grains $panicle^{-1}$, number of filled grains $panicle^{-1}$, unfilled grain $panicle^{-1}$, and 1000-grain weight were recorded from these sample plants. The spikelet fertility and sterility percent was also calculated from these recorded data. Rice grain yield was taken from whole plot harvest and converted to tones ha^{-1} at 14% moisture content. The major or dominant weed species can be determined from summed dominance ratio (SDR) values expressed as a percentage which was computed using the following equation (Janiya and Moody, 1989).

$$\text{SDR of a species} = \frac{\text{Relative density (RD)} + \text{Relative dry weight (RDW)}}{2}$$

Where,

$$RD = \frac{\text{Density of a given species}}{\text{Total density}} \times 100$$

$$RDW = \frac{\text{Dry weight of a given species}}{\text{Total dry weight}} \times 100$$

Weed control efficiency (WCE) of different treatments was calculated as follows from the weed dry weight data as follows (Hasnauzzaman et al., 2008):

WCE (%) = (DWC – DWT) / DWC x 100

Where, DWC is the dry weight of weeds in weedy check plots; DWT is the dry weight of weeds in treated plots.

Weed index (%) and yield increase over control (%) were calculated following the procedure by Pal et al. (2009):

Weed index (%) = (Weed free yield –yield of the treatment)

Table 3. Herbicide treatments in main season 2008-2009 (Season II).

Label	Treatment	Rate of application	Time of application
T1	Pretilachlor fb. Bentazon/MCPA	0.5 kg ai ha^{-1}fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 43DAS
T2	Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.1 kg ai ha^{-1} + 0.06 fb. 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T3	Bispyribac-sodium fb. Bentazon/MCPA	0.03 kg ai ha^{-1} fb 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T4	Propanil / Benthiocarb fb. Bentazon/MCPA	1.2/2.4 kg ai ha^{-1}fb 0.6/0.1 kg ai ha^{-1}	10 DAS fb. 43 DAS
T5	Pendimethalin fb. Bentazon/MCPA	1.0 kg ai ha^{-1}fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 43 DAS
T6	Pretilachlor fb. Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.5 kg ai ha^{-1}fb. 0.1 + 0.06 fb 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 30 DAS fb. 43DAS
T7	Pendimethalin fb. Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	1.0 kg ai ha^{-1}fb. 0.1 kg ai ha^{-1}+ 0.06 kg ai ha^{-1}fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 30 DAS fb. 43DAS
T8	Pretilachlor + Pendimethalin fb. Bentazon/MCPA	0.375/0.75 kg ai ha^{-1} fb. 0.6/0.1 kg ai ha^{-1}	1 DAS fb. 43 DAS
T9	Weed free check		10 DAS to 74 DAS
T10	Weedy check		Up to harvest

/ Means that the herbicides were formulated as a proprietary mixture, + means that the herbicides were tank-mixed and applied at the same time, DAS = days after sowing, fb = followed by.

/weed free yield x 100

Yield increase over control (% YIOC) = (Yield of the treatment – weedy yield)/ weedy yield x 100

Economic analysis was performed to determine the efficiency of different treatments following the procedure by Hussain et al. (2008). Two manual weeding was found sufficient to keep the plots (where applicable) weed free throughout the growing period and the labour requirement for a hectare of land was considered as 100 labourer. The cost for labourer was RM 20 labourer^{-1} day^{-1}. For spraying of herbicide per round per hectare one labourer was required. The amount of commercial product of herbicide required per hectare was calculated and the cost of each herbicide was estimated based on their market price. The market price of paddy was collected from different rice growing areas and was considered as RM 900 t^{-1} for calculating the gross return. The net benefit per hectare for each treatment was calculated by deducting the weed management cost from the gross return.

Data analysis

SAS statistical software package version 9.1 (SAS, 2003) was used for analyzing data using ANOVA technique. Significant differences among means were adjudged by using Fisher's protected Least Significant Difference (LSD) test at $p \leq 0.05$.

RESULTS

Weed infestation

A total of 21 weed species belonging to 9 families were observed in weedy check plots of aerobic rice. Seven weed species belong to Poaceae, four species to Cyperaceae, three species to Rubiaceae, two species to Fabaceae and one species from each of Ameranthaceae, Asteraceae, Capparaceae, Onagraceae, and Sterculiaceae were identified (Table 4). The weeds of the Poaceae and Cypeaceae families belong to grass and sedge groups, respectively. The weeds of the other families belong to the broadleaf weed group. Thus, the aerobic rice field was infested with 7 grass weeds, 4 sedge weeds and 10 broadleaf weeds. Among these 21 weeds, five (*Calopogonium mucunoides, Cyperus pilosus, Mimosa invisa, Panicum repense* and *Paspalam conjugatum)* were perennial and the rest 16 were annual weeds. The weed abundance at 30, 60 and 75 days after sowing (DAS) in both the seasons in the weedy aerobic rice plots was ranked based on summed dominance ratio (SDR). In both the seasons, *Eleusine indica* was the most dominant weed species followed by *Digitaria scandans* for all the dates of observation (Table 4). Other dominant weeds were: *Cyperus iria*, *Echinochloa colonum*, *Mimosa invisia*, *Calopogonium mucunoides* and *Fimbrystylis miliceae*. The rank position of these five weed species varied with season and growth stage of the crop. For example, *E. colona* was more dominant than *Cyperus iria* at 30 DAS in the off season while that was reverse in the main season. *Mimosa invisa* and *Calopogogium mucunoides* were more prevalent in the off season than that in the main season. In the off season, *E. colonum* was dominant at 30 DAS but was not present at 60 and 75 DAS. This situation was just reverse in the main season. *C. mucunoides* was more abundant at 60 and 75 DAS than at 30 DAS in off season. At 75 DAS, *C. iria* was not found in the off season but that was abundant in the main season. In this study, *Eleusine indica*, *D. scandense*, *C. iria* and *E.*

Table 4. Summed dominance ratio (SDR) of weed species present in the weedy aerobic rice plots at 30, 60 and 75 days after sowing (DAS) in off season 2008 and main season 2008-2009.

