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Impacts of weed competition on plant characters and the critical period of weed control in rice under saline environment

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Abstract

An experiment was conducted in pots at the glasshouse of the Universiti Putra Malaysia during June to November 2011 to determine the critical period of weed-crop competition in transplanted rice under saline condition. One salt tolerant rice variety (MR232) and three salt tolerant weed species (*Ehinochloa colona, Cyperus iria* and *Jussia linifolia)* were studied under three salinity levels. Different durations of weed interference and weed-free period were imposed to understand the impact of time on crop characteristics of rice. Critical periods of weed competition under 5% and 10% loss were determined through Logistic and Gompertz equations. Results revealed that the critical period of crop-weed competition were different under different salinity levels. The rice and weed dry matter, rice plant height, chlorophyll content, leaf area, number of tillers, filled grain, 1000 grain weight and grain yield were reduced with increased crop-weed competition period. Weed dry weight was also increased with prolonged weed competition period. The critical period of crop-weed competition increased with the elevated salinity levels. The critical period for weed competition under 5% yield loss at 0, 4 and 8 dS m^{-1} were 14 to 55, 12 to 64 and 7 to 80 days, respectively. The estimated critical period for rice at 10% yield loss level were 36 to 45, 32 to 48 and 23 to 64 days at 0, 4 and 8 dS m^{-1}, respectively. The present study concludes that more intensive weed management operations in rice are needed under saline than at non-saline environments.

Keywords: Weed management, critical period of weed competition, Logistic and Gompertz equations, Rice.
Abbreviations: CPWC_ritical period of weed control, SPAD_Special Products Analysis Division, DM_Dry Matter, DAT_days after transplant, DAS_days after sowing.

Introduction

Globally weeds are serious pests of rice causing annual yield loss of 9.5% worldwide (Alam, 2003; Rabbani et al, 2011). The annual rice yield loss has been reported as 30–40 in Sri Lanka (Abeysekera, 2001), 30–90 in India (Murkhopadhyay, 1995), 57–61 in Philippines (Mukherjee et al., 2008) and 10–42% in Malaysia (Karim et al, 2004). The yield loss depends on the infesting weed species, their population density and duration of infestation, as well as on the soil conditions including its type, pH value and salinity levels (Evans et al., 2003; Azmi et al., 2007). Weed control in Malaysia is mainly done with herbicide, which is associated with risk of environmental hazards and development of herbicide resistance in weeds. Therefore, sustainable weed management strategies should be adopted for controlling weeds at the proper time in right manner depending on soil condition and weed predominance to avoid environmental hazards as well as economic loss.
An understanding of the critical period of weed control (CPWC) and the factors affecting it are essential for making proper decision on appropriate timing of weed control and efficient use of herbicide (Knezevic et al., 2002). The critical period of weed control is a period in the crop growth cycle, in which weeds must be controlled to prevent economic crop yield loss due to weed competition (Hall et al., 1992; Knezevic et al., 2002). Thus, the CPWC is an important consideration in the development of appropriate weed management strategies (Swanton and Weise, 1991).
The CPWC is determined by calculation of the time interval between two separately measured competition components. The critical duration of weed interference and the maximum length of time before early emerging weeds can grow and interfere with the crop before unacceptable yield loss is incurred. The critical weed-free period, the minimum length of time required for the crop to be maintained weed free before yield loss caused by subsequent emerging weeds is no longer of concern (Knezevic et al., 2002). Consequently, the interference from weeds before or after the CPWC will not result in unacceptable yield reduction. Juraimi et al. (2009) reported that the critical periods of weed competition in rice ranges between 5 and 52 days after sowing (DAS).

Table 1. Effect of weed competition period on some growth and yield parameters of rice (pooled across the 3 salinity levels).

