Scientific Research and Essays Vol. 7(1), pp. 12-23, 9 January, 2012
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.362
ISSN 1992-2248 ©2012 Academic Journals

Full Length Research Paper

Response of weed flora to different herbicides in aerobic rice system

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Accepted 19 December, 2011

Weed is the major limitation to the adoption of aerobic rice system, the most potential water saving rice production technology. Herbicide is the appropriate tool to address this problem but suitable herbicide or their combination in controlling the predominant weed flora in this system is not established. The present study was conducted to evaluate the response of weed flora in the aerobic rice field to the sequential application of a single, proprietary or tank mixed herbicides in dry season 2008 and wet season 2008 to 2009. Results revealed that different weed species responded variably to herbicides tested. In the present study, the most dominant weeds were: *Eleusine indica*, *Digitaria ascendense*, *Echinochloa colonum* and *Cyperus iria*. The most effective control of weed flora was obtained by Pretilachlor fb Bentazon/MCPA, Cyhalofob-butyl + Bensulfuron fb Bentazon/MCPA, Pendimethalin fb Bentazon/MCPA, Propanil/Benthiocarb fb Bentazon/MCPA, and Pretilachlor / Pendimethalin fb Bentazon/MCPA. The study concludes that the combinations of herbicides dryer broader spectrum of weed control and the herbicide selection should be based on the target weed species in addition to their broader category of grass, sedge and broadleaf for planning an effective weed control program for aerobic rice.

Key words: Herbicide combination, weed abundance, weed control, sedge, grass, broadleaf weeds, dry seeded rice.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population (FAO, 2004). The crop is wetly grown under flooded irrigated conditions for better establishment and easy weed control. However, sustainability of water resources has been of major concern (Juraimi et al., 2010) and declining water availability threatens the sustainability of traditional flood-irrigated rice ecosystem (Anwar et al., 2010). In Asia, it is predicted that 17 million hactar of irrigated rice areas may enjoy "physical water scarcity" and 22 million ha areas may subject to "economic water scarcity" by 2025 (Bouman and Tuong, 2001).Therefore, it is no longer feasible to flood rice field to ensure better crop establishment and control weeds as well (Johnson and Mortimer, 2005).

Research efforts have so far been concentrated on development of water saving technologies for the last few decades to sustain rice production. Aerobic rice system has been evolved as the most promising water saving technology in rice culture wherein the crop is established via direct seeding in non-puddled and non-flooded fields (Mahajan et al., 2009; Anwar et al., 2010). Rice

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cultivation using this system can save about 50 to 60% irrigation water and increase the water productivity by around 200% (Bouman et al., 2002, Wang et al., 2002) as compared to lowland flooded system. Apart from less water requirement, aerobic rice demands fewer labors (since direct seeded) and capital input (Singh et al., 2008) which in turn minimizes production cost to a great extent (Mann et al., 2007). Thus, aerobic rice system has huge potential as a water-wise technology but its adoption has been impeded by serious weed problem. In aerobic rice system, the dry-tillage practices and aerobic soil conditions are highly conducive for germination and growth of weeds which results in higher weed pressure coupled with greater grain yield losses compared to flooded rice (Balasubranmanian and Hill, 2002; Mahajan et al., 2009; Rao et al., 2007). Therefore, developing a sustainable weed management approach has been a challenge for widespread adoption of aerobic rice technology.

Hand weeding is very easy and environment-friendly but tedious and highly labor intensive. Farmers very often fail to remove weeds due to unavailability of labor at peak periods. Moreover, morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. Considering all these situations, herbicide is being considered as the most practical, effective and economical means of weed management in rice (De Datta, 1981). Despite some adverse environmental impacts, no viable alternative is presently available to shift the herbicide dependence for weed management in rice.

Application of some pre-emergence herbicides including pedimethalin, butachlor, thiobencarb, oxadiazon, oxyfluorfen and nitrofen were found to provide a fair degree of weed control in wet direct seeded rice (Pellerin and Webster, 2004). But, application duration of all those pre-emergence herbicides is very narrow, usually 0 to 5 days of seeding, and they require adequate moisture during their application. Therefore, under aerobic soil conditions post-emergence herbicides may perform better (Mahajan et al., 2009). Among the post emergence herbicides ethoxysulfuron cyhalofop-butyl, pritilachlor, chlorimuron, metsulfuron, bispyribac sodium, penoxsulam effectively controlled weeds in aerobic rice (Mann et al, 2007; Singh et al., 2008; Mahajan et al., 2009; Juraimi et al, 2010). The repeated use of same herbicide causes development herbicide resistance in weeds (Kim, 1996) and therefore, alternate application of herbicides with different modes of action would necessarily be needed to combat this troublesome situation. Application of different herbicides as proprietary or tank mixture could help to prevent resistance problem as well as shift in weed population, which is always associated with the use of a single herbicide (Wrubel and Gressel, 1994). Kim and Im (2002) reported that bensulfuron-methyl is active against broad-leaf weeds but application of bensulfuron-methyl mixed with 2, 4-D increased the spectrum of weed control. On the other hand, Damalas et al. (2006) reported that single application of penoxulum gave 94% control of both *Echinochloa oryzoides* and *Echinochloa phyllopogon* but mixture of penoxulum with bentazon, azimsulfuron or MCPA resulted in reduced control of *E. phyllopogon* in rice. Therefore, the knowledge on synergistic and antagonistic behavior of herbicides is essential.

The weed flora composition and their abundance in aerobic rice differ from that of puddled flooded rice system (Mahajan et al., 2009).Information regarding weed flora composition and their response to different herbicides in aerobic rice system is meager. In general, most of the soil applied rice herbicides require moist or even flooded condition for their efficient actions against weeds which is not satisfied under aerobic system. Therefore, the efficacy of herbicides under aerobic soil conditions needs to be evaluated for selecting suitable herbicides towards successful weed management in this system. Generally, most herbicides dryer effective options for selective weed control and a single herbicide cannot control all weeds of the community (Corbelt et al., 2004). The combined application of different herbicides with different mode of action is required for most effective weed management and avoiding development of herbicide resistance. To the best of our knowledge, a very few studies in this line have so far been conducted with aerobic rice. Therefore, the present study was undertaken with a view to evaluating the response of weed flora to a diverse range of herbicides under field conditions for selecting suitable herbicides and their combinations for sustainable weed control in aerobic rice system.