		Off season 2008			Main season 2008-2009				
	Weed species	**30 DAS**	**60 DAS**	**75 DAS**	**30 DAS**	**60 DAS**	**75 DAS**	**Weed type**	**Family**
1	*Eleusine indica* (L.) gaertn.	56.81	56.66	24.46	66.12	46.96	46.16	Grass	Poaceae
2	*Digitaria ascendens* (H.B.R. Henr.)	25.75	20.06	27.56	11.63	13.30	23.47	Grass	Poaceae
3	*Cyperus iria* L.	3.03	5.20	-	12.37	7.45	3.28	Sedge	Cyperaceae
4	*Echinochloa colona* (L.) Link	7.12	-	-	3.52	22.01	16.12	Grass	Poaceae
5	*Mimosa invisa* Mart.	3.85	7.01	21.90	0.38	0.15	2.43	Broadleaf	Fabaceae
6	*Fimbristylis miliacea* (L.) Vahl	-	-	5.61	4.80	2.10	1.82	Sedge	Cyperaceae
7	*Calopogonium mucunoides* Desv.	2.09	8.36	6.95		0.23	0.28	Broadleaf	Fabaceae
8	*Cyperus pilosus* Vahl.	0.07	0.54	4.96		-	1.13	Sedge	Cyperaceae
9	*Dactyloctenium aegyptium* (L.) Beauv.	-	1.20	3.39		0.93	1.45	Grass	Poaceae
10	*Panicum repens* L.	-	-	-		0.16	0.60	Grass	Poaceae
11	*Cleome rutidosperma* DC.	-	0.96	-	0.39	0.38		Broadleaf	Capparaceae
12	*Cyperus compressus* L.	-	-	-	0.16	-		Sedge	Cyperaceae
13	*Paspalum conjugatum* (L.) Berg	-	-	-	0.05	-	0.13	Grass	Poaceae
14	*Leptochloa chinensis* (L.) Nees	-	-	-		3.96	2.29	Grass	Poaceae
15	*Melochia corchorifolia* L.	0.26	-	0.96	0.11	0.05		Broadleaf	Sterculiaceae
16	*Borreria laevis* (Lam.) Griseb	-	-	-	0.22	0.53	0.38	Broadleaf	Rubiaceae
17	*Oldenlandia dichotoma* Hook f.	-	-	-	0.11	0.06		Broadleaf	Rubiaceae
18	*Ludwigia hyssopifolia* (G. Don) Excell	-	-	1.49	0.07	0.25		Grass	Onagraceae
19	*Hedyotis corymbosa* (L.) Lam.	-	-	2.72	0.05	-	0.19	Broadleaf	Rubiaceae
20	*Ageratum conyzoides* L.	0.20	-	-		-	0.13	Broadleaf	Asteraceae
21	*Amaranthus spinosus* L.	0.47	-	-		-		Broadleaf	Amaranthaceae

colonum are generally dominant weeds in the aerobic rice field while *Mimosa invisa, C. mucunoides* and *Fimbrystylis miliceae* sometimes may become dominant. The abundance of other 14 weed species was very low and sparse in the aerobic rice system (Table 4).

Weed control

Herbicide treatments had significant effect on weed density in both the seasons at all the three observation dates (30, 60 and 75 DAS) except that for 75 DAS in the off season. The highest weed population (280.0 plants m^{-2}) was found in T16 (weedy check) and the lowest (5.7 plants m^{-2}) in T7 (Propanil/Benthiocarb) at 30 DAS in the off season trial. The weed density found in T7 was very close to those obtained with T4 (Cyhalofop-butyl + Bensufuron fb Bentazone/MCPA) and T2 (Pretilachlor fb Bentazone/MCPA) treatments. The unweeded plots at 60 DAS had the highest weed population of 112 weeds m^{-2} (Table 5). The manual weed free treatment (T15) and application of Propanil/Benthiocarb fb Manual weeding (T7) did not have any weed at 60 DAS. All the plots receiving herbicide treatments followed by Manual weeding (T1, T3, T5, T9, T11 and T13) showed significantly lower weed density than weedy check. On the other hand, the plots receiving herbicide followed by Bentazone/MCPA showed lower weed density than weedy check, although, the decrease was not significant. It was interesting to note that the weed density in T10 (Fenoxaprop-

Table 5. Effect of different herbicide treatments on weed density, weed biomass and weed control efficiency (%) in aerobic rice field in off season 2008.

Treatment	Weed density (number m^{-2})			Weed biomass (g m^{-2})			Weed control efficiency (%)		
	30DAS	60DAS	75 DAS	30DAS	60DAS	75 DAS	30DAS	60DAS	75 DAS
T1	89	42	43	71.42	14.02	44.30	67.15	89.07	33.05
T2	51	59	36	65.35	62.27	53.80	69.94	51.46	18.69
T3	120	12	29	85.77	8.11	22.87	60.55	93.67	65.44
T4	40	21	18	43.97	24.50	14.33	79.78	80.90	78.34
T5	90	29	22	61.79	15.93	12.73	71.58	87.58	80.76
T6	82	98	45	54.60	139.21	60.33	74.89	-8.53	8.82
T7	6	0	16	9.53	0.00	18.53	95.62	100.00	71.99
T8	66	29	19	29.17	23.56	37.90	86.59	81.63	42.72
T9	101	67	39	77.12	20.47	9.97	64.53	84.04	84.93
T10	150	110	46	115.27	47.92	30.66	46.99	62.64	53.66
T11	166	42	15	85.41	28.93	11.70	60.72	77.44	82.32
T12	188	88	70	141.90	142.53	178.13	34.74	-11.12	-169.22
T13	89	40	41	45.07	12.77	21.61	79.27	90.05	67.34
T14	116	68	11	45.61	75.17	33.97	79.02	41.40	48.66
T15	0	0	0	0.00	0.00	0.00	100.00	100.00	100.00
T16	281	112	47	217.43	128.27	66.17	0.00	0.00	0.00
Sig. level	***	**	ns	**	***	*	-	-	-
$LSD_{0.05}$	97.03	65.06	49.05	89.353	64.78	78.911	-	-	-