Treatments	Plant height (cm)	leaf area (cm^2 $hill^{-1}$)	Chlorophyll (SPAD value)	Effective tiller $hill^{-1}$	Filled grain $panicle^{-1}$	1000 grain weight (g)
Weed-free until 15 DAT	97.70 e	629.4 f	36.96 fg	3.46 ef	80.78 ef	21.47 bcd
Weed-free until 30 DAT	99.63 de	710.5 e	38.01 c-f	4.26 de	81.66 de	21.85 abc
Weed-free until 45DAT	103.03 cde	793.93 cd	38.35 b-e	4.67 bcd	86.88 bcd	22.18 ab
Weed-free until 60 DAT	105.06 bcd	795.36 cd	38.46 b-e	5.23 ab	89.66 abc	22.25 ab
Weed-free until 75 DAT		822.06 bcd	39.51 ab	5.55 a	90.66 ab	22.35 a
Weed-free check	111.64 a	907.86 a	40.01 a	5.72 a	93.29 a	22.38 a
Weedy until 15 DAT	109.833 ab	869.73 ab	39.49 ab	5.25 ab	87.11 bcd	22.01 abc
Weedy until 30DAT	105.478 a-d	841.26 bc	39.21 abc	5.05 abc	83.44 cde	21.86 abc
Weedy until 45 DAT	102.97 cde	806.8 cd	38.58 bcd	4.71 bcd	81.88 de	21.30 cde
Weedy until 60 DAT	101.48 de	768.83 de	37.78 d-g	4.56 bcd	79.66 efg	20.69 de
Weedy until 75 DAT	99.37 de	730.66 e	37.23 efg	3.91 e	77.32 fg	20.45 ef
Weedy check	99.31 de	643.33 f	36.80 g	2.76 f	66.99 g	20.23 f
F- test	**	**	**	**	**	**
CV (%)	6.38	8.364	4.365	6.532	7.41	3.81

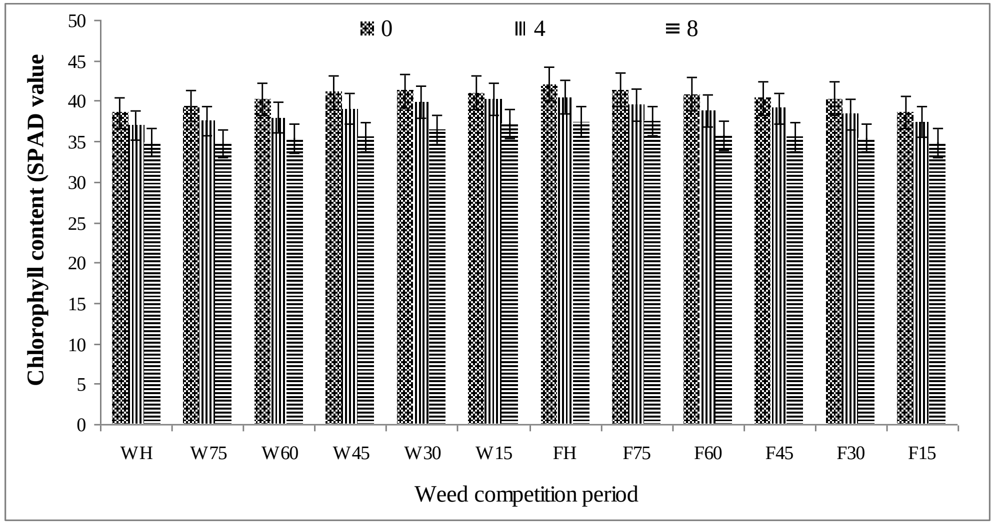


Fig 1. Effect of weed competition period on chlorophyll content of rice plant. (WH=weedy for season-long, W75=weed for 75 DAT, W60=weedy for 60 DAT, W45=weedy for 45 DAT, W30= Weedy for 30 DAT, W15=weedy for 15 DAT, FH=weed free for season-long, F75= weed free for 75 DAT, F60= weed free for 60 DAT, F45= weed free for 45 DAT, F30= weed free for 30 DAT, F15= weed free for 15 DAT).

The critical period for controlling *Fimbrystylis miliacea* in the direct seeded rice was between 14–28 DAS (Begum et al., 2008). However, many interacting factors like crop cultivar, weed species, crop management practices and environment affect the critical period, which have made the determination of CPWC a difficult task (Hartzler, 2008).

The salt affected area in Malaysia and many other countries are increasing due to the rising of sea level because of global climate changes (Kathiresan, 2005; Lund et al., 2006). The rice cultivation may be extended to the coastal saline areas to ensure food security. Rice is less tolerant to salt than many weed species (Kim et al., 1999) and; therefore, the crop will be subjected to more weed pressure under saline environment than the non-saline condition (Murrillo-Amador et al., 2002). Hence, the weed control strategy under saline environments may be different from the non-saline areas. Although much research have been done for understanding the influences of saline habitats on seed germination, growth, reproduction and population dynamics of crop plants (Khan et al., 2002) but report on critical period of weed-crop competition in rice under saline environments has been done yet. Thus, the objectives of the present study were (1) to determine the critical period of weed competitions in rice under saline conditions and also (2) to identify the yield components, which are most affected by the duration of weed interference under different salinity levels.

