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Critical Period of Weed Competition in Direct Seeded Rice Under Saturated and Flooded Conditions

Abdul Shukor Juraimi[1*], M.Y. Mohamad Najib[2], M. Begum[3], A.R. Anuar[4], M. Azmi[2] and A. Puteh[4]

[1]Department of Crop Science, [4]Department of Land Management,
Faculty of Agriculture, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor, Malaysia
[3]Institute of Tropical Agriculture, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor, Malaysia
[2]Malaysian Agriculture Research and Development Institute,
MARDI Seberang Perai, Peti Surat 203,
13200 Kepala Batas, Pulau Pinang, Malaysia
[*]E-mail: ashukor@agri.upm.edu.my

ABSTRACT

Field experiment was conducted at the Malaysian Agriculture Research and Development Institute (MARDI) station, Seberang Perai, Penang in off-season 2005 and main season 2005/2006, to determine the critical period of weed competition in saturated and flooded conditions. The experiment consisted of different seasons, namely weed free and no weeding periods. Sum Dominance Ratio showed that the weed compositions were different in the saturated condition, as compared to the flooded condition for both seasons. The dominance ranking of weed groups in the off- season in 2005 in saturated condition was sedges, followed by grasses and broadleaved, while during the main season of 2005/2006, grassy weeds were the most dominant, followed by sedges and broadleaved weeds. In the flooded condition, the dominance rankings of weed groups (such as broadleaved>grass>sedges) were the same in both seasons. The number of tillers, along with rice grains yield, was significantly affected by the weed competition in both saturated and flooded conditions. Yield loss due to weed competition was higher in the saturated condition (54.5%) than in the flooded condition (35.2%). Based on the 5% level of yield loss, the critical period in the off-season of 2005 was between 2 – 71 days, after sowing (DAS) in saturated condition, and 15 – 73 DAS in flooded condition. Meanwhile in the main season of 2005/2006, the critical period was between 0 – 72 DAS in the saturated condition and 2 – 98 DAS in the flooded condition.

Keywords: Rice-weed competition, weed control, minimal water condition

INTRODUCTION

Global climatic change, either directly or indirectly, induces changes in land use (Kathiresan, 2005). Scarcity and growing competition for fresh water resources also reduce its availability for irrigation and rice cultivation will be affected by this phenomenon. Weed has always been a “perennial problem” in rice fields in Malaysia. Weed emergence in relation to crop emergence is an important factor in weed-crop competition. Weeds which emerge along with crop plants have an adverse effect

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[*]Corresponding Author

on the crop yields. A crop loss due to weed competition varies with the duration of weed infestation of the crop. The crop is likely to experience yield reduction, unless weeds are kept free during a part of its growing period (Azmi *et al*., 2007). Weed interference and yield losses in direct seeded rice was 55% (Ampong Nyarko and De Datta, 1991) and uncontrolled *Fimbristylis miliacea* alone reduced grain yields by 42% (Begum, 2006). The optimum time, at which crop must be free of the adverse effect of weeds, is referred to as the critical period of weed competition. Almost all the annual crops are susceptible to weed competition during the early stage of development, particularly within the first one-third to one-half of the crop life cycle (Mercado, 1979). The critical period of weed competition represents the time interval (overlap) between the two separate components: (i) the length of time crop must be free of weed after planting so that later-emerging weeds do not reduce yield, and (ii) the length of time weeds which emerge with the crop can remain before they begin to interfere with crop growth (Ghosheh *et al*., 1996; Hall *et al.,* 1992). Thus, weed control during this period is necessary to avoid considerable reduction in crop yield (Weaver, 1984). This may be accomplished by removing weed at the beginning of the critical period or keeping the crop weed-free until the end of the critical period (Woolley *et al*., 1993). Begum *et al*. (2008) observed that based on the predicted logistic and gompertz curves, the critical period for controlling of rice weed *F. miliacea* in direct seeded rice was between 14 – 28 DAS. Ghosheh *et al*. (1996) pointed out that long critical periods are indicative of more competitive weeds or less competitive crops. In general, the critical period is one of the important alternative weed management strategies in order to minimize the labour requirement for weeding operations, enhance the efficiency of herbicide use and maximize economic returns. However, determining when the critical period occurs is difficult due to many interacting factors involved, including crop cultivar, weed community, crop management practices and environment (Hartzler, 2008). The critical period of weed interference in direct-seeded rice, under saturated and flooded conditions, are very meager. Thus, this study was carried out to determine the critical period of weed competition in direct-seeded rice under saturated and flooded conditions.