MATERIALS AND METHODS

Site description

Field experiments were conducted at Seberang Perai Station, Penang, Malaysia (N 05°32.760', E 100° 28.079', elevation 17.4 to 18.3 m) of the Malaysian Agricultural Research and Development Institute (MARDI) during the Dry (April - July2008) and Wet (November, 2008 to February, 2009) seasons. The soil belongs to Sogomana series with an 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/100g, respectively. The local climate is tropical with annual average rainfall ranging between 156 to 208 cm and the annual average minimum and maximum temperatures were 25 and 35°C, respectively.

Experimental treatments and design

Eleven herbicides that is, two pre-emergence (Pretilachlor and Pendimethalin), six early post-emergence (Cyhalofop-butyl, Bispyribac-sodium, Propanil, Benthiocarb, Fenoxaprop-p-ethyl and Quinclorac) and three post-emergence (Bensulfuron, Bentazon and MCPA) were included in the tests (Table 1). Eight and nine herbicide treatments were used in the dry season 2008 (Table 2) and Wet season 2008 to 2009 (Table 3) experiments, respectively. The experiments were laid out in randomized complete block

Table 1. List of herbicides used in the experiment with their family and mode of action.

Active ingredient	Chemical family	Mode of action
Pretilachlor (30% w/v)	Chloroacetamide	Inhibitor of synthesis of very long-chain fatty acids
Pendimethalin (34% w/w)	Dinitroaniline	Microtubule assembly inhibitor
Cyhalofop-butyl (10.1% w/w)	Aryloxyphenoxy propionate	Acetyl CoA carboxylase (ACCase) inhibitor
Bensulfuron-methyl (10% w/w)	Sulfonylurea	Acetolactate synthase (ALS) , also called Acetohydroxyacid synthase (AHAS) inhibitor, blocks branched chain amino acid biosynthesis
Bispyribac-sodium (9.7% w/w)	Pyrimidinlthio-benzoate	Acetolactate synthase (ALS) inhibitor, also called Acetohydroxyacid synthase (AHAS) inhibitor, blocks branched chain amino acid biosynthesis
Propanil (20% w/w)	Amide	Photosynthesis inhibitor at Photosystem II
Benthiocarb (40% w/w)	Thiocarbamate	Inhibitor of lipid synthesis
Fenoxaprop-p-ethyl (6.7% w/w) /safener	Aryloxyphenoxy propionate	Acetyl CoA carboxylase (ACCase) inhibitor
Quinclorac (50% w/w)	Quinaline carboxylic acid	Cell wall biosynthesis inhibitor
Bentazon (37.9% w/w) /	Benzothiadiazole	Photosynthesis inhibitor at photosystem II
MCPA (6.2% w/w)	Phenoxy	Synthetic auxins

design with four replications. The herbicides were applied as single application, tank mixes and sequential application at the recommended rates using 250 L of water per ha by the handheld sprayer.

Crop husbandry

Aerobic rice germplasm AERON 1, developed by International Rice Research Institute (IRRI), the Philippines, was used as the plant material in the study. AERON stands for Aerobic Rice Observation Nursery. Seeds were collected from Malaysian Agriculture Research and Development Institute (MARDI). Rice seeds were spot sown in the plots of 5 m × 5 m in 25 cm apart rows with 20 cm intra-row spacing. 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. 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 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 wettain soil moisture at field capacity level, when needed. Pesticide (TREBON) and fungicide (SCORE) were used to control leaf folder and leaf blast respectively, whenever necessary.

Data collection

A 50 × 50 cm quadrat was used for measuring weeds density and dry weight at 30, 60 and 75 days after sowing (DAS). The quadrate was placed in four randomly selected spots in each plot and all the weeds were collected. The weeds were identified, counted species-wise and biomass was weighed after drying at 70°C for 72 h in electric oven. Absolute density of each species (no. m^{-2}) was recorded. The weed control was estimated as the percentage of weeds that were killed by any particular treatment in comparison with untreated control (Pacanoski and Glatkova, 2009). The dominant weed species were determined based on the sum dominance ratio (SDR) values expressed as a percentage, 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,

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

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

Statistical analysis

Data analysis was done using SAS statistical software package version 9.1 (SAS, 2003) for analysis of variance (ANOVA) and significant differences among the treatment means tested Fisher’s protected Least Significant Difference (LSD) test at $p \leq 0.05$.

RESULTS

Weed abundance

The weedy check plots were infested by 14 and

Table 2. Herbicide treatments in dry season 2008 experiment.

Label	Treatments	Rate (kg a.i. ha^{-1})	Time of application (DAS)
T1	Pretilachlor fb. Bentazon/MCPA	0.5 fb. 0.6/0.1	1 fb. 43
T2	Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.1 + 0.06 fb. 0.6/0.1	10 fb. 43
T3	Bispyribac-sodium fb. Bentazon/MCPA	0.03 fb 0.6/0.1	10 fb. 43
T4	Propanil / Benthiocarb fb. Bentazon/MCPA	1.2/2.4 fb 0.6/0.1	10 fb. 43
T5	Pendimethalin fb. Bentazon/MCPA	1 fb. 0.6/0.1	1 fb. 43
T6	Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA	0.06 fb. 0.6/0.1	10 fb. 43
T7	Quinclorac fb. Bentazon/MCPA	0.25 fb. 0.6/0.1	10 fb. 43
T8	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.

Table 3. Herbicide treatments in Wet season 2008-2009 experiment.

Label	Treatments	Rate (kg a.i. ha^{-1})	Time of application (DAS)
T1	Pretilachlor fb. Bentazon/MCPA	0.5 fb. 0.6/0.1	1 fb. 43
T2	Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.1 + 0.06 fb. 0.6/0.1	10 fb. 43
T3	Bispyribac-sodium fb. Bentazon/MCPA	0.03 fb 0.6/0.1	10 fb. 43
T4	Propanil / Benthiocarb fb. Bentazon/MCPA	1.2/2.4 fb 0.6/0.1	10 fb. 43
T5	Pendimethalin fb. Bentazon/MCPA	1.0 fb. 0.6/0.1	1 fb. 43
T6	Pretilachlor fb. Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	0.5 fb. 0.1 + 0.06 fb 0.6/0.1	1 fb. 30 fb. 43
T7	Pretilachlor + Pendimethalin fb. Bentazon/MCPA	0.375/0.75 fb. 0.6/0.1	1 fb. 43
T8	Pendimethalin fb. Cyhalofop-butyl + Bensulfuron fb. Bentazon/MCPA	1.0 fb. 0.1 + 0.06 fb. 0.6/0.1	1 fb. 30 fb. 43
T9	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.