Results and Discussion

Effect of weed interference period on morpho-physiological parameters under saline condition

Rice plant height

The plant height of rice was significantly influenced by weed competition period, increased the length of weed interference and caused shortest plant but there was no significant adverse effect after 45 DAT in weedy treatments (Table 1). The tallest plants were found in season-long weed-free treatments under non-saline conditions, while the season-long weedy treatments resulted in shortest plants under saline conditions. The second tallest plants were produced in weed-free treatment for 15 days at all the salinity levels (Table 2). In general, the height of rice plants increased with prolonged weed-free conditions and decreased with extended weed infested period. The results are in accordance with the previous research, where the taller rice plants were found in all weed-free treatments (Begum et al., 2008). Azmi (1990) pointed that the plant height of rice decreased when weeds were allowed to compete till 30 DAT and up to harvest. Begum (2006) observed that the plant height of rice significantly reduced when rice plant competed with *F. miliacea* for 70 days or longer. Similarly, Chauhan and Johnson (2010) noted that plant height of rice was significantly reduced by competition with jungle rice (*Echinochloa colona*), and the reduction was increased in higher weed density. McGregor et al. (1988) reported that rice plant height was significantly decreased with weed competition for 40 days or longer. The present study revealed a greater reduction in plant height with weed competition under salinity conditions, which might be due to extra impacts of the salinity stress.

Leaf area

The main effect of weed interference period on leaf area was shown in Table 1. The leaf area of rice was adversely affected by increasing the length of weed interference period and, conversely favourably influenced by the increasing span of weed free period, up to 30 DAT (Table 2). The maximum leaf area was observed in the season-long weed-free treatments with 1185.6 cm^2 $hill^{-1}$, and gradually decreased in all the weedy treatments at 0 dS m^{-1} salinity. A similar trend was observed at 4 and 8 dS m^{-1} saline environments, while the lowest leaf areas were found in the 15 days weed-free treatment in the control and 8 dS m^{-1} salinity, and in the season-long weedy treatments at 4 dS m^{-1} salinity (Table 2).
It was evident that leaf area of rice was affected by weed infestation at all the salinity levels. These results clearly indicate that DM production in rice was decreased with the duration of weed competition. Season long weedy treatment produced lowest rice plant biomass due to a consequence of disturbance in mineral supply, lower water potential and nutrient uptake disturbance by weeds which resulted in reduced growth and lower rice leaf area. The results are in accordance with the findings of Munene et al. (2008) and Estorninos et al., (2002) who observed that the leaf areas were significantly reduced with the duration of weed competition in rice.

Leaf chlorophyll content

The chlorophyll (chl) content (SPAD value) was decreased with increasing the duration of weed interference period (Table1). The maximum chl content (42.10) was observed in the season-long weed-free treatment followed by 75 day weed-free and 30 day weedy treatments (>41) while the minimum chl content was found in the season-long weedy treatments (Fig. 1). At 4 dS m^{-1}, the maximum value was recorded in the season-long weed-free and 15 day weedy treatments with >40, while the minimum value was found in season-long weedy treatments.

At 8 dS m^{-1}, the highest chl was produced in 75 day weed-free treatment followed by the season-long weed-free treatments, while the lowest value was obtained in 75 day weedy treatment followed by 15 day weed-free and 75 day weedy treatments. The other treatments recorded the intermediate values. The results indicated that leaf chl content was reduced in weedy treatments but the reduction trend increased with increasing the duration of weedy period. Chlorophyll is the main pigment of photosynthesis in plants. It is strongly influenced by environmental factors (Qiu et al., 2007). Reduction in chl content under severe weed competition period and also salinity can be attributed to a salt-induced weakening of protein-pigment-lipid complex or increased chlorophyllase enzyme activity (Ghassemi-Golezanie et al., 2012). Reduction in leaf chlorophyll content index due to weed competition and salinity stress may limit photosynthesis and yield. Similar findings were reported by Abdollahian and Williams (2005) who observed a significant reduction in leaf chl content in sugar beet from the competition with *Chenopodium album.* Weeding durations significantly influenced the chl content of cowpea, and chl content became reduced from weed competition (Olorunmaiye, 2010).