MATERIALS AND METHODS

Two experiments were carried out in two cropping seasons, off season 2005 and main season 2005/2006, at the experimental field in MARDI Seberang Prai Research Station, in Penang. The soil was Sogomana soil series with an average pH 5.0, 1.1% organic matter content and 8.4 Cation Exchange Capacity (CEC). The local climate is tropical with the annual average rainfall ranges between 156 – 208mm. Meanwhile, the minimum and maximum annual temperatures were 25 and 35˚C, respectively. Land preparation was done according to the MARDI Rice Cultivation Manual 2002. Healthy rice seeds of the MR220 variety (150 kg ha^{-1}) were used and drum-seeded to facilitate and avoid crop damage, due to manual hand weeding, and water was applied according to the treatment throughout the growing period. The total required fertilizer was applied at 170 kg N/ha, 80 kg P_2O_5/ha and 150 kg K_2O/ha as urea, Triple super phosphate (TSP) and Muriate of potash (MOP) respectively. The fertilizers were applied at 15, 35, 55 and 75 DAS, in accordance with the split of N as 15%, 35%, 25% and 25%; P_2O_5 70%, 20% and 10%; K_2O 15%, 45%, 30% and 10%. The experiment was established in the split plot design, with four replications. Two water regimes (flooded and saturated) were the main plot, and the times of weed removal were subplots. The weed removal treatments were divided into two components, the weed-free period and weed competition periods (*Fig. 1*). These plots were kept free of weeds by hand weeding for 0, 15, 30, 45, 60 and 75 days, after sowing (DAS) and subsequently weeds were allowed to grow until harvest in weed-free treatment; the weeds were allowed to compete for 0, 15, 30, 45, 60 and 75 DAS, after which

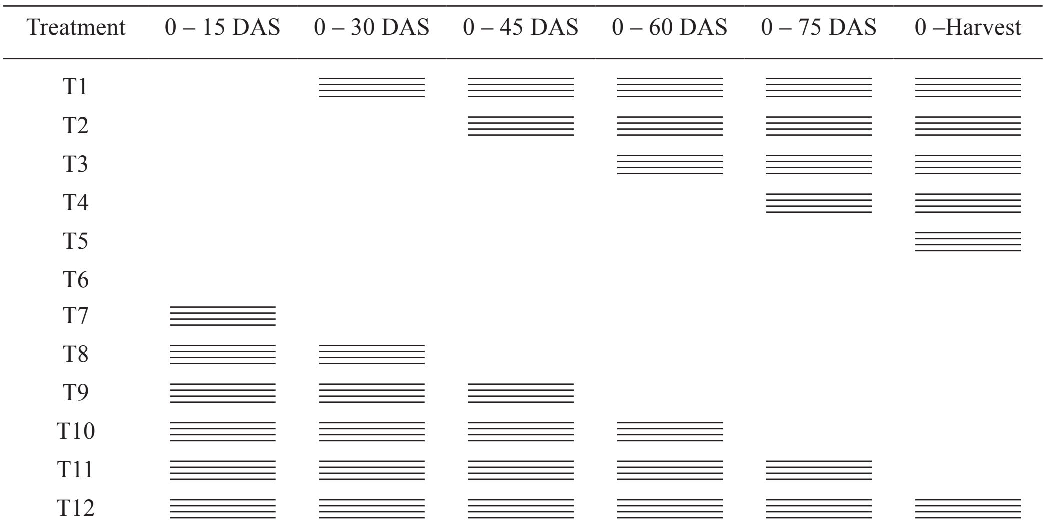
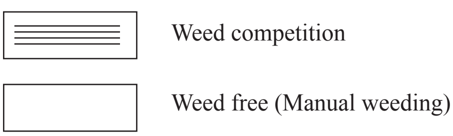


Fig. 1: Time of weed removal treatments in saturated and flooded conditions



the plots were free from the weeds until harvest for the weed competition treatment.

The twelve weed removal treatments (T1 – T12) for both water regimes were as follows:

- T1: Weed-free until 15 DAS
- T2: Weed-free until 30 DAS
- T3: Weed-free until 45 DAS
- T4: Weed-free until 60 DAS
- T5: Weed-free until 75 DAS
- T6: Weed-free from sowing to maturity
- T7: Weedy until 15 DAS
- T8: Weedy until 30 DAS
- T9: Weedy until 45 DAS
- T10: Weedy until 60 DAS
- T11: Weedy until 75 DAS
- T12: Weedy from sowing to maturity

A total of 96 plots were prepared and each plot size was 8m × 7m. These plots were separated by 25 cm width and 25 cm height of levee constructed before seeding. Overflow canals were also constructed to ensure that the saturated condition was maintained throughout the experiment. Water was introduced at 7 DAS, and maintained thereafter in both treatments, less than 2 cm water depth for the saturated condition and 5 – 10 cm water depth in the flooded condition. At 60 DAS, weeds were recorded using 0.5m × 0.5m quadrat according to Kim and Moody (1983) at 30, 60 and 90 DAS. The weeds were separated into different species and dried in an oven for 48 hours at 65°C and dry matter was determined. The tillers of rice were recorded at the day of sampling 30, 60 and 90 DAS, using the same size of quadrat. The yields of rice grain were obtained from the centre of the 5 m × 5 m area of each plot at harvesting 115 DAS and converted to t/ha at 14% moisture.