19 weed species in the dry season and wet season, respectively.

A total of 21 weed species were found to be infesting the aerobic rice field representing 9 families; 7 from Poaceae, 4 from Cyperaceae, 3 from Rubiaceae, 2 from Fabaceae, and 1 from each of Amaranthaceae, Asteraceae, Capparaceae, Onagraceae and Sterculiaceae (Table 4). Among the weed flora 7 were grasses, 4 were sedges and 10 were broadleaved. The dry season crop was infested with 4 grass weeds, 2 sedge weeds and 8 broad leaf weeds while wet season crop was infested by 7 grass weeds, 4 sedge weeds and 8 broadleaf weeds (Table 4). Among these 21 weeds, five (*Calopogonium mucunoides, Cyperus pilosus, Mimosa invisa, Panicum repense and Paspalam conjugatum)* are perennial and the rest 16 are annual weeds. Based on summed dominance ratio (SDR), in both the seasons, *E. indica* was the most dominant weed species followed by *Digitaria ascandens* at all the sampling dates except for 75 DAS in the dry season where *D. ascandens* was more dominant than *E. indica* (Table 4).

In the dry season, the third most dominant weeds were *Echinochloa colona* (SDR 7.12%), *C. mucunoides* (SDR 8.36%) and *M. invisa* (SDR 20.90%) respectively at 30 DAS, 60 DAS and 75 DAS. On the other hand, in the wet season, *Cyperus iria* (SDR 12.37%) was the third dominant weed at 30 DAS while *E. colona* occupied the position both 60 DAS (SDR 22.01%) and 75 DAS (16.12%). The result showed that the other dominant weeds next to the two most dominant weeds (*E. indica* and *D. ascendens*) were: *C. iria*, *E. colonum*, *M. invisia*, *C. mucunoides and Fimbrystylis miliceae*. The rank position of these five weed species varied with seasons and growth stages of the crop. For example, *E. colona* was more dominant than *C. iria* at 30 DAS in the dry season while *M. invisa* and *C. mucunoides* were abundant in wet season. *E. colonum* was dominant at 30 DAS but it was not at all present at 60 and 75 DAS in the dry season. This situation was just reverse in the wet season. *C. iria* was less abundant in the dry season but highly abundant in the wet season (Table 4).

Grass weeds contributed to 84.69, 83.04 and 55.32% of the total weed population of 294, 112 and 47 weeds m^{-2} at 30, 60 and 75 DAS, respectively in the dry season.

The contribution in the wet season was 75.91, 85.54

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 dry season 2008 and wet season 2008 to 2009.

Weed species	Dry season 2008			Wet season 2008-2009			Weed type	Family
	30 DAS	60 DAS	75 DAS	30 DAS	60 DAS	75 DAS		
Eleusine indica (L.) gaertn.	56.81	56.66	24.46	66.12	46.96	46.16	Grass	Poaceae
Digitaria ascendens (H.B.R. Henr.)	25.75	20.06	27.56	11.63	13.30	23.47	Grass	Poaceae
Cyperus iria L.	3.03	5.20	-	12.37	7.45	3.28	Sedge	Cyperaceae
Echinochloa colona (L.) Link	7.12	-	-	3.52	22.01	16.12	Grass	Poaceae
Mimosa invisa Mart.	3.85	7.01	21.90	0.38	0.38	2.71	Broadleaf	Fabaceae
Calopogonium mucunoides Desv.	2.09	8.36	6.95	-	-	-	Broadleaf	Fabaceae
Fimbristylis miliacea (L.) Vahl	-	-	-	4.80	2.10	1.82	Sedge	Cyperaceae
Cyperus pilosus Vahl.	0.07	0.54	3.96		-	1.13	Sedge	Cyperaceae
Dactyloctenium aegyptium (L.) Beauv.	-	1.20	3.39		0.93	1.45	Grass	Poaceae
Panicum repens L.	-	-	-		0.16	0.60	Grass	Poaceae
Cleome rutidosperma DC.	-	0.96	-	0.39	0.38		Broadleaf	Capparaceae
Cyperus compressus L.	-	-	-	0.16	-		Sedge	Cyperaceae
Paspalum conjugatum (L.) Berg	-	-	-	0.05	-	0.13	Grass	Poaceae
Leptochloa chinensis (L.) Nees	-	-	-		3.96	2.29	Grass	Poaceae
Melochia corchorifolia L.	0.26	-	2.96	0.11	0.05		Broadleaf	Sterculiaceae
Borreria laevis (Lam.) Griseb	-	-	-	0.22	0.53	0.38	Broadleaf	Rubiaceae
Oldenlandia dichotoma Hook f.	-	-	-	0.11	0.06		Broadleaf	Rubiaceae
Ludwigia hyssopifolia (G. Don) Excell	-	-	2.49	0.07	0.25		Grass	Onagraceae
Hedyotis corymbosa (L.) Lam.	-	-	2.72	0.05	-	0.19	Broadleaf	Rubiaceae
Ageratum conyzoides L.	0.20	-	2.61		-	0.13	Broadleaf	Asteraceae
Amaranthus spinosus L.	0.47	-	1.00		-		Broadleaf	Amaranthaceae

and 90.87% of the total weed population of 465, 332 and 263 weeds m^{-2} at 30, 60 and 75 DAS, respectively. It was noted that the density of broad leaf weeds was higher than sedges in the dry season but that was reverse in the wet season (Figure 1).

In both the seasons, the highest absolute density was found with *E. indica* occupying 44.90, 58.04 and 27.66% of the total weed population at 30, 60 and 75 DAS, respectively in the dry season and 59.78, 42.46 and 44.11%, respectively in the wet season. The next highest density was found with *D. ascendens* comprising 31.63, 24.11 and 23.40%, respectively at 30, 60 and 75 DAS in the dry season and11.18, 14.16 and 27.38%, respectively in the Wet season (Figure 2). The density of *E. colona* was lower than *D. ascendens* at all the dates of observation in both the seasons except at 60 DAS in the Wet season (Figure 2). The present study revealed the most infesting weeds species in the aerobic rice field were: three grass weeds (*E. indica*, *D. ascendens*, *E. colona*), two sedge weeds (*C. iria* and *F. milliaceae),* and two broadleaf weeds (*M. invisa* and *C. mucunoides)*.