Table 2. Interaction effect of weed competition period and salinity levels on plant height and leaf area of rice .

Weed competition period	Plant height (cm)			Leaf area (cm^2 $hill^{-1}$)		
	Salinity levels (dS m^{-1})					
	0	4	8	0	4	8
Weed-free until 15 DAT	105.96 b	99.96 f	88.33 b	858.7 e	663.8 ef	365.7 f
Weed-free until 30 DAT	107.73 b	102.83 ef	89.86 ab	971.2 c-e	744.2 de	416.1 d-f
Weed-free until 45DAT	112.50 ab	106.30 b-e	90.30 ab	1128.7 ab	779.0 cd	474.1 b-d
Weed-free until 60 DAT	113.16 ab	110.33 a-c	91.70 ab	1089.0 a-c	793.2 cd	503.9 a-c
Weed-free until 75 DAT	119.00 ab	111.20 ab	93.66 ab	1107.4 ab	847.4 bc	511.4 a-c
Weed-free check	124.50 a	114.20 a	96.33 a	1185.6 a	975.0 a	563.0 a
Weedy until 15 DAT	124.23 a	108.93 b-d	96.23 a	1138.2 ab	947.8 a	523.2 ab
Weedy until 30DAT	114.26 ab	106.06 c-e	96.10 a	1093.7 a-c	935.5 ab	494.6 a-c
Weedy until 45 DAT	110.76 ab	104.20 d-f	94.20 ab	1125.4 ab	817.0 cd	478.0 b-d
Weedy until 60 DAT	107.80 b	103.96 d-f	92.46 ab	1070.0 a-d	771.2 cd	465.3 b-e
Weedy until 75 DAT	107.10 b	102.36 ef	90.83 ab	1010.2 b-d	739.4 de	442.4 c-e
Weedy check	104.93 b	98.06 f	87.06 b	939.0 de	595.1 f	395.9 ef

Means with the same letter in a column do not differ significantly at P=0.05 (LSD test).

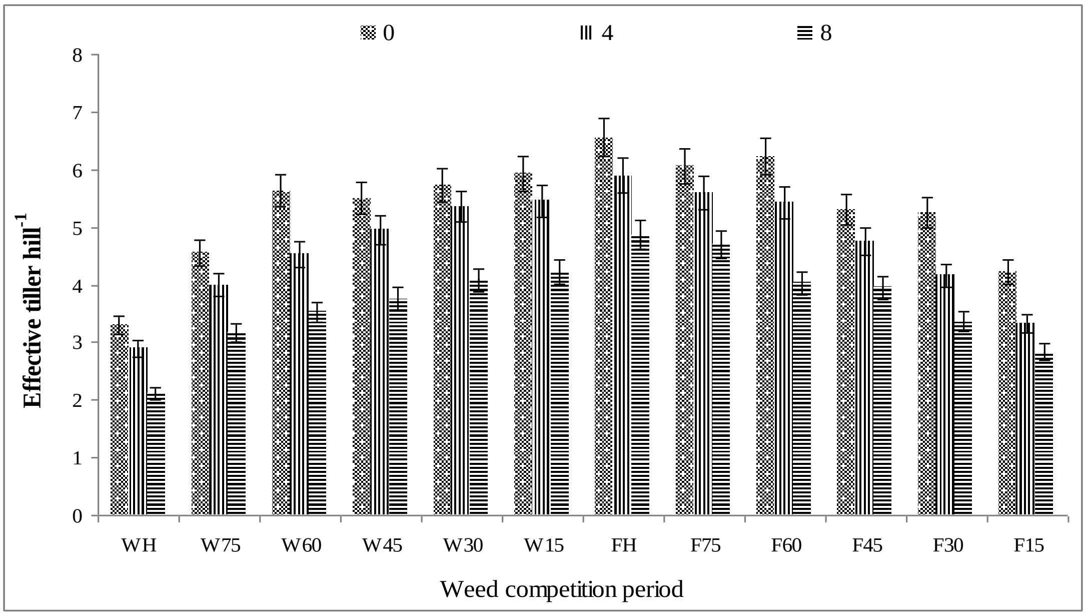


Fig 2. Effect of weed competition period on effective tiller $hill^{-1}$ of rice plant. (WH=weedy for season-long, W75=weed for 75 DAT, W60=weedy for 60 DAT, W45=weedy for 45 DAT, W30= Weedy for 30 DAT, W15=weedy for 15 DAT, FH=weed free for season-long, F75= weed free for 75 DAT, F60= weed free for 60 DAT, F45= weed free for 45 DAT, F30= weed free for 30 DAT, F15= weed free for 15 DAT)