The summed dominance ratio (SDR) of the weed species was computed using the following equation (Janiya and Moody, 1989):

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

Where,

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

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

The number of tiller and grain yields were subjected to the Analysis of Variance using the Statistical Analysis System (SAS). The means separation was done using the Duncan New Multiple Range Test (DNMRT). The grain yield was analyzed using the non-linear models. The critical weed-free period and the critical time of weed removal were calculated by substituting rice yields, expressed as per cent of control, into the Gompertz and logistic equations, respectively. The yield loss levels of 5 and 10% were chosen arbitrarily (Kiani and Faravani, 2003; Martin *et al.,* 2001; Hall *et al.,* 1992). The equation with the highest co-efficient of determination (r^2) value was judged as the most appropriate (Papamichail *et al.,* 2008).

RESULTS AND DISCUSSION

Weed Composition and Summed Dominance Ratio (SDR)

In saturated condition, the number of weed species was higher (10 species) in the off-season than the main season (*Figs. 2a* and *2b*). Sedges were dominant weeds (6 – 27 % SDR), followed by grasses (8 – 12 % SDR) and broadleaved weeds (2 – 6 % SDR) in the off-season, while in the main season, grasses were among the dominant (4 – 35% SDR), followed by broadleaved weeds (8 – 13 % SDR) and sedges (6% SDR) (*Fig. 2b*). According to Bhagat *et al*. (1996), the composition of rice weed communities is strongly influenced by water management practices. The saturated condition usually favoured germination of sedges and grassy weeds. Tanaka (1976) found that sedges and grasses accounted for more than 90 % of the total dry weight in saturated condition. In addition, Bhagat *et al*. (1999) also reported that the dominance of *Echinochloa* species and *Lepthocloa chinensis* was favoured by the saturated condition. The six most dominant weeds in the saturated condition in the off-season were *Cyperus iria, F. miliacea, Cyperus digitatus, Echinochloa crus-galli, Echinochloa colona* and *L*. chinensis. Weed succession from

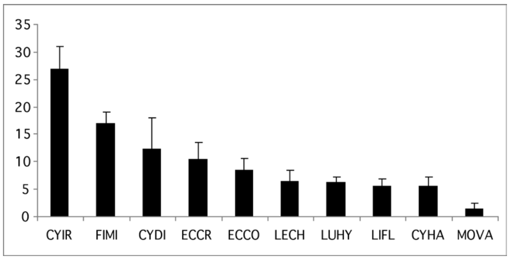


Fig. 2a: Weed dominance ranking (SDR) in off-season 2005 under saturated condition

CYIR = *Cyperus iria,* FIMI = *Fimbristylis miliacea,* CYDI = *Cyperus difformis,* ECCR = *Echinochloa crus-galli,* ECCO = *Echinochloa colona,* LECH = *Leptochloa chinensis,* LUHY = *Ludwigia hysopifolia,* LIFL = *Limnocharis flava,* CYHA = *Cyperus haspan,* MOVA = *Monochoria vaginalis*

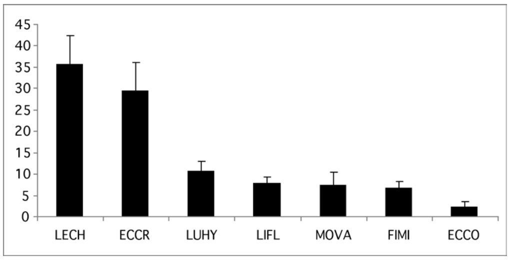


Fig. 2b: Weed dominance ranking (SDR) in main season 2005/06 under saturated condition

LECH = *Leptochloa chinensis,* ECCR = *Echinochloa crus-galli,* LUHY = *Ludwigia hysopifolia,* LIFL = *Limnocharis flava,* MOVA = *Monochoria vaginalis,* FIMI = *Fimbristylis miliacea,* ECCO = *Echinochloa colona* sedges in the off-season to more competitive grassy weed were observed in the main season (*Fig. 2b*), followed by broadleaved weeds and sedges. *Lepthocloa chinensis* and *E. crus-galli* were at the higher rank of dominant in the main season. This succession was due to ability of the weeds to produce more seeds which contribute to additional soil seed bank in the off-season and emerge in the main season. Early raining in the main season had also changed the environment which encouraged weed seeds to germinate better. On the other hand, the composition of the weed flora might differ, depending on the water supply (Bhan, 1983), cultural practices such as tillage, crop establishment technique, irrigation and fertilizer used at various times during the year (Mabbayad *et al.,* 1983).

In flooded condition, broadleaved weeds *Monochoria vaginalis* and *Limnocharis flava* were recorded dominant in both seasons (*Figs. 2c* and *2d*). Tanaka (1976) reported that broadleaved weeds were dominant over grassy and sedges in the flooded condition. At IRRI, De Datta (1981) reported that flooding to a depth of 15 cm from 4 days after seeding to the late dough-ripening stage allowed more broadleaved weeds and suppressed grass and sedge emergence. Kent and Johnson (2001) also observed that the increase in flooding depth and flooding duration encouraged most of the broadleaved weeds.