Weed control

Weed flora responded differently to herbicide treatments at all the sampling dates (30, 60 and 75 DAS) in both the seasons. In the Dry season, the lowest weed densities of 40 and 21 weeds m^{-2}were registered at 30 and 60 DAS with T2 (Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA), while at 75 DAS, the lowest one (11 weeds m^{-2}) was found with T5 (Pendimethalin fb Bentazon/MAPA). In the Wet season, the lowest total weed density at 30 DAS was found with T1 (Pretilachlor fb Bentazon/MAPA) while at 60 and 75 DAS, T8 (Pendimethalin fb Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA) allowed least weed density (80 and 80 weeds/m^2, respectively). It was found that the weed density reduced significantly for all herbicide treatments at 30 DAS in both the seasons. Although, all the herbicide treatments reduced weed density at 60 and 75 DAS in the Wet season, the significant reduction was only caused by Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA and Propanil/Benthiocarb fb Bentazon/MAPA at 60 DAS and only for Pendimehalin fb Bentazon/MAPA at 75 DAS (Table 5 and 6).

In the dry season, at 30 DAS, more than 80% weed reduction was provided by T1 (Pretilachlor fb Bentazon/MAPA) and T2 (Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA), more than 60% weed was controlled by T3 (Bispyribac-sodium fb Bentazon/MAPA), T4 (Propanil/Benthiocarb fb Bentazon/MAPA) and T5 (Pendimehalin fb Bentazon/MAPA) treatments while other treatments controlled less than 50% weed. On the contrary, in the Wet season, T1 (Pretilachlor fb Bentazon/MAPA) gave more than 80% control, T2

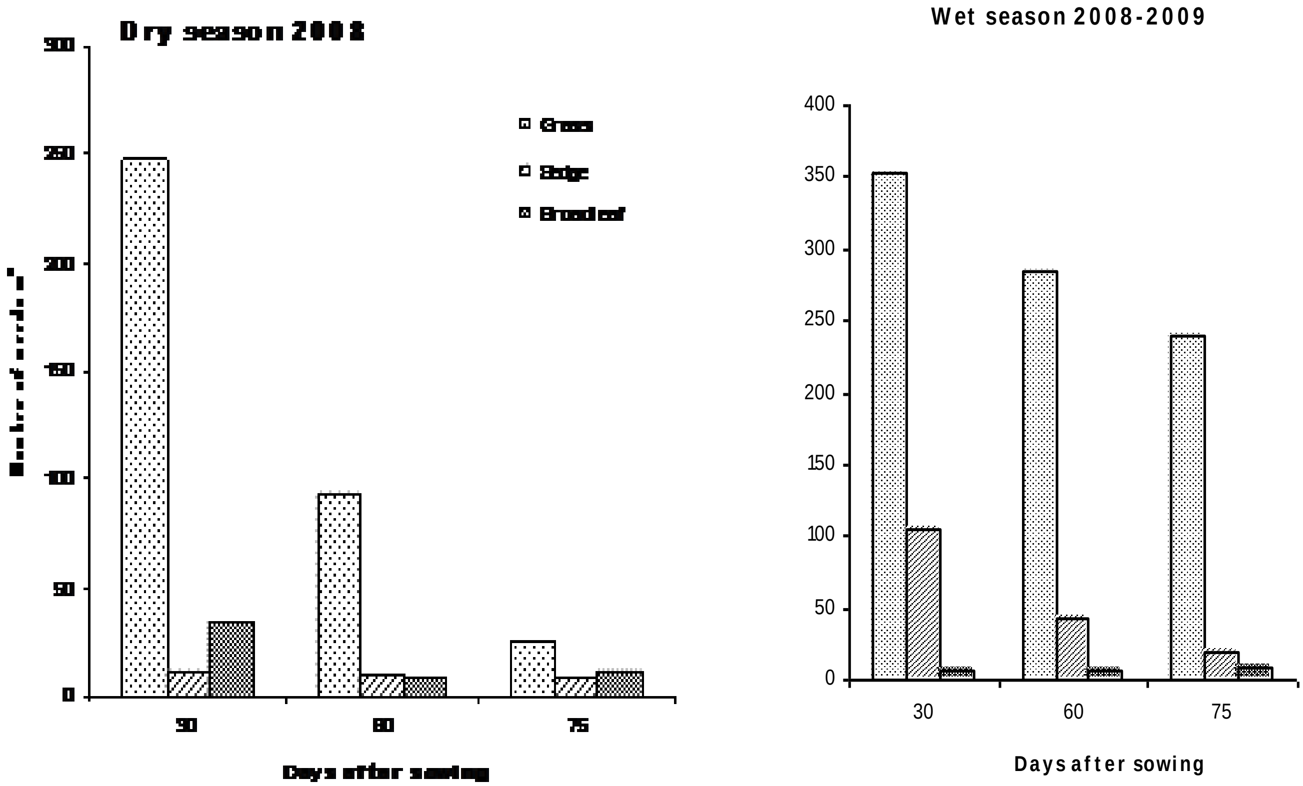

Figure 1. Absolute density of grass, sedge and broadleaf weeds in unweeded aerobic rice field at 30, 60 and 75 days after sowing in dry season 2008 and wet season 2008 to 2009.