Crop and weed dry matter

Crop and weed dry weight was influenced with increasing the duration of weed interference period in all salinity levels. However, both weed and crop dry matters (DM) decreased at higher salinity levels (Table 1). The highest weed DM was found with season-long weedy pots in all salinity levels. The treatments where weeds were allowed to grow at the early stages (15 DAT) accumulated higher DM than those allowed to grow at the later stages of the crop growth. For example, when the weeds were allowed to grow for 45 days from transplanting, they showed higher DM than those allowed for 45 days after transplanting. The weed DM accumulation for early 45 days were 22.21, 16.51 and 14.09 gm^{-2} at 0, 4 and 8 dS m^{-1}, while those values for late 45 days were 14.54, 12.70 and 9.67 g m^{-2}, respectively. Thus, the result clearly showed that the weed free condition at early crop growth stage is more important than the weed free condition at the later one. The result further indicated that the weeds emerging at the later growth stages offer less competition to crops as it accumulates lower DM (Uremis et al., 2009). The results indicate that the treatments which were recorded the highest weed DM showed the lowest crop DM because the reduction rate of DM was higher in crops than in weeds and; thus, the increase of weed DM decreased the crop DM (Fig. 3).

At harvest, the maximum rice DM (503.6 g m^{-2}) was recorded in season-long weed-free treatments, followed by 15 day weedy treatments. DM was found to be decreased by both weed competition and also salt stress. The lowest DM (136.6 g m^{-2}) was observed in the season-long weedy treatments followed by 75 day weedy treatments at 8 dS m^{-1} with 168.6 g m^{-2}. These results clearly indicate that the DM production in rice decreased due to weed competition as a consequence of disturbance in nutrient supply and distribution, lower water potential which resulted in reduced growth and straw production (Ali and Awan, 2004).

Table 3. Interaction effect of weed competition period and salinity levels on crop and weed dry matter (DM).

Weed competition period	Crop dry matter (g m^{-2})			Weed dry matter (g m^{-2})		
	Salinity levels (dS m^{-1})					
	0	4	8	0	4	8
Weed-free until 15 DAT	450.6 ef	339.0 cd	222.0 bc	25.98 d	19.70 d	16.24 d
Weed-free until 30 DAT	460.0 de	341.6 cd	238.3 ab	22.32 e	17.67 de	13.43 de
Weed-free until 45DAT	470.3 b-e	348.3 cd	249.3 ab	14.54 f	12.70 efg	9.67 f
Weed-free until 60 DAT	473.3 b-d	367.6 bc	255.0 ab	6.76 h	5.31 h	4.25 gh
Weed-free until 75 DAT	482.3 bc	383.0 ab	262.6 ab	4.66 hi	3.41 hi	2.47 h
Weed-free check	503.6 a	397.3 a	277.0 a	0.0 i	0.0 i	0.0 h
Weedy until 15 DAT	492.0 ab	388.6 a	262.6 ab	12.76 g	10.89 g	8.55 fg
Weedy until 30DAT	482.0 bc	374.0 ab	254.6 ab	16.11 f	13.19 fg	11.13 ef
Weedy until 45 DAT	471.0 b-e	347.0 cd	240.0 ab	22.21 e	16.51 def	14.09 de
Weedy until 60 DAT	463.6 c-e	318.3 de	238.3 ab	33.44 c	27.29 c	20.53 c
Weedy until 75 DAT	387.3 d-f	266.6 ef	168.6 cd	53.66 b	43.66 b	32.38 b
Weedy check	319.0 f	217.6 f	136.6 d	70.98 a	55.96 a	44.37 a

Means with the same letter in a column do not differ significantly at P=0.05 (LSD test).