Number of Tillers and Rice Grain Yield

In the off-season, the numbers of tillers at 30, 60 and 90 DAS were significantly affected by the weeding interval treatments, both in saturated and flooded conditions (Tables 1 and 2). The significant highest number of tillers, at 30 DAS, were recorded from T6 (weed free throughout) in the flooded condition (598 tillers) and saturated condition (549 tillers), respectively. The numbers of tillers were significantly reduced as the weed free periods reduced or as the weed competition periods increased in both the flooded and saturated conditions. The trend is almost the same in the main season, but the numbers of tillers were generally much lesser as compared to the off-season (Tables 3 and 4).

The yield of rice grains was significantly affected by the weeding interval treatments and water regime treatments in both seasons (Tables 1, 2, 3 and 4). Significant higher rice grain yields of 5.4 and 5.2 ton/ha were recorded in the flooded, weed free treatment throughout sowing to maturity (T6) in the off-season and main season, respectively (Tables 1 and 3). This rice grain yield was not significantly different as compared to the rice grain yield of weed free until 30 DAS to 75 DAS, and the weed competition until 15 DAS in the off-season (Table 1) and the weed free until 60 DAS to 75 DAS and the weed competition until

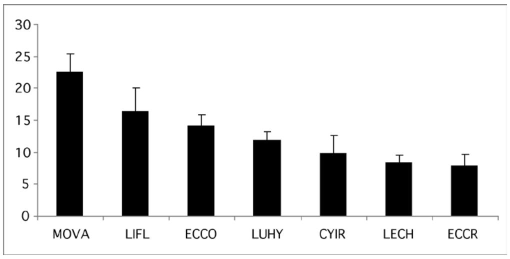


Fig. 2c: Weed dominance ranking (SDR) in off-season 2005 under flooded condition

MOVA = *Monochoria vaginalis,* LIFL = *Limnocharis flava,* ECCO = *Echinochloa colona,* LUHY = *Ludwigia hysopifolia,* CYIR = *Cyperus iria,* LECH = *Leptochloa chinensis,* ECCR = *Echinochloa crus-galli*

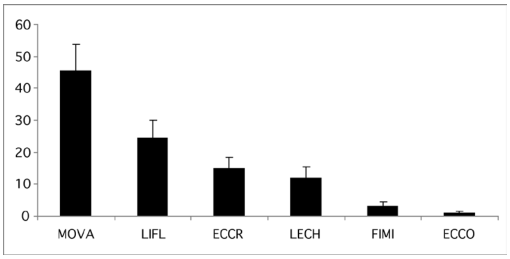


Fig. 2d: Weed dominance ranking (SDR) in main season 2005/06 under flooded condition

MOVA = *Monochoria vaginalis,* LIFL = *Limnocharis flava,* ECCR = *Echinochloa crus-galli,* LECH = *Leptochloa chinensis,* FIMI = *Fimbristylis miliacea,* ECCO = *Echinochloa colona*

TABLE 1
Effect of weeding regime on tiller and grain yield in flooded condition (off-season 2005)

Weed Removal Treatments	Number of tiller/m^2			Grain Yield (t/ha)
	30DAS	60DAS	90DAS	
Weed-free until 15 DAS (T1)	488de	395bc	364bc	4.48bc
Weed-free until 30 DAS (T2)	440fg	407bc	394bc	4.66abc
Weed-free until 45 DAS (T3)	488cde	415abc	385bc	4.76abc
Weed-free until 60 DAS (T4)	511c	433ab	387bc	4.80abc
Weed-free until 75 DAS (T5)	559b	435ab	425b	5.18ab
Weed-free from sowing to maturity (T6)	598a	473a	489a	5.40a
Weedy until 15 DAS (T7)	493cd	394bc	399bc	5.34a
Weedy until 30 DAS (T8)	462ef	432ab	397bc	4.36c
Weedy until 45 DAS (T9)	488cde	400bc	419b	4.36c
Weedy until 60 DAS (T10)	430g	369c	370bc	4.18cd
Weedy until 75 DAS (T11)	471de	397bc	371bc	4.08cd
Weedy from sowing to maturity (T12)	399h	364c	356c	3.50d
R^2	0.934	0.510	0.578	0.649
C.V	3.439	8.893	9.454	10.274
Significant values	0.0001	0.0111	0.0018	0.0001

Means within columns with the same alphabets are not significantly different at P> 0.05

TABLE 2
Effect of weed competition period on the number of tiller and grain yield in saturated condition (off-season 2005)