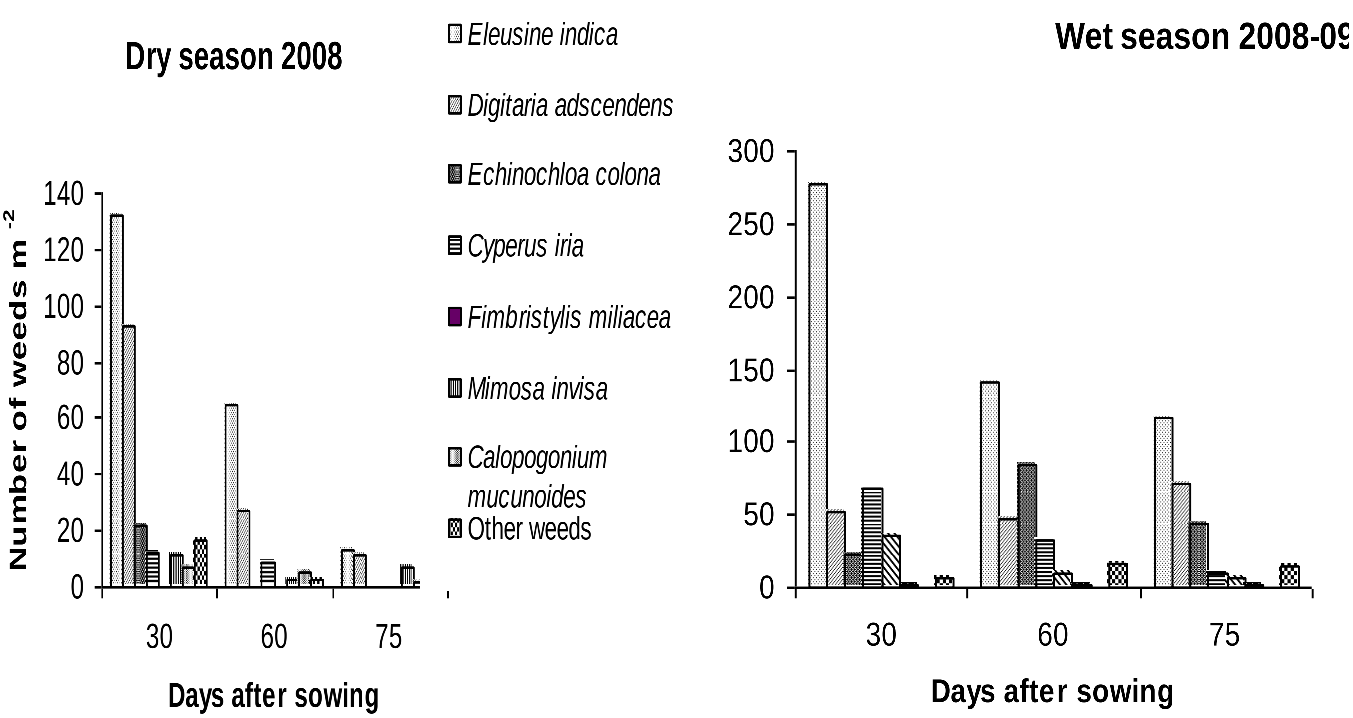

Figure 2. Absolute density of different major weeds in unweeded aerobic rice field at 30, 60 and 75 days after sowing in dry season 2008 and wet season 2008 to 2009.

Table 5. Effect of herbicide treatment on weed density (no. m^{-2}) and weed control (%) in aerobic rice field at 30, 60 and 75 DAS in dry season 2008.

Treatment	30 DAS				60 DAS				75 DAS			
	GR	SG	BL	Total	GR	SG	BL	Total	GR	SG	BL	Total
T1	26 (89.52)	1 (91.67)	24 (29.41)	51 (82.65)	38 (58.82)	0 (100.00)	20 (-125.5)	58 (47.59)	31 (-19.23)	1 (88.89)	4 (66.66)	36 (23.40)
T2	41 (83.47)	0 (100.00)	10 (70.59)	40 (86.39)	12 (86.77)	0 (100.00)	9 (3.33)	21 (81.25)	10 (60.38)	2 (77.78)	5 (58.33)	17 (63.82)
T3	82 (66.94)	0 (100.00)	0 (100.00)	82 (72.11)	85 (8.60)	2 (83.00)	11 (-25.56)	98 (12.50)	42 (-62.69)	2 (77.78)	1 (91.67)	45 (4.26)
T4	22 (91.13)	0 (100.00)	44 (-29.41)	66 (77.55)	28 (70.21)	1 (90.00)	1 (92.22)	29 (73.84)	18 (30.77)	0 (100.0)	1 (91.67)	19 (59.57)
T5	44 (82.26)	22 (-83.33)	50 (-47.06)	116 (60.54)	16 (82.47)	37 (273.0)	14 (-55.56)	67 (39.55)	4 (10.62)	0 (100.0)	7 (41.67)	11 (76.59)
T6	14 (94.35)	71 (-491.7)	75 (-120.41)	150 (48.98)	0 (100.00)	81 (-723.0)	30 (-303.3)	111 (-5.98)	0 (100.00)	21 (-133.3)	27 (-125.0)	48 (-2.12)
T7	142 (42.74)	23 (-91.67)	22 (35.29)	188 (36.05)	73 (21.51)	12 (-20.0	3 (66.67)	88 (21.48)	66 (-153.8)	0 (100.0)	3 (75.00)	69 (-46.8)
T8	248	12	34	294	93	10	9	112	26	9	12	47
Sing.level	***	***	*	***	**	ns	***	**	**	*	**	*
LSD	59.89	26.12	38.58	68.99	49.75	41.60	12.46	52.48	30.12	12.32	12.16	35.53

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 = Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA, T6 = Quinclorac fb. Bentazon/MCPA. T7 = Pendimethalin fb. Bentazon/MCPA, T8 = Weedy check, GR = Grass, SG = Sedge, BL = Broadleaf, Figures in parenthesis indicate % weed control over weedy check.

Table 6. Effect of herbicide treatment on weed density (no. m^{-2}) in aerobic rice field at 30, 60 and 75 DAS in wet season 2008 to 2009.

Treatment	30 DAS				60 DAS				75 DAS			
	GR	SG	BL	Total	GR	SG	BL	Total	GR	SG	BL	Total
T1	79 (77.62)	1 (99.05)	2 (71.43)	82 (82.37)	156 (45.07)	0 (100.0)	4 (33.33)	160 (52.80)	123 (48.54)	3 (84.21)	2 (60.0)	128 (51.33)
T2	134 (62.04)	3 (97.15)	1 (85.71)	138 (70.32)	172 (39.44)	1 (97.62)	1 (83.33)	174 (50.14)	103 (56.90)	3 (84.21)	0 (100.0)	106 (59.32)
T3	314 (11.05)	0 (100.0)	0 (100.0)	314 (32.26)	199 (29.93)	0 (100.0)	0 (100.0)	199 (41.30)	149 (37.53)	0 (100.0)	0 (100.0)	149 (43.34)
T4	106 (69.97)	6 (94.05)	0 (100.0)	112 (75.70)	102 (64.08)	2 (95.23)	1 (83.33)	105 (69.32)	109 (54.39)	3 (84.21)	1 (80.0)	113 (57.03)
T5	94 (73.37)	35 (66.67)	2 (71.42)	131 (72.04)	114 (59.86)	17 (59.52)	3 (50.00)	134 (60.47)	119 (50.21)	6 (68.42)	2 (60.0)	127 (51.71)
T6	166 (52.97)	3 (97.43)	1 (85.71)	170 (63.23)	147 (48.24)	2 (95.23)	2 (66.66)	151 (55.16)	146 (38.91)	2 (89.47)	2 (60.0)	150 (42.97)
T7	132 (62.61)	15 (86.19)	3 (57.14)	150 (67.96)	72 (74.65)	7 (83.33)	2 (66.66)	81 (76.40)	72 (69.46)	9 (52.63)	1 (80.0)	82 (68.82)
T8	99 (71.95)	7 (93.33)	0 (100.0)	106 (77.00)	99 (65.14)	1 (97.62)	3 (50.00)	103 (68.44)	84 (64.85)	0 (100.0)	1 (80.0)	85 (67.68)
T9	353	105	7	465	284	42	6	332	239	19	5	263
Sing.level	**	**	*	**	**	**	*	***	*	*	*	**
LSD	145.44	48.537	3.29	164.48	85.007	21.143	3.3718	89.124	79.546	9.856	2.419	82.952