T1 = Pretilachlor fb. Manual Weeding, T2 = Pretilachlor fb. Bentazon/MCPA, T3 = Cyhalofop-butyl + Bensulfuron fb. Manual Weeding, T4 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T5 = Bispyribac-sodium fb. Manual Weeding, T6 = Bispyribac-sodium fb. Bentazon/MCPA, T7 = Propanil/Benthiocarb fb. Manual Weeding, T8 = Propanil/Benthiocarb fb. Bentazon/MCPA, T9 = Fenoxaprop-p-ethyl/safener fb. Manual Weeding, T10 = Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA, T11 = Quinclorac fb. Manual Weeding, T12 = Quinclorac fb. Bentazon/MCPA , T13 = Pendimethalin fb. Manual Weeding, T14 = Pendimethalin fb. Bentazon/MCPA, T15 = Weed free check, T16 = Weedy check.

p-ethyl fb Bentazone/MCPA) was higher than that in the weedy check. At 75 DAS, the weed population found with weedy check was 47.3 weeds m^{-2} which was similar with those for T6, T10 and T12 (Table 5). All other treatments gave significantly lower weed population than the control (weedy plots). In the main season, the weed densities for weedy check plots were 464, 338 and 263 weeds m^{-2}, respectively at 30, 60 and 75 DAS. Herbicide treated plots showed significantly lower weed density than those of weedy check plots in all the dates of observation (Table 6). Among the herbicide treated plots, the lowest weed population at 30 DAS was found with T1 (82 weeds m^{-2}) which was very close to that of T8 (107 weeds m^{-2}). The weed population found at 60 DAS was the lowest with T7 (80 weeds m^{-2}) and highest with T10 (weedy check). The weed population found in T2 (169 weeds m^{-2}) and T3 (199 weeds m^{-2}) were significantly higher than that of T7 but similar to those of other treatments (Table 6). At 75 DAS, T7 also showed the lowest weed population (82 weeds m^{-2}) which was very close to that of T8 (85 weeds m^{-2}). There was no weed in the weed free plots as because when they appeared, was removed by hand weeding.

Weed biomass was significantly affected by different herbicide treatments as observed at 30, 60 and 75 days after sowing (DAS) in both seasons. In the off season, the weed biomass at 30 DAS in weedy check plot was the highest (217.43 g m^{-2}) while that was the lowest (9.53 gm^{-2}) for T7 (Table 5). The weed dry matter in T8 was very close to that of T7 and the values for all other herbicide treated plots did not vary significantly from that of T7 except for T10 and T12. The weed

Table 6. Effect of different herbicide treatments on weed density, weed biomass and weed control efficiency (%) in aerobic rice field in main season 2008-2009.

Treatment	Weed density (number m^{-2})			Weed biomass (g m^{-2})			Weed control efficiency (%)		
	30DAS	60DAS	Harvest	30DAS	60DAS	Harvest	30DAS	60DAS	Harvest
T1	82	160	128	35.7	108.8	84.2	84.68	51.33	42.48
T2	138	169	107	65.0	133.4	72.4	76.33	44.80	48.19
T3	315	199	149	143.3	165.4	102.0	44.98	28.32	25.90
T4	113	104	113	46.9	56.1	60.4	80.51	74.42	57.77
T5	130	134	127	73.5	96.4	86.4	67.17	55.82	43.64
T6	171	152	150	60.8	82.5	81.0	75.34	63.03	45.71
T7	149	80	82	75.0	60.8	60.0	67.58	70.10	57.61
T8	107	107	85	47.2	74.3	49.1	78.65	65.65	66.44
T9	0	0	0	0.0	0.0	0.0	100.00	100.00	100.00
T10	464	338	263	251.4	225.3	144.8	0.00	0.00	0.00
Sig. Level	***	***	***	***	***	***	-	-	-
$LSD_{0.05}$	154.70	84.09	77.88	83.772	67.438	50.436	-	-	-

T1 = Pretilachlor fb Bentazon/MCPA, T2 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T3 = Bispyribac-sodium fb. Bentazon/MCPA, T4 = Propanil/Benthiocarb fb. Bentazon/MCPA, T5 = Pendimethalin fb. Bentazon/MCPA, T6 = Pretilachlor fb Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T7 = Pendimethalin fb. Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T8 = Pretilachlor/ Pendimethalin fb Bentazon/MCPA, T9 = Weed free check, T10 = Weedy check.

biomass in T12 (141.9 gm^{-2}) was statistically similar to that of T16 (weedy check). However, T10 produced weed biomass significantly lower than that of weedy check. At 60 DAS, the highest weed biomass was obtained with T12 (142.5 gm^{-2}) which was similar to that obtained at T6 (139.2 gm^{-2}) and T16 (128.3 gm^{-2}). The highest weed biomass at 75 DAS was found with T12 (178.1 gm^{-2}) which was also significantly higher than that of weedy check plots (66.17 gm^{-2}). Weed biomass at 30, 60 and 75 DAS in the main season significantly differed with different herbicide treatments. In all the cases, the highest weed biomass was found with the weedy check plots and those were significantly higher than those obtained in all the herbicide treatments except for T3 at 30 DAS (Table 6). Thus, it appeared that all the herbicide treatments except T3 effectively reduced the weed biomass in the aerobic rice field.

The weed control efficiency of different herbicide treatments at 30, 60 and 75 DAS in both off and main season varied significantly. In the off season, at 30 DAS, the highest (95.62%) weed control efficiency was found with T7 (Propanil/Benthiocarb fb Manual weeding) followed by T8 (86.59%), T4 (79.78%), T13 (79.27%) and T14 (79.02%). The weed control efficiency was the lowest with T12 (34.74%) followed by T10 (46.99%). At 60 DAS, the weed control efficiency of T7 was 100% and that of T13 was 90.05%. The effect of T12 on weed control was negative (-11.12%) but that of T11 was 77.44%. The weed control efficiency of T14 was only 41.40% while that for T2 was 51.46% (Table 5). All other treatments showed higher weed control efficiency than T2 at 60 DAS. The weed control efficiency of different treatment at 75 DAS was the highest with T9 (84.93%) which was closely followed by T11 (82.32%) and T5 (80.76%). The weed control efficiency of T12 was highly negative (-169.22%) and that of T6 was very negligible (8.82%). In the main season, the weed control efficiency of different treatments varied and the highest values at 30, 60 and 75 DAS were obtained with T1 (84.64%), T4 (74.42%) and T8 (66.44%) treatments, respectively (Table 6).