Weed Removal Treatments	Number of tiller/m^2			Grain Yield (t/ha)
	30DAS	60DAS	90DAS	
Weed-free until 15 DAS (T1)	509bc	345d	343de	2.88d
Weed-free until 30 DAS (T2)	536ab	364d	383bc	3.14bcd
Weed-free until 45 DAS (T3)	485cd	381d	384bc	3.20bcd
Weed-free until 60 DAS (T4)	460de	414bc	373cd	3.32bcd
Weed-free until 75 DAS (T5)	405f	423b	408b	3.52bc
Weed-free from sowing to maturity (T6)	549a	501a	500a	4.40a
Weedy until 15 DAS (T7)	510bc	400bc	374cd	3.56b
Weedy until 30 DAS (T8)	530ab	361d	361cde	3.34bcd
Weedy until 45 DAS (T9)	440e	354d	346de	3.20bcd
Weedy until 60 DAS (T10)	360f	348d	344de	2.92cd
Weedy until 75 DAS (T11)	391f	299e	332ef	2.90cd
Weedy from sowing to maturity (T12)	309g	288e	307f	2.00e
R^2	0.958	0.892	0.889	0.748
C.V	3.848	6.218	5.375	11.832
Significant values	0.0001	0.001	0.0001	0.0001

Means within columns with the same alphabets are not significantly different at P> 0.05

TABLE 3
The effect of weed competition period on the number of tiller and grain yield in flooded condition (main season 2005/2006)

Weed Removal Treatments	Number of tiller/m²			Rice Grain Yield (t/ha)
	30DAS	60DAS	90DAS	
Weed-free until 15 DAS (T1)	280bc	283bc	297b	1.24e
Weed-free until 30 DAS (T2)	280bc	326abc	327ab	2.68bcde
Weed-free until 45 DAS (T3)	355ab	335abc	311b	3.15bdc
Weed-free until 60 DAS (T4)	361ab	339abc	331ab	3.68abc
Weed-free until 75 DAS (T5)	393a	352ab	364a	4.31ab
Weed-free from sowing to maturity (T6)	403a	363a	368a	5.24a
Weedy until 15 DAS (T7)	370ab	352ab	345ab	3.89abc
Weedy until 30 DAS (T8)	381ab	276bc	302b	2.13cde
Weedy until 45 DAS (T9)	319ab	275bc	330ab	1.65de
Weedy until 60 DAS (T10)	290bc	282bc	309b	1.62de
Weedy until 75 DAS (T11)	285bc	280bc	297b	1.50de
Weedy from sowing to maturity (T12)	205c	268c	295b	1.11e
R^2	0.565	0.474	0.469	0.677
C.V	18.587	14.813	9.924	41.793
Significant values	0.0013	0.0205	0.0187	0.0001

Means within columns with the same alphabets are not significantly different at P> 0.05

TABLE 4
Effect of weed competition period on the number of tiller and grain yield in saturated condition (main season 2005/2006)

Weed Removal Treatments	Number of tiller/m²			Grain Yield (t/ha)
	30DAS	60DAS	90DAS	
Weed-free until 15 DAS (T1)	376cd	363bcd	238de	2.18de
Weed-free until 30 DAS (T2)	387bc	363bcd	237de	2.40cd
Weed-free until 45 DAS (T3)	364cd	416ab	278abcd	2.82bc
Weed-free until 60 DAS (T4)	357cd	374bcd	301abc	3.06ab
Weed-free until 75 DAS (T5)	448ab	354bcd	320ab	3.29ab
Weed-free from sowing to maturity (T6)	461a	490a	332a	3.38.3a
Weedy until 15 DAS (T7)	410abc	399abc	311ab	2.37cd
Weedy until 30 DAS (T8)	385c	427ab	303abc	1.74ef
Weedy until 45 DAS (T9)	364cd	297cd	274bdc	1.62fg
Weedy until 60 DAS (T10)	397abc	367bcd	266bcde	1.62fg
Weedy until 75 DAS (T11)	390bc	376bcd	251cde	1.20gf
Weedy from sowing to maturity (T12)	310d	293d	213e	1.15g
R^2	0.572	0.513	0.603	0.871
C.V	10.800	16.705	12.711	15.666
Significant	0.0017	0.0084	0.0004	0.0001

Means within columns with the same alphabets are not significantly different at P> 0.05

15 DAS in main season (Table 3). Thus, weed control during this period is necessary to avoid considerable reduction in the crop yield. The yield of rice grains in the saturated condition was lower as compared to the flooded condition in both seasons. The highest rice grain yields in the saturated condition were only 4.4 and 3.4 ton/ha in the weed-free treatment throughout sowing to maturity (T6) in the off-season and main season, respectively. Mohankumar and Alexander (1989) observed the highest grain yield from the flooding condition as compared to the continuous saturated condition. The results also showed that the weed competition period from sowing to maturity (T12) produced the lowest rice grain yield in the main season (1.1 ton/ha) and the off-season (2.0 ton/ha) at saturated condition. Meanwhile, Becker and Johnson (1999) also found that rice yield was drastically reduced as a consequence of increased weed infestations in the saturated condition.