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 and T9 = Weedy check GR = Grass, SG = Sedge, BL = Broadleaf, Figures in parenthesis indicate % weed control over weedy check.

(Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA), T4 (Propanil/Benthiocarb fb Bentazon/MAPA), T5 (Pendimehalin fb Bentazon/MAPA) and T7 (Pretilachlor+ Pendimehalin fb Bentazon/MAPA) provided more than 70% weed control while T3 (Bispyribac-sodium fb Bentazon/MAPA) executed only 32% weed control at 30 DAS. At 60 DAS, T2 (Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA) exhibited 81% control and T4 (Propanil/Benthiocarb fb Bentazon/MAPA) showed 74% control while other treatments gave less than 50% weed control. Fenoxaprop-p-ethyl fb Bentazon/MAPA failed to control any weed as recorded at 60 DAS in the Dry season. In the Wet season, T8 (Pendimethalin fb Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA) provided more than 76% control. On the other hand, T4 (Propanil/Benthiocarb fb Bentazon/MAPA), T5 (Pendimehalin fb Bentazon/MAPA) or T7 (Pretilachlor+ Pendimehalin fb Bentazon/MAPA) exhibited more than 60% control but other treatments showed less than 50% control. In the Dry season at 75 DAS, it was found that T5 (Pendimehalin fb Bentazon/MAPA) showed more than 75% control but T2 (Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA) or T4 (Propanil/Benthiocarb fb Bentazon/MAPA) gave about 60% control while other treatments provided very poor control of weeds (Table 5). In the wet season, the highest control of about 68% was found in T8 (Pendimethalin fb Cyhalfop-butyl + Bensulfuron fb Bentazon/MAPA) and T7 (Pretilachlor + Pendimehalin fb Bentazon/MAPA) but other treatments showed 43 to 59% weed control (Table 6).

The evaluation regarding the response of different weed groups like grasses, sedges and broadleaved to herbicide treatments revealed very important information. In the Dry season, at 30 DAS, treatment T4 and T5 controlled more than 90%, T1, T2 and T7 more than 80% and T3 and T6 about 67 and 43% of grass weeds. T2, T3 and T4 showed 100%, T1 showed more than 90% control of sedge weeds but T5, T6 and T7 did not render any control of sedge weeds. T3, T2, T6 and T1 exhibited 100, 71, 35 and 29% control of broad leaf weeds, respectively. No broadleaf weed was controlled by T4, T5 and T7 treatments (Table 5). In the dry season, at 60 DAS, 100% grass weed was controlled by T5, more than 80% byT2 and T7while very poor control by other treatments. It was also found that 100% control of sedge weed was done by T1 and T2 at 60 DAS but no control was found with T5, T6 and T7 treatments (Table 5). In the Wet season, more than 80% sedge and broad leaf weed control was evident with all the treatments at 30, 60 and 75 DAS except for T5 and T6. Very poor grass weed control was found with T3 and T6 while others gave very reasonable control to grass weeds at all the dates of observation (Table 6).

A further enquiry in to species wise weed killing effect of different herbicide treatments revealed that the effect of grass herbicide to all grass species is not similar. For example, in the dry season, T6 and T3 were not very effective against *E. indica* but were highly lethal against *E. colona* and *Dactylectonium aescandens*. On the other hand, T1 and T2 provided almost 100% control to *E. indica* leaving *D. ascendens* uncontrolled (Tables 7 and 8). T3 and T6 were very effective against *E. colona* and *D. ascendens* but showed very poor performance against *E. indica.* T7 was highly effective against *E. indica* and *D. ascendens* but not against *E. colona*. All the herbicide treatments showed very good control to *C. iria* and *F. miliceae* except T5, T6 and T7. *M. invisa* was completely controlled by T2 and T3 but not at all by T5 and T7. In the wet season, all the treatments gave fair control of *E. indica* except T3. On the other hand, T3 provide about 100% control to *D. ascendens* and *E. colona*. A fair control of *D. ascendens* was found with T5 and T3 while other treatments failed to control the same weed. T2, T3, T4 and T8 gave effective control of *E. colona* at 30 DAS but their effect varied remarkably at 60 and 75 DAS. On the contrary, T3 and T7 provided excellent control of *E. colona* at 60 and 75 DAS. All the herbicide treatments showed excellent control of *C. iria* and *F. miliceae* at all the dates of observation in the dry season except T5 for *C. iria. M. invisa* was effectively controlled by all the herbicide treatments in the dry season except for T1, T5 and T7 (Table 7).

DISCUSSION

Weed density as well as species diversity were higher in the Wet season than the Dry season. This might be related to the soil moisture differences in between the seasons. The Wet season in Malaysia is characterized by frequent rainfall which might have caused saturation condition of the field in most of the time. These alternate wetting and drying situation encouraged the development of more weeds compared with the dry season crop (Juraimi et al., 2009, 2010). Weed species responded differently to changing water regimes and therefore, the soil moisture regime is the major factor influencing weed flora composition (Drost and Moody, 1982).

In both the seasons, grass weed comprised the majority of the weed community contributing about 74 and 84%, respectively for dry season and wet seasons. In the dry season, broadleaf weed was higher than the sedges while reverse occurred in the wet season. *E. indica*, *D. adscendens* and *E. colona* were the dominant grass weeds, *C. iria* and *F. miliceae* were dominant sedge weeds while *Mimosa invisa* was the only abundant broad leaf weed in the present aerobic rice field. The weed composition in the experimental field was far different from that found in the same location under wet direct seeded condition by Juraimi et al. (2010). They reported that *F. milliceae*, *Ludwigia hyssopifolia*, *Leptochloa chinensis* and *Echinochloa crus-galli* were the dominant weeds. They also reported that the weed composition and abundance varied between the seasons which corroborate our observations. However, the weed

Table 7. Effect of different herbicide treatments on absolute density of weeds (no. m^{-2}) in aerobic rice field during dry season 2008.