Leaf chlorophyll content (SPAD) and phytotoxicity

Different herbicide treatments had significant effect on SPAD (Silicon Photon Activated Diode) value only at 70 DAS but not at 20, 30, 40, 50 and 60 DAS in the off season trial. The effect was significant for all these observation dates in the main season. In the off season, the highest SPAD value at 70 DAS was obtained with T3 (44.7) followed by T8 (44.6). The value in T3 was statistically similar to those of all other herbicide treated plots except for T5 (39.3). The lowest SPAD value was found with the weedy check plot (Table 7). In the main season, the highest SPAD values were found with T8 for all the dates of observations and the lowest with weedy check plots. The SPAD values for T8 at 20, 30, 40, 50, 60 and 70 DAS were 28.0, 38.9, 38.8, 41.5, 45.9 and 47.4, respectively. The SPAD values obtained with T8 did not differ significantly with other herbicide treatments in each of the dates of observation but significantly different from those of weedy check plots (Table 8). The SPAD value obtained in the weed free plots was statistically similar to those obtained for herbicide treated plots. The field was visited at 7 and 14 days after each herbicide application to record the phytotoxicity on the herbicide treated plants but however, no phytotoxicity symptom was observed in

Table 7. Effect of different herbicide treatment on leaf chlorophyll content (SPAD value) of aerobic rice at different days after sowing (DAS) in off season 2008.

Treatment	Time of observation					
	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS
T1	29.0	32.6	32.5	42.0	44.0	43.0
T2	26.6	31.6	30.0	39.1	43.9	43.9
T3	31.6	34.0	34.2	39.6	45.5	44.7
T4	30.9	34.3	29.6	38.6	42.1	41.4
T5	31.9	34.8	31.1	38.0	40.6	39.3
T6	31.2	36.3	31.4	41.5	43.0	43.0
T7	30.0	34.4	33.8	38.7	42.5	42.3
T8	30.9	34.7	35.3	40.9	44.8	44.6
T9	31.5	34.3	31.1	40.1	43.4	41.8
T10	28.1	30.8	28.2	37.0	42.7	41.3
T11	30.9	33.9	30.5	37.5	40.8	40.5
T12	31.8	34.4	30.8	39.1	41.6	40.5
T13	30.3	33.3	30.8	38.3	43.0	43.4
T14	26.4	30.3	30.0	37.6	39.4	42.7
T15	29.4	32.5	29.4	38.0	42.0	40.5
T16	30.0	33.4	28.4	37.9	40.2	35.9
Sig. Level	ns	ns	ns	ns	ns	*
$LSD_{0.05}$	4.139	4.265	6.310	4.640	4.380	4.176

T1 = Pretilachlor fb. Manual Weeding, T2 = Pretilachlor fb. Bentazon/MCPA, T3 = Cyhalofop-butyl + Bensulfuron fb. Manual Weeding, T4 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T5 = Bispyribac-sodium fb. Manual Weeding, T6 = Bispyribac-sodium fb. Bentazon/MCPA, T7 = Propanil/Benthiocarb fb. Manual Weeding, T8 = Propanil/Benthiocarb fb. Bentazon/MCPA, T9 = Fenoxaprop-p-ethyl/safener fb. Manual Weeding, T10 = Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA, T11 = Quinclorac fb. Manual Weeding, T12 = Quinclorac fb. Bentazon/MCPA , T13 = Pendimethalin fb. Manual Weeding, T14 = Pendimethalin fb. Bentazon/MCPA, T15 = Weed free check, T16 = Weedy check.

any herbicide treated plots (data not shown).

Yield contributing characters

Herbicide treatments did not have any significant effect on plant height at harvest and height growth rate (HGR) between 0 to 30 DAS in both the seasons (Tables 9 and 10). The HGR between 30 and 60 DAS differed significantly in the off season but not in the main season. In the off season, the highest HGR (2.59 cm day^{-1}) was found with T8 and the lowest (1.68 cm day^{-1}) with weedy control. The height growth rate obtained with T8 was statistically similar to those values for T1, T2, T3, T4, T6, T7, and T14. The value obtained with weed free treatment was statistically similar to T16 and the rest of the herbicide treated plots. Number of total tillers m^{-2} did not differ significantly due to herbicide treatments in the off season but did differ in the main season. In the off season, the highest number of total tillers m^{-2} was obtained with T5 (338.1) and the lowest with T10 (227.5). The number of tillers m^{-2} obtained with T5 was statistically similar to those obtained in all other herbicide treated plots except T1 (275.0) and T3 (264.4). The number of spikelet per panicle and filled grains per panicle did not show significant variation due to herbicide treatment in the off season but varied significantly in the main season. Both the number of spikelet per panicle (124.5) and filled grain per panicle (103.4) were the highest with T4 and the lowest (63.0 and 52.5, respectively) with T10 in off season (Table 9). The number of spikelet per panicle (124.5) and filled grain per panicle (103.4) obtained in T4 were statistically at par with those obtained for all the herbicide treated plots except for T3. The values for T3 were similar to those for weedy check plots. Grain fertility percentage and thousand seed weight did not show significant variation due to different herbicide treatments in both the seasons.

Grain yield and weed index

Grain yield differed significantly due to different herbicide treatments in both seasons (Tables 9 and 10). In the off season, the highest grain yield (2.96 t ha^{-1}) was obtained in T4 (Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA) which was very close to that obtained in weed free plots (2.88 t ha^{-1}). The lowest yield (0.19 t ha^{-1}) was found with T16 (weedy check). The yield obtained with T4 (2.99 t ha^{-1}) was statistically similar to those obtained with all the herbicide treated plots but this yield was significantly higher than those for T2 (1.34 t ha^{-1}), T10 (1.26 t ha^{-1}),

Table 8. Effect of different herbicide treatment on leaf chlorophyll content (SPAD value) of aerobic rice at different days after sowing (DAS) in main season 2008-2009.