Critical Period of Weed Competition

The Gompertz and Logistic equation was fitted to determine the critical period of the weed competition. Based on 5% and 10% levels of yield loss, the critical period can be predicted from the weed-free and weed interference duration curves (Norsworthy and Oliveira, 2004). In the off-season, the critical periods of the weed competition in the saturated condition, at 5% and 10% yield losses, were between 2 to 71 DAS and 5 to 52 DAS, respectively (*Fig. 3a*). Meanwhile in the flooded condition, the critical period was predicted between 15 to 73 DAS and 25 to 51 DAS at 5% and 10% yield loss, respectively (*Fig. 3c*). In the main season 2005, the critical periods of the weed competition in the saturated condition, at 5% and 10% yield loss, were between 0 to 72 DAS and 2 to 55 DAS (*Fig. 3b*). In the flooded condition, the critical period was predicted between 2 to 98 DAS and 4 to 84 DAS (*Fig. 3d*). Johnson *et al*. (2004) found that the critical periods of the weed control

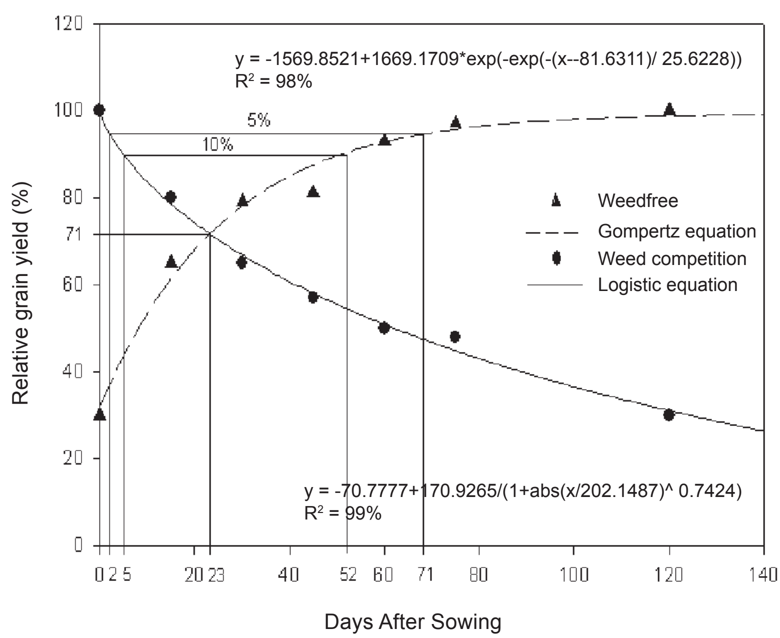


Fig. 3a: Critical period of the weed competition under saturated condition in off-season 2005

to obtain 95% of weed-free yield were estimated to be between 29 to 32 DAS in wet-seeded rice and 4 to 83 DAS in dry-seeded rice.

The result also showed that a critical period of weed competition in the off-season started early and a longer weed-free period was needed in the saturated condition compared to flooded condition, due to the higher weed infestation. Smith and Fox (1973) reported that few or no weed seedlings emerged when the soil was flooded, but at the field capacity, all the weed species emerged readily. The critical period was also observed to be early in the main season (*Fig. 3b* and *Fig. 3d*) as compared to the off-season. To maintain a 95% of rice yield in the main season in the saturated condition, weed control has to be done as early as 0 DAS and needs to be maintained until 72 DAS (Table 5), and the infestation of weeds above certain density at this time will cause a significant yield reduction. In the off-season, weed control must be done on the second day after sowing

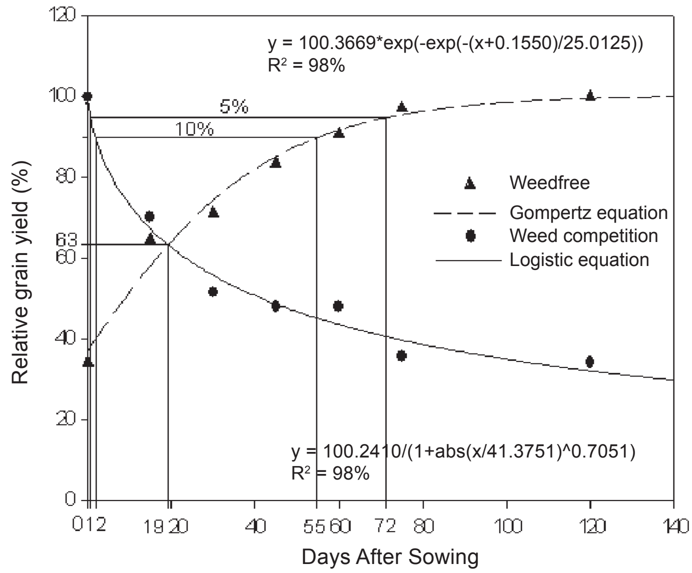


Fig. 3b: Critical period of the weed competition under saturated condition in main season 2005/2006

TABLE 5
The estimated critical periods of weed competition for 5 and 10 % yield losses

Seasons	Water Regimes	Maximum weed infestation period		Minimum weed free period	
		5%	10%	5%	10%
Off-season 2005	Saturated (DAS)	2	5	71	52
	Flooded (DAS)	15	25	73	51
Main season 2005/2006	Saturated (DAS)	0	2	72	55
	Flooded (DAS)	2	4	98	91