Treatment	¥EI			DA			EC			CI			FM			MI		
	30	60	75	30	60	75	30	60	75	30	60	75	30	60	75	30	60	75
T1	7	0	4	17	10	1	2	4	12	1	0	1	0	0	0	6	11	2
T2	0	0	0	41	2	4	0	3	0	0	0	0	0	0	0	0	0	0
T3	75	81	22	7	0	4	0	1	1	0	0	1	0	0	1	0	0	0
T4	0	0	6	0	21	4	22	7	0	0	0	0	0	0	0	8	0	0
T5	15	5	2	6	6	3	23	5	1	13	31	1	2	6	0	12	3	1
T6	1	0	0	0	0	1	3	0	0	37	33	1	35	49	21	18	3	3
T7	117	64	45	26	3	7	0	0	0	21	0	1	2	12	0	2	0	1
T8	132	65	13	93	27	11	22	0	0	12	9	0	0	0	0	11	3	7

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 = Fenoxaprop-p-ethyl/safener fb. Bentazon/MCPA, T7 = Quinclorac fb. Bentazon/MCPA, T8 = Weedy check ¥ EI = *Eleusine indica*, DA = *Digitaria scandense*, EC= *Echinochloa colona*, CI= *Cyperus iria*, FM= *Fimbrystylis miliceae*, MI= *Mimosa invisa.*

Table 8. Effect of different herbicide treatments on absolute density of weeds (no. m^{-2}) in aerobic rice field during wet season 2008 to 2009.

Treatment	EI			DA			EC			CI			FM			MI		
	30	60	75	30	60	75	30	60	75	30	60	75	30	60	75	30	60	75
T1	36	87	84	35	29	26	8	40	8	1	1	1	0	0	0	1	2	1
T2	67	53	41	67	60	22	0	18	13	3	1	3	0	0	0	0	0	0
T3	313	189	141	1	0	2	0	0	2	0	0	0	0	0	0	0	0	0
T4	64	46	76	41	22	15	0	5	15	8	2	2	0	0	0	1	1	0
T5	78	71	75	2	15	11	13	28	26	30	9	3	5	1	3	1	1	1
T6	86	55	54	31	42	56	48	40	29	0	2	2	1	0	0	1	1	1
T7	94	49	39	12	19	23	19	3	3	14	5	6	1	1	2	1	1	1
T8	73	43	46	25	29	29	1	26	9	5	4	0	2	1	0	1	1	1
T9	278	141	116	52	47	72	23	84	43	68	32	9	36	10	6	1	1	1

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 and T9 = Weedy check¥ EI = *Eleusine indica*, DA = *Digitaria scandense*, EC= *Echinochloa colona*, CI= *Cyperus iria*, FM= *Fimbrystylis miliceae*, MI= *Mimosa invisa*

flora found in the present study hardly similar to those obtained in their study. The differential weed flora composition and their abundance suggest that weed control strategy in aerobic rice system should be different from other rice systems.

There was variation in weed control in different herbicide combinations. Among the seven combinations in the dry season, treatment T6 and T7 showed very poor performance. T6 (Fenoxaprop-p-ethyl fb Bentazone/MCPA) was efficient against grass weed (>95% weed killed) but not effective against sedges and broadleaf weeds. On the other hand, T7 gave very poor control to all the weeds in these three groups. Fenoxaprop is a selective herbicide against grass weeds in rice (Jordan, 1995; Zhang et al., 2005). MCPA is a selective herbicide for broadleaf weeds while Bentazon is effective against broadleaf and sedges (Mallory-Smith and Retziner Jr., 2003). Sedge and broadleaf weeds were not controlled by Bentazon/MCPA when applied after Fenoxaprop, although, it was supposed to control it. These two herbicides (Bentazon and MCPA) were available as commercial product Basagran M60 (a proprietary mixture) and were applied at 43 DAS. It controlled sedge and broadleaf weeds effectively in most of the treatments in both the seasons but failed to control them in T6 plots. This might be due to the age of the weeds indicating that the herbicide may not be effective against older weeds at the recommended dose.

T7 (Quinclorac fb Bentazon/MCPA) exhibited moderate control on grass weeds (43 and 36% at 30 and 60 DAS) and fair to good control of broadleaf weed (35, 67 and 73% at 30, 60 and 75 DAS, respectively) but no control of sedge weeds at 30 and 60 DAS. However, this treatment combination showed no grass weed control at 75 DAS. Quinclorac is a selective auxin herbicide used in rice to control monocot and dicot weeds, particularly *E. crusgalli*. Application of quinclorac induces ACC (1-aminocyclopropane-1-carboxylic acid) synthase activity, which promotes ethylene biosynthesis in susceptible dicotyledons. This increased level of ethylene triggers abscisic acid (ABA) accumulation that causes growth inhibition and senescence of target plants. The mechanism of weed killing by quinclorac in grass is different. It stimulates tissue cyanide accumulation in sensitive grasses and the accumulated cyanide causes phytotoxicity characterized by root and shoot growth inhibition and tissue chlorosis and necrosis. Quinclorac is not selective to sedges and therefore, it did not control the sedge weeds. Although it is selective for broadleaf and grass weeds, the performance differs with target species. A close look to the effect of quinclorac to different grass weeds showed that it gave 100 and 72% control of *E. colona* and *D. ascendense* respectively but only 11% control of *E. indica*, the most dominant weed. Basagran controlled broadleaf weed effectively (67%) at 60 DAS but not the sedges at that stage. It was expected that Basagran would control sedges but it did not probably due to that aged sedges are not sensitive to Bentazon at the recommended dose (Vidotto et al., 2007).