Treatment	Time of observation					
	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS
T1	26.0	37.2	38.2	41.9	44.4	46.0
T2	27.7	37.3	38.9	41.2	44.0	44.7
T3	25.3	33.5	34.5	39.7	42.4	41.6
T4	26.5	37.8	38.8	42.5	45.0	47.1
T5	26.1	34.0	34.0	38.5	42.1	45.2
T6	26.1	36.7	37.7	39.0	42.2	43.3
T7	27.8	36.2	35.1	40.2	44.8	44.9
T8	28.0	38.9	38.8	41.5	45.9	47.4
T9	25.8	37.8	38.1	43.9	45.2	46.3
T10	23.0	26.3	27.5	33.6	34.3	37.0
Sig. Level	**	**	***	**	**	**
$LSD_{0.05}$	2.439	6.117	5.233	4.392	5.173	4.378

T1 = Pretilachlor fb Bentazon/MCPA, T2 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T3 = Bispyribac-sodium fb. Bentazon/MCPA, T4 = Propanil/Benthiocarb fb. Bentazon/MCPA, T5 = Pendimethalin fb. Bentazon/MCPA, T6 = Pretilachlor fb Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T7 = Pendimethalin fb. Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T8 = Pretilachlor/ Pendimethalin fb Bentazon/MCPA, T9 = Weed free check, T10 = Weedy check.

T12 (1.36 t ha^{-1}) and T14 (1.58 t ha^{-1}) plots. In the main season, the highest yield was noticed with T9 (2.75 t ha^{-1}) and the lowest with T10 (0.32 t ha^{-1}). The yield of T4 (Propanil/Benthiocarb fb Bentazon/MCPA) and T7 (Pendimethalin fb Cyhalopfop-butyl+Bensulfuron fb Bentazon/MCPA) were the same (2.22 t ha^{-1}) which was statistically similar to that of weed free plot (T9). The application of Pretilachlor + Pendimethalin fb Bentazon/MCPA (T8) also gave statistically similar yield to that of T9. In contrast, all other herbicide treated plots gave grain yield significantly lower than T9 but higher than weedy check (T10). It is notable that the weed free plot gave 1441% (Table 9) and 772% higher yields (Table 10) than weedy plots in the off season and main season, respectively. In the off season, the plot treated with Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA (T4) gave more yield increase than the weed free plot (Table 9).

The weed index for the weedy plots were 93.51 and 88.54% in the off season and main season, respectively (Tables 9 and 10). For the weed free plots, the weed index was zero for both the season as the weed index indicated the yield loss over the weed free plots. The weed index for T4 (Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA) in the off season was negative (-2.44%). The weed index for T9 was 3.11% which was closely followed by T8 having 6.66% weed index. In the main season, the lowest weed index (19.26%) was found with T7 (Pendimethalin fb Cyhalopfop-butyl + Bensulfuron fb Bentazon/MCPA) which was very close to that (19.38%) obtained with T4 (Propanil/Benthiocarb fb Bentazon/MCPA).

Economic analysis

Economic analysis revealed that the highest net benefit (RM 2336 ha^{-1}) in the off season was achieved from the plots treated with T4 (Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA) which was followed by T8 (Propanil/Benthiocarb fb Bentazon/MCPA) having net benefit of 2072 RM ha^{-1} and T6 (Bispyribac-sodium fb Bentazon/MCPA) with benefit of RM 1935 ha^{-1} (Table 11). It was noted that the plots treated with herbicide and either followed by manual weeding or Bentazon/MCPA gave remarkably higher net benefit than only manual weeded weed free plots (RM 473 ha^{-1}). The economic analysis for the main season crop also showed that herbicide treated plots gave very high benefit over hand weeded weed free plots (Table 11). The highest net benefit (RM1642 ha^{-1}) was obtained in T4 plots (Propanil/Benthiocarb fb Bentazone/MCPA) followed by T8 (Pretilachlor + Pendimethalin fb Bentazone/MCPA) plots having net benefit of RM 1359 ha^{-1} while the net benefit for the manual weeded weed free plot (T9) was only RM 473 ha^{-1}.

DISCUSSION

The most dominant weed species infesting the crop was ranked based on their SDR, as this value is more informative than any other single measure in reflecting the contribution of a species in a weed community (Bhagat et al., 1999). The most dominant weed species identified in the aerobic rice fields for both main and

Table 9. Effect of different weed control treatments on crop characters, yield parameters, yield and weed index of aerobic rice in off season 2008.

Treatment	PHH	HGR 0-30	HGR 30-60	TNH	SPP	FGN	GF (%)	TSW	GY (t/ha)	YIOC (%)	WI (%)
T1	125.8	1.61	2.31	287.0	116.8	97.7	83.7	29.80	2.25	1101.7	22.02
T2	128.2	1.69	2.41	317.7	111.6	92.6	83.3	31.83	1.34	613.7	53.69
T3	132.6	2.01	2.34	277.7	134.3	110.7	83.2	29.30	2.62	1301.7	9.04
T4	122.2	1.98	2.25	300.7	108.7	89.1	82.7	29.60	2.96	1478.6	-2.44
T5	122.3	1.90	2.07	264.3	99.6	87.5	87.8	30.83	2.51	1241.9	12.92
T6	127.4	1.89	2.26	289.3	106.8	90.3	84.9	29.67	2.39	1177.8	17.08
T7	132.5	1.69	2.31	318.0	116.2	96.4	83.1	28.77	2.15	1049.6	25.40
T8	133.8	1.75	2.59	255.7	151.1	125.9	84.4	28.37	2.69	1338.5	6.66
T9	146.1	2.09	1.95	297.3	110.7	96.7	87.7	30.93	2.80	1393.2	3.11
T10	132.7	1.77	1.93	302.7	107.9	92.6	86.5	30.70	1.26	575.2	56.18
T11	124.3	2.03	1.73	289.7	103.4	90.7	87.8	31.77	2.22	1083.8	23.18
T12	127.2	1.97	1.85	307.3	107.8	92.1	85.7	30.37	1.36	626.5	52.86
T13	123.3	1.77	2.02	286.3	111.0	92.5	84.6	30.80	2.14	1041.0	25.96
T14	121.7	1.71	2.14	277.7	104.3	87.0	84.1	29.97	1.58	742.7	45.31
T15	128.8	1.92	2.04	309.0	103.1	85.3	83.8	30.30	2.88	1441.0	0.00
T16	121.4	2.07	1.68	280.3	86.5	74.3	85.6	30.60	0.19	0	93.51
Sig. Level	ns	ns	**	ns	ns	ns	ns	ns	***	-	-
$LSD_{0.05}$	17.202	0.326	0.437	54.69	47.122	37.482	6.326	2.291	0.962	-	-