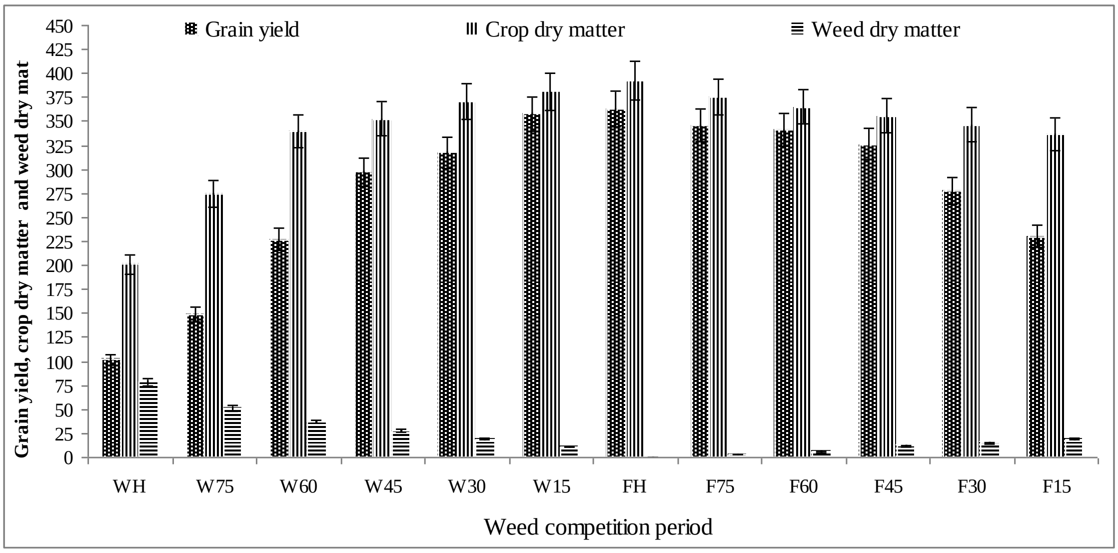


Fig 3. Relationship between rice grain yield, rice crop dry matter and weed dry matter (g m^{-2}) (pooled across the 3 salinity levels). WH=weedy for season-long, W75=weed for 75 DAT, W60=weedy for 60 DAT, W45=weedy for 45 DAT, W30= Weedy for 30 DAT, W15=weedy for 15 DAT, FH=weed free for season-long, F75= weed free for 75 DAT, F60= weed free for 60 DAT, F45= weed free for 45 DAT, F30= weed free for 30 DAT, F15= weed free for 15 DAT).

The weed DM was more in weedy check compared to other weed-free treatments due to weed pressure. However, the rice DM was low due higher weed-crop competition. Biomass accumulation of rice was adversely affected by increasing the length of weed interference period and, conversely (favourably) influenced by the increasing span of weed free period, up to 30 or 45 DAT. At early crop stage, weed may be better competitor than the crop, which is likely due to competitive advantages for the weeds in term of pre-emption of resources. Similar results were also reported by many researchers (Begum et al., 2008; Juraimi et al., 2009; Chauhan and Johnson, 2010) who observed that the rice straw was significantly suppressed by weed interference when the weeds were allowed to grow until certain period.

Effect of weed interference period on rice yield and yield components under saline condition

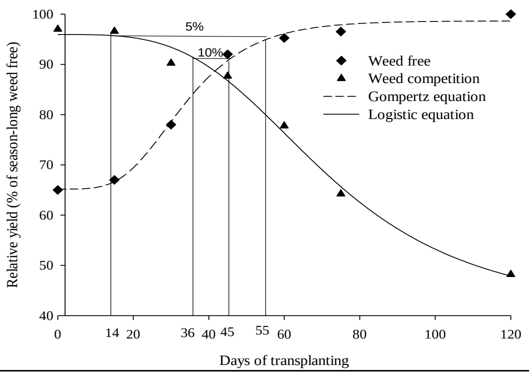
Number of effective tiller hill^{-1}

The tiller number of rice was significantly reduced by the effect of weed competition period. The results revealed that the number of tiller hill^{-1} was significantly higher in weed-free treatments than weedy treatments (Table 1). The highest number of effective tillers (6.23/plant) were produced in 60 day weed-free treatments at zero salinity level while at 4 and 8 dS m^{-1} salinity levels, the highest numbers were noted in the season-long weed-free treatment with 5.80 and 4.27 effective tillers hill^{-1}, respectively (Fig. 2). The lowest number was obtained at 0 dS m^{-1} in the 75 day weedy treatment with 4.96 hill^{-1}, while at 4 and 8 dS m^{-1} the lowest numbers were recorded in season-long weedy treatments with 4.00 and 3.20 effective tillers hill^{-1}, in that order. The result indicated that the effective tillers of rice were adversely affected by increasing the length of weed interference period which might be due to reduce the ability of rice to compete for light and nutrition and increasing the disadvantage of the crop in weed competition (Johnson et al., 1998). The results are in accordance with the findings of Azmi (1990), who argued significant decrease in tiller numbers with weed competition period during 45 DAS to harvest. Juraimi et al (2009) pointed out that the tillers number of rice were significantly affected by the weeding competition period, both in saturated and flooded conditions. Similarly, Begum