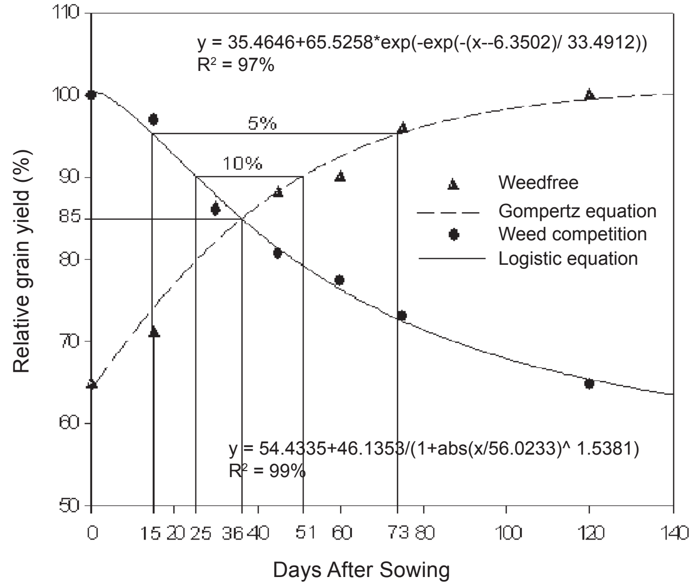


Fig. 3c: Critical period of the weed competition under flooded condition in off-season 2005

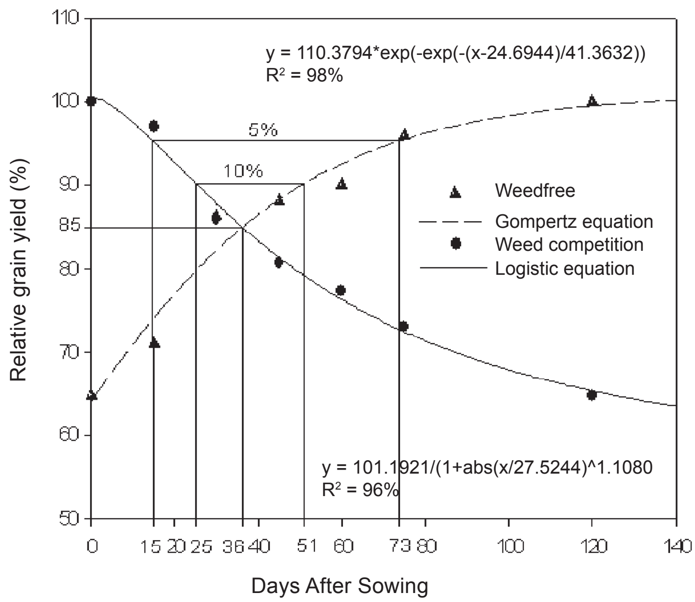


Fig. 3d: Critical period of the weed competition under flooded condition in main season 2005/200

to prevent 5% yield loss and this needs to be maintained until 71 DAS. The success of the weed control operations is dependent on the time of weed seedling emergence, weed species and stage of crop growth. Timely applications of effective herbicide are able to reduce losses when there is an occurrence of targeted weeds (Azmi and Supaad, 1990), optimize herbicides efficacy against weeds and also minimize production cost or protect crops against injury (Baki and Azmi, 1992).

CONCLUSIONS

Weed composition and critical period of weed competition were obviously influenced by water regime treatments in both seasons. In the off-season, the hierarchical dominance of weed group in saturated condition was sedges>grasses>broadleaved weeds, while in the main season, the hierarchical ranking was grasses>sedges>broadleaved weed. In the flooded condition, the dominance ranking was reversed than the saturated condition in both seasons. The reduction in the grain yield, caused by increasing the duration of weed competition, was found to be higher in the saturated condition than in the flooded condition in both seasons. Based on the results gathered in the present study, to prevent 5% yield loss the critical periods in the off-season were 2 – 71 and 15 – 73 DAS in the saturated and flooded condition, respectively; whereas, in the main season, the critical periods were 0 – 72 and 2 – 98 DAS in the saturated and flooded conditions, respectively.

ACKNOWLEDGMENTS

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REFERENCES

Ampong-Nyarko, K. and De Datta, S.K. (1991). *A Handbook for Weed Control in Rice*. International Rice Research Institute, Los Banos, Philippines. p.113.

Azmi, M., Abdul Shukor, J. and Mohamad Najib, M.Y. (2007). Critical period for weedy rice control in direct-seeded rice. *Journal of Tropical Agriculture and Food Science*, *35*(2), 319 – 332.

Azmi, M. and Supaad, M.A. (1990). Rumput sambau-rumpai utama tanaman padi tabur terus di kawasan Muda, Kedah. *Teknologi Padi, 2,* 1 – 6. MARDI, Malaysia.

Baki, B.B. and Azmi, M. (1992). The protocol of herbicide application in direct seeded rice in Peninsular Malaysia. In *Proceedings of the 1st Weed Control Congress* (p. 62 – 65).