PHH, Plant height at harvest; HGR0-30 and HGR 30-60 , height growth rate between 0 and 30 DAS and 30 and 60 DAS, respectively; TNH, tiller no. m^{-2} at harvest; SPP, number of spikelet $panicle^{-1}$; FGN, number of filled grain $panicle^{-1}$; GF, filled grain (%); TSW, thousand seed weight; GY, grain yield (t ha^{-1}); YIOC, increase of grain yield over control (unweeded check); weed index, increase of yield over the weed free control. T1 = Pretilachlor fb. Manual Weeding, T2 = Pretilachlor fb. Bentazon/MCPA, T3 = Cyhalofop-butyl + Bensulfuron fb. Manual Weeding, T4 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T5 = Bispyribac-sodium fb. Manual Weeding, T6 = Bispyribac-sodium fb. Bentazon/MCPA, T7 = Propanil/Benthiocarb fb. Manual Weeding, T8 = Propanil/Benthiocarb fb. Bentazon/MCPA, T9 = Fenoxaprop-p-ethyl/safener fb. Manual Weeding, T10 = Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA, T11 = Quinclorac fb. Manual Weeding, T12 = Quinclorac fb. Bentazon/MCPA , T13 = Pendimethalin fb. Manual Weeding, T14 = Pendimethalin fb. Bentazon/MCPA, T15 = Weed free check, T16 = Weedy check.

off seasons could be ranked in the order of: *E. indica*> *D. ascendens*> *C. iria*> *E. colona*> *C. mucunoides* >*M. invisa*. In both seasons, *E. indica* was the top ranking dominant weed followed by *D. ascendens;* although, the rank position for other four species varied depending on the season and growth stage of the crop. The weed dominance ranking could be changed with cropping season. Juraimi et al. (2009) found the dominant weed species in wet direct seeded rice under saturated soil condition in dry season (off season) in the order of: *C. iria*> *F. miliacea*> *C. digitatus*> *E. crus-galli*> *E. colona* > *L. chinensis*. While the dominance raking changed in the wet season (main season) and grass weeds (*L. chinensis* and *E. crus-galli*) became more dominant than the sedge weeds. The change in the abundance of certain weeds may be related to change in soil moisture levels in cropping seasons (Janiya and Moody, 1982).

In this study, weed density in the main season was much higher than that of off season. In the off season, the weed population (number m^{-2}) in the unweeded plots at 30, 60 and 75 days after sowing were 280, 112 and 47 with corresponding dry biomass of 217, 128 and 66 gm^{-2}, respectively. On the other hand, the weed population (number m^{-2}) in wet season at 30, 60 and 75 days after sowing were 464, 338 and 251 with the corresponding dry biomass of 251, 225 and 145 gm^{-2}, respectively. The result showed that the weed pressure in the main season was higher than the off season. The higher weed population and dry biomass in the main season was probably related to the saturated soil condition because of rainfall that encouraged weed seeds to germinate

Table 10. Effect of different weed control treatments on crop characters, yield parameters, yield and weed index of aerobic rice in main season 2008-2009.

Treatment	PHH	HGR 0-30	HGR 30-60	TNH	SPP	FGN	GF (%)	TSW	GY (t/ha)	YIOC (%)	WI %)
T1	105.9	2.09	1.21	275.0	116.0	98.3	84.60	26.39	1.57	397.7	42.94
T2	104.3	2.00	1.49	295.3	116.8	95.8	82.03	26.09	1.78	465.8	35.14
T3	100.0	1.80	1.15	264.4	88.8	75.5	84.95	25.20	1.30	314.2	52.52
T4	107.1	2.25	0.91	295.0	124.5	103.4	83.28	26.53	2.22	603.3	19.38
T5	105.0	2.08	1.30	338.1	99.3	84.5	84.78	27.33	1.74	451.4	36.79
T6	104.8	2.02	1.33	298.4	107.0	90.5	84.80	26.84	1.84	482.6	33.22
T7	122.0	2.01	1.33	308.1	114.0	98.5	86.33	26.87	2.22	604.4	19.26
T8	109.6	2.45	0.92	331.6	120.0	100.8	84.28	27.09	1.87	493.0	32.07
T9	118.9	1.90	1.40	323.8	119.5	103.0	86.13	26.20	2.75	772.4	0.00
T10	89.3	1.58	0.94	227.5	63.0	52.5	82.43	27.57	0.32	0.0	88.54
Sig. Level	ns	ns	ns	*	**	**	ns	ns	***	-	-
$LSD_{0.05}$	21.153	0.58	0.581	60.154	29.81	25.925	5.192	2.088	0.903	-	-

PHH, Plant height at harvest; HGR0-30 and HGR 30-60, height growth rate between 0 and 30 DAS and 30 and 60 DAS, respectively; TNH, tiller number m^{-2} at harvest; SPP, number of spikelet $panicle^{-1}$; FGN, number of filled grain $panicle^{-1}$; GF, filled grain (%); TSW, thousand seed weight; GY, grain yield (t ha^{-1}); YIOC, increase of grain yield over control (unweeded check); weed index, increase of yield over the weed free control. T1 = Pretilachlor fb Bentazon/MCPA, T2 = Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA, T3 = Bispyribac-sodium fb. Bentazon/MCPA, T4 = Propanil/Benthiocarb fb. Bentazon/MCPA, T5 = Pendimethalin fb. Bentazon/MCPA, T6 = Pretilachlor fb Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T7 = Pendimethalin fb. Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA, T8 = Pretilachlor/ Pendimethalin fb Bentazon/MCPA, T9 = Weed free check, T10 = Weedy check.

better than the off season (Bhagat et al., 1996; Saiful, 2008; Juarimi et al., 2009). The overall weed density and dry matter found in this study is higher, reflecting the fact that rice under aerobic system is subjected to more weed pressure than transplanted or wet directed seeded systems. Mahajan et al. (2009) found almost double weed density and biomass in aerobic rice field than those of conventional transplanted rice at 35 and 75 days after sowing /transplanting. The high weed pressure in the aerobic rice field may be related to dry soil tillage (favourable 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).