Pretilachlor fb Bentazon/MCPA and Cyhalofop-butyl + Bensulfuron fb Bentazon/MCPA provided similar weed control effect in both the seasons. Pretilachlor and Cyhalofop-butyl +Bensulfuron gave similar control on grass and sedges in both the seasons at 30 DAS. However, tank mix application of Cyhalofop-butyl and Bensulfuron was more efficient in controlling broadleaf weeds than single pretilachlor. Basagran M60 (Bentazon/MCPA) application as post herbicide after Cyhalofop-butyl + Bensulfuron application also provided higher degree of grass and broadleaf weed control at 60 and 75 DAS compared with the application of Basagran after pretilachlor. Thus it appears that combined application of Cyhalofop-butyl + Bensulfuron is more effective than single application of pretilachlor in controlling weeds in aerobic rice. Cyhalofop-butyl provides post-emergence control of selected grass weeds by inhibiting acetyl coenzyme-A carboxylase (ACCase) which is responsible for the biosynthesis of fatty acids in selected grass species. This blockage of fatty acid production results in the loss of lipids and eventually death of the dividing cells in the growing point or tip of the grass. Since this site of action is exclusive to certain grasses, it does not provide control of broadleaf weeds. On the other hand, Bensulfuron is a highly selective herbicide used in rice to control sedge and broadleaf weeds. Thus the expected control of grass, sedge and broadleaf weed was achieved from the tank mixed application of these two herbicides.

Application of Pendimethalin fb Bentazon/MCPA, Propanil/Benthiocarb fb Bentazon/MCPA and Bispyribac sodium fb.Bentazon/MCPA showed very good weed control at 30 DAS in both the seasons. Since the follow up application of Bentazon/MCPA was done at 43 DAS, the effect on weed control was solely because of base herbicide application. The performance of these three pre-emergence or early post-emergence herbicides could be ranked as: pendimethalin> propanil/benthiocarb> Bispyribac sodium. Bispyribac sodium gave control similar to other two herbicides in the Dry season but its performance in the Wet season was relatively poor. Bispyribac sodium gave poor control to *E. indica* in both the seasons. Pendimethalin was highly effective in controlling *E. indica* and *D. ascendens* but failed to control of *E. colona*. On the other hand, Propanil /benthiocarb provided very good control to all these three weed species. Propanil is selective for grass weeds, especially for barnyard grass (*E. crus-galli*) and it does not provide residual weed control (Ntanos et al., 2000). Repeated use of Propanil may be helpful in reducing weed density but repeated application of the same herbicide may develop propanil-resistant biotypes of the target weeds (Giannopolitis and Vassiliou, 1989). Therefore, thiobencarb is mixed with it to provide residual weed control when applied post emergence (POST) with propanil (Crowford and Jordan, 1995). The follow up application of Bentazon/MCPA after these three basal herbicides showed that the weed control by Bnetazon/MCPA depends on the efficacy of the pre-emergence or early post-emergence herbicide applied and therefore, the performance registered at 60 and 75 DAS could be ranked as: Propanil/benthiocarb>Pendimethalin>Bispyribac sodium.

Juraimi et al. (2010) found that sequential application of propanil/benthiocarb fb Bentazon/MCPA and penoxsulam

+ benthiocarb fb Bentazon/MCPA provided 100% control of all grasses, sedges and broadleaf weeds in direct wet seeded rice. The dominant weed species were *E. crus-galli*, *Leptochloa chinensis* and *F. miliceae*. They also found that the application of tank mixtures of two or more herbicides followed by sequential application of Bentazon/MCPA provided a broader spectrum of weed control compared with their single or tank mixed application. Singh et al. (2008) reported that Pretilachlor/chlorimuron + metsulfuron provided more weed control than Cyhalofop-butyl/chlorimuron + metsulfuron application in rice under aerobic system where the performance of Cyhalofop-butyl/chlorimuron + metsulfuron was similar to Cyhalofop-butyl/ 2, 4-D. The efficacy of different herbicides such as bisypribac sodium, cyhalofop-butyl, molinate, propanil and quinclorac in controlling *Echinochloa spp* varied due to variation in tolerance or resistance to herbicides of *Echinochloa* population (Fischer et al., 1993). Pacanoski and Glatkova (2009) reported that Stam F-34 + Bentazon (Propanil + bentazon), Mefenacet 53 WP (Mefenacet + Bensulfuron-methyl), Rainbow (Penoxulam) and Gulliver+Trend (Azimsulfuron + adjuvant) all provided excellent control of *E. crus-galli, Cyperus rotundus* and *Heteranthera limosa* when applied to direct wet seeded rice at tillering stage.

Mahajan et al. (2009) reported that post-emergence application of bispyribac sodium was more efficient in weed control than pendimethalin or pretilachlor. In our experiment, the performance of pendimethalin was higher than bispyribac sodium. This difference may attribute to difference in the abundant weed species. *Euphorbia hirta*, *Eclipta alba*, *Digitaria sanguinalis* and *Trianthema portulacastrum* were the major weeds in their research field while *E. indica*, *D. ascendense, E. colona*, *C. iria* were the major weeds in our case. The present study showed that bispyribac sodium is highly ineffective to control *E. indica*, the major weed in the present research field. Pretilachlor is a pre emergence selective herbicide used to control of barnyard grass, psrandletop, nutgrass, duck tongue weed in rice. Pendimethalin is a selective herbicide used in rice to control most annual grasses and certain broadleaf weeds. On the other hand, bispyribac sodium is a systemically active post-emergence broad spectrum herbicide used in rice to kill annual grasses, sedges and broadleaf weeds. It controls weeds by inhibiting the acetolactate synthase (ALS) enzyme that is, blocking of branched chain amino acid biosynthesis. The field must be irrigated after 1 to 3 days of application to get desired weed control. Pretilachlor fb.Cyhalofop-butyl + Bensulfuron and Pendimethalin fb. Cyhalofop-butyl + Bensulfuron increased the spectrum of weed control because of diversified weed control mechanism. However, Pretilachlor/Pendimethalin tank mixed application gave more control than Pretilachlor fb. Cyhalofop-butyl + Bensulfuron and Pendimethalin fb.Cyhalofop-butyl + Bensulfuron. Moreover, Pretilachlor/Pendimethalin tank mixed will reduce the application cost because it is applied in one occasion while other combinations are applied twice.

Conclusion

Response of weed flora differs with herbicides because different herbicides work based on their site-specific mode of action. Therefore, application of a single herbicide can't provide good weed control. Proprietary mixture or tank mixture of herbicides with different modes of actions appeared to be more effective than their single application. The effect of post-emergence herbicides also depends on the performance of pre-emergence or early post-emergence herbicides applied before it. Therefore, selection of herbicide to control weed is a very important task. Further research on the synergistic and antagonistic effects of different herbicide mixture on crop and weed as well as on the environment needs to be assessed before final recommendation.

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