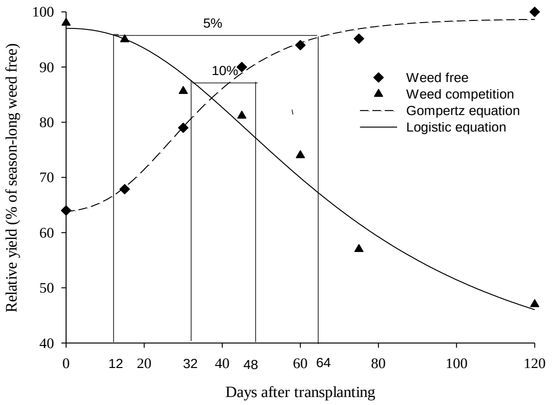
Table 4. Interaction effect of weed competition period and salinity levels on filled grain and 1000 grain weight of rice.

Weed competition period	No. of filled grains panicle^{-1}			1000 grain weight (g)		
	Salinity levels (dS m^{-1})					
	0	4	8	0	4	8
Weed-free until 15 DAT	94.67 ef	89.67 a-c	58.00 cd	22.31 b	21.59 c	20.53 bc
Weed-free until 30 DAT	96.33 de	90.00 a-c	58.66 b-d	22.29 b	22.29 a	20.67 bc
Weed-free until 45DAT	103.66 b	94.33 a-c	62.66 bc	23.23 a	22.21 ab	20.90 abc
Weed-free until 60 DAT	109.00 a	95.66 a-c	64.33 ab	23.48 a	22.28 a	21.05 ab
Weed-free until 75 DAT	103.00 b	99.33 ab	69.66 a	23.15 a	22.56 a	21.34 a
Weed-free check	109.10 a	100.44 a	70.33 a	23.24 a	22.43 a	21.48 a
Weedy until 15 DAT	104.00 b	94.00 a-c	63.33 bc	22.40 b	22.34 a	21.36 a
Weedy until 30DAT	101.00	91.00 a-c	58.33 b-d	22.31 b	21.98 abc	21.01 ab
Weedy until 45 DAT	96.33 de	91.00 a-c	58.33 b-d	21.98 bc	21.64 bc	20.29 cd
Weedy until 60 DAT	97.00 d	88.66 bc	53.33 de	21.87 bc	21.04 cd	19.17 de
Weedy until 75 DAT	91.33 fg	88.00 bc	52.63 de	21.11 d	20.89 cd	19.35 de
Weedy check	83.00 g	78.33 c	39.66 e	21.68 cd	20.33 d	19.04 e

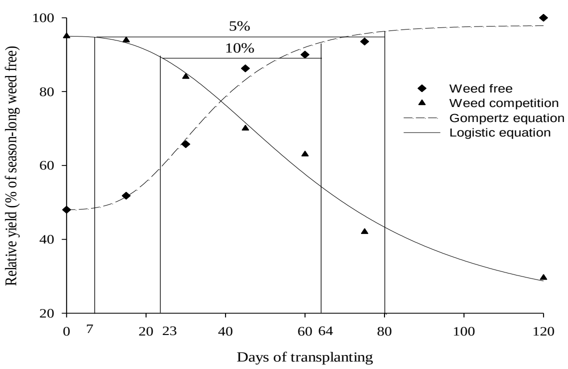
Means with the same letter in a column do not differ significantly at P=0.05 (LSD test).



Gompertz equation, Ry=66.01+32.45*exp(-exp(-(x-29.62)/11.50))
R^2=0.992
Logistic equation, RY=42.66+51.96/(1+abs(x/70.20)^4.05
R^2=0.991



Gompertz equation, RY=50.83+48.75*exp(-exp(-(x-16.24)/21.03))
R^2=0.993
Logistic equation,
RY=39.41+53.85/(1+abs(x/65.53)^3.20
R^2=0.972



Gompertz equation,
RY=46.54+50.02*exp(-exp(-(x-29.38)/14
R^2=0.986
Logistic equation