Weed free plots by manual weeding had 100% weed control efficiency and it was caused due to removal of all weeds whenever they emerged and grow. However, almost all the herbicide treatments showed very good degree of weed control. In both seasons, application of propanil/ benthiocarb, pendimethalin or pretilachlor showed very high weed control (80-90%) as observed at 30 DAS. Bispyribac-sodium showed a promising performance in the off season but its performance was poor in the main season. Hossain (2008) found that Bispyribac sodium gave good degree of control in dry direct seeded rice (about 91% weed control). The variation in the performance of this herbicide in this study could be related to the variation in weed species between the seasons. Bispyribac sodium is a selective herbicide effective for the control of grasses, sedges and broadleaf weeds in rice and is effective as a soil or foliar treatment (Schmidt et al., 1999). It is a member of the pyridiminyloxybenzoic chemical family (Darren and Stephen, 2006) and inhibits the enzyme acetohydroxy acid synthase, also known as acetolactate synthase (ALS), in susceptible plants. This ultimately reduces transport of photosynthate from source leaves to roots, resulting in root growth inhibition (Devine, 1989). Mahajan et al. (2009) reported that bispyribac sodium reduced weed dry matter to the tune of 81.3, 61.7 and 22.1% over weedy check, pendimethalin + 1 HW, and pretilachlor + metsulfuron, respectively.

In the off season, pendimethalin fb Bentazone/ MCPA gave higher weed control than pretilachlor fb Bentazone/MCPA while reverse occurred during the main season. This variation might be related to variation in weed dominance between the seasons and efficacy of herbicides relative to soil moisture regimes (Juraimi et al., 2010). On the other hand, propanil/Benthiocarb fb Bentazone/ MCPA gave consistently high control in both the

Table 11. Impact of different weed control treatments on economic analysis of aerobic rice in off season 2008 and main season 2008-2009.

Off season 2008						Main season 2008-2009					
Treatment	Cost for herbicide + spraying (RM ha^{-1})	Cost for hand weeding (RM ha^{-1})	Total weeding cost (RM ha^{-1})	Gross return (RM ha^{-1})	Net profit (RM ha^{-1})	Treatment	Cost for herbicide + spraying (RM ha^{-1})	Cost for hand weeding (RM ha^{-1})	Total weeding cost (RM ha^{-1})	Gross return (RM ha^{-1})	Net profit (RM ha^{-1})
T1	125	1000	1125	2025	900	T1	205	-	205	1411	1206
T2	205		205	1202	997	T2	324	-	324	1604	1280
T3	244	1000	1244	2362	1118	T3	218	-	218	1174	956
T4	324		324	2660	2336	T4	352	-	352	1994	1642
T5	138	1000	1138	2261	1123	T5	280	-	280	1563	1283
T6	218		218	2153	1935	T6	449	-	449	1652	1203
T7	272	1000	1272	1937	665	T7	524	-	524	1997	1473
T8	352		352	2424	2072	T8	322	-	322	1681	1359
T9	170	1000	1170	2516	1346	T9	-	2000	2000	2473	473
T10	250		250	1138	888	T10	-	-	-	284	284
T11	230	1000	1230	1994	764						
T12	310		310	1224	914						
T13	200	1000	1200	1922	722						
T14	280		280	1420	1140						
T15	-	2000	2000	2596	596						
T16	-	-	-	169	169						

Amount of commercial herbicide products (ha^{-1}): 0.5kg Pretilachlor = 1.5 L Sofit, 0.1 kg Cyhalofop-butyl = 1.0 L Clincher, 0.06 kg Bensulfuron = 0.6 kg Londax, 0.03 kg Bispyribac sodium = 0.1 L Nominee100 SC, 1.2 kg Propanil + 2.4 kg Benthiocarb = 6L Satunil, 0.06 kg Fenoxaprop-p-ethyl = 0.87 L Rumpas M, 0.25 kg Quinclorac = 0.5 kg Facet, 1 kg Pendimethalin = 3 L Prowl, 0.6 kg Bentazon + 0.1 kg MCPA = 1.6 L Basagran M 60. Market price of herbicide commercial products: Sofit N300 EC: 70 RM L^{-1}, Prowl: 60RM L^{-1}, Clincher 100 EC: 110RM L^{-1}, Londax : 19 RM 100 g^{-1}, Nominee 100 SC: 98 RM 250 ml^{-1}, Satunil: 42 RM L^{-1}, Rumpas M: 43 RM 250ml^{-1}, Facet : 42RM 100g^{-1} and Basagran M60: 38 RM L^{-1}. Manual weeding cost: 100 labourers ha^{-1} for 2 weedings @ 20 RM day^{-1} $labourer^{-1}$, Herbicide application cost: 1 $labourer^{-1}$ ha^{-1} $round^{-1}$at 20 RM day^{-1} $labourer^{-1}$, Market price of paddy: 900.00 RM ton^{-1}, Gross return = paddy yield (ton ha^{-1}) × market price (RM ton^{-1}), Net profit = gross return – total weeding cost.

seasons. Propanil is a herbicide of Amide chemical family acting as a photosynthesis inhibitor in the photosystem II. This herbicide does not provide residual weed control and therefore, thiobencarb is used along with propanil to provide residual weed control (Crawford and Jordan, 1995). Cyhalofop-butyl+Bensulfuron fb Bentazone/MCPA also provided good control in both seasons. Cyhalofop-butyl is effective on *Echinochloa* species and other species as well (Singh et al., 2008). Fenoxaprop-p-ethyl or Quinclorac did not show good weed control efficiency in the off season crop and thus these herbicides (Fenoxaprop and Quinclorac) were excluded from the test in the following main season.