Becker, M. and Johnson, D.E. (1999). Rice yield productivity in irrigated systems of the forest zone in Cote d'Ivoire. *Field Crops Research, 60,* 201 – 208.

Begum, M. (2006). Biology and management of *Fimbristylis miliacea* (L.) Vahl. Ph.D Thesis, Universiti Putra Malaysia, Serdang, Malaysia.

Begum, M., Juraimi, A.S., Rajan, A., Syed Omar, S.R. and Azmi, M. (2008). Critical period competition between *Fimbristylis miliacea* (L.) Vahl and rice (MR 220). *Plant Protection Quarterly, 23*(4), 153 – 157.

Bhan, V.M. (1983). Effect of hydrology, soil moisture regime, and fertility management on weed populations and their control in rice. In *Proceedings of the Conference on Weed control in Rice* (p. 47 – 56). IRRI-IWSS. Los Banos, Philippines.

Bhagat, R.M., Bhuiyan, S.I. and Moody, K. (1996). Water, tillage and weed interactions in lowland tropical rice: a review. *Agricultural Water Management, 31,* 165 – 184.

Bhagat, R.M., Bhuiyan, S.I., Moody, K. and Estorninos, L.E. (1999). Effect of water, tillage and herbicides on ecology of weed communities in intensive wet-seeded rice system. *Crop Protection, 18,* 293 – 303.

De Datta, S.K. (1981). *Principles and Practices of Rice Production*. New York: John Wiley & Sons.

Ghosheh, H.Z., Holshouser, D.L. and Chandler, J.M. (1996). The critical period of Johnsongrass

(*Sorghum halepense*) control in field corn (*Zea mays*). *Weed Science, 44,* 944 – 947.

Hall, M.R., Swanton, C.J. and Anderson, G.W. (1992). The critical period of weed competition in grain corn (*Zea mays*). *Weed Science, 40,* 441 – 447.

Hartzler, B. (2008). Critical period of competition. *http://www.weeds.iastate.edu*

Janiya, J.D. and Moody, K. (1989). Weed populations in transplanted ana wet-seeded rice as affected by weed control method. *Tropical Pest Management, 35*(1), 8 – 11.

Johnson, D.E., Wopereis, M.C.S., Mbodj, D., Diallo, S., Powers, S. and Haefele, S.M. (2004). Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. *Field Crops Research, 85,* 31 – 42.

Kathiresan, R.M. (2005). Effect of global warming on weed invasion world wide. In *Proceedings of 20th APWSS conference* (p. 91 – 98). New Delhi, India.

Kent, R.J. and Johnson, D.E. (2001). Influence of flood depth and duration on growth of lowland rice weeds, Cote d'Ivoire. *Crop Protection, 20,* 691 – 694.

Kiani, M.R. and Faravani, M. (2003). Critical period of weed control in direct seeded tomato (*Lycopersicon esculetum*). In *Proceedings of 19th Asian Pacific Weed Science Society Conference* (p. 282 – 287), Manila, Philippines.

Kim, S.C. and Moody, K. (1983). Minimum sampling size and minimum quadrat number for weed data collection in transplanted rice. *Journal of Korean Society of Crop Science, 28*(3), 319 – 322.

Mabbayad, M.O., Pablico, P.P. and Moody, K. (1983). The effect of time and method of land preparation on weed population in rice. In *Proceeding 9th Asian Pacific Weed Science Society Conference* (pp. 357 – 368). Manila, Philippines.

Martin, S.G., Van Acker, R.C. and Friesen. L.F. (2001). Critical period of weed control in spring canola. *Weed Science, 49,* 326 – 333.

Mercado, B.L. (1979). *Introduction of Weed Science*. Southeast Asia regional Center for Graduate Study and Research in Agriculture (SEARCA), College Laguna, Philippines. 292 p.

Mohankumar, B. and Alexander, D. (1989). Influence of water regimes on growth and yields of transplanted rice. *Oryza., 26*(1 – 2), 103 – 105.

Norsworthy, J.K. and Oliveira, M.J. (2004). Comparison of the critical period for weed control in wide- and narrow-row corn. *Weed Science, 52,* 802 – 807.

Papamichail, D., Eleftherohorinos, I., Froud-Williams, R. and Gravanis, F. (2008). Critical period of weed competition in cotton in Greece. *http://www.phytoparasitica.org. Phytoparasitica, 30,* 1.

Smith, Jr., R.J. and Fox, W.T. (1973). Soil water and the growth of rice and weeds. *Weed Science, 21*(1), 59 – 63.

Tanaka, I. (1976). Climatic influence on photosynthesis and respiration of rice plants. Climate and Rice, International Rice Research Institute, Los Banos, Laguna, Philippines.

Weaver, S.E. (1984). Critical period of weed competition in three vegetable crops in relation to management practices. *Weed Research, 24,* 317–325.

Woolley, B.L., Michales, T.E., Hall, M.R. and Swanton, C.J. (1993). The critical period of weed control in white bean (*Phaseolus vulgaris*). *Weed Science, 41,* 180 – 181.