The grain yield of most of the herbicide treated plot was similar to that obtained from weed free plots in both seasons. It was interesting to note that in the dry season, the yield of herbicide treated plot (Cyhalofop-butyl + Bensulfuron fb Bentazone/MCPA) was even higher (2.96 t ha^{-1}) than the weed free plots (2.88 t ha^{-1}). It is established that productivity of rice depends on interaction of various physiological and biological functions in plants. Higher leaf chlorophyll content is the indication of higher photosynthetic efficiency of plants resulting in higher yield (Channappagoudar et al., 2008). Higher yield in weed free plots or different herbicide treated plots may be attributed to their efficiency of weed control resulting in higher photosynthetic capacity as reflected by high SPAD value (Sharma and Singh, 1981). The SPAD meter provides a very easy, swift and non-destructive method for estimating relative leaf chlorophyll content. Higher SPAD values indicate greener and healthier plants. In this study, the SPAD values for the weedy plots were lower than the weed free treatments. It was further noticed that the SPAD value of the herbicide treated plots did not significantly vary from that of weed free plots. Moreover, in some cases the SPAD values of the herbicide treated plots were higher than that of weed free plots indicating healthier plants in the herbicide treated plots. This result suggested that the herbicide application does not create negative impact on leaf chlorophyll content and photosynthesis of rice crop (Sharma and Singh, 1981). The lower SPAD value is associated with high weed interference resulting in yield decrease in aerobic rice (Anwar et al., 2010). In this study, no visual leaf toxicity symptom in rice plant was found in the herbicide treated plots. Pacanoski and Glatkova (2009) also found no visual toxicity symptom in rice leaf with the application of different herbicides such as Bentazone, Propanil, Penoxulam and Bensulfuron-methyl.

Weed index is an ideal parameter to judge the effectiveness of herbicide. This is an indicator of reduction of crop yield due to presence of weeds in comparison with weed free check. The lower weed index indicates higher effectiveness of a herbicide. In both season, the highest effectiveness was found with hand weeding. The performances of different herbicides treatment vary with seasons. The best performance was obtained with T4 (Cyhalofop-butyl + Bensulfuron fb Bentazone/MCPA) followed by T9 (Fenoxaprop-p-ethyl/safener fb Manual weeding) and T8 (Propanil/Benthiocarb fb Bentazone/MCPA) in the dry season while the best performance was noticed with T7 (Pendimethalin fb Cyhalofop-butyl + Bensulfuron fb Bentazone/MCPA) followed by T4 (Propanil/Benthiocarb fb Bentazone/MCPA) and T8 (Pretilachlor + Pendimethalin fb Bentazone/MCPA) in the wet season. This result showed that application of Cyhalofop-buty + Bensulfuron fb Bentazone/MCPA or application of Pendimethalin fb Cyhalofop-buty + Bensulfuron fb Bentazone/MCPA could be considered as the best herbicide treatment. However, an herbicide treatment may give high yield or low weed index but this treatment could be considered as best practice if it showed best economic efficiency or highest net benefit. The weed index in the unweeded plots for off season and main season in this study were 93.51 and 88.54%, respectively. Similar weed index of about 88% was found in unweeded plots in aerobic rice system (Singh et al., 2008). The application of different herbicides improves the yield of rice in aerobic system and in some cases the yields of herbicide treated plots were similar to that of weed free plots. Singh et al. (2008) reported that the application of Cyhalofop-butyl/chlorimuron + Metsulfuron/HW and pretilachlor/chlorimuron + Metsulfuron/HW treatments gave similar yield to that of weed free control plots in aerobic rice system.

The economic analysis in this study showed that any of the herbicide treatment gives higher net return than manual weed free treatments in both seasons. This result indicated that herbicide application is more profitable than manual weeding. In our trial, two weeding was considered requiring 100 labourers for manual weeding ha^{-1}. This is the lowest labourer involvement in weeding operation while literature suggests a minimum of 190 labourers to complete weeding operation ha^{-1}. Therefore, the cost involvement in this study is minimal to that of actual situation. The highest net benefit of RM 1642 ha^{-1} was found with T4 followed by T7 (RM 1473 ha^{-1}) and T8 (RM 1359 ha^{-1}) against the net benefit for manual weeding of RM 473 ha^{-1} in the off-season. The highest net benefit was achieved with T4 (RM 2336 ha^{-1}) followed by T8 (RM 2072 ha^{-1}) and T6 (RM 1935 ha^{-1}) against the net benefit of RM 596 ha^{-1} for the manual weed free treatment in the main season. This result confirmed that manual weeding is costly and uneconomical than herbicide application in the weed control of aerobic rice. A number of reports supported this study and concluded that herbicide application could give significantly higher net benefit than manual weeding in rice (Islam et al., 2000; Hussain et al., 2008). Islam et al. (2000) compared hand weeding with different herbicides and found that Pretilachlor (500 g $ai.ha^{-1}$) was the most successful herbicide with higher yield and cost-benefit ratio. Hussain et al. (2008) found that Nominee 100SC (Bispyribac-sodium) was the best herbicide with higher net benefit than hand weeded control. In their trial, the paddy yield was higher in the hand weeded plots by 0.56 t ha^{-1} than Nominee treated plots but the net benefit was higher with herbicide.

Hand weeding is time consuming, expensive and tedious though much effective. Under the present situation of unavailability of labourers and high wages, manual weed control is not possible. Hence, chemical weed control appears to hold a great promise in dealing with effective, timely and economic weed suppression (Wibawa et al., 2010).

Weed control efficiency cannot be considered as the only criterion to determine the suitability of a herbicide rather cost-effectiveness should also be taken into consideration while making any decision. Generally, the growers prefer an effective herbicide with acceptable cost. The efficacy of herbicides tested in this study was evaluated in term of weed control efficiency (%) and weed index (%). Based on the weed index values and net benefit from economic analysis, it appeared that application of Propanil/Benthiocarb fb Bentazone/MCPA or Cyhalofop-butyl + Bensulfuron fb Bentazone/MCPA or Pendimethalin fb Cyhalofop-butyl + Bensulfuron fb Bentazone/MCPA or Pretilachlor + Pendimethalin fb Bentazone/MCPA could be the possible alternative options for effective and economic weed control as well as avoiding the risk of developing resistant weed biotypes in rice under aerobic system. Manual weeding is not at all cost-effective and therefore, weed management by applying the aforementioned herbicide combinations in rotation may be practiced to run the aerobic rice system as a profitable business venture. However, the yield of the aerobic rice variety used in the trial was very low and therefore, varietal improvement is also necessary for sustaining rice production in aerobic soil conditions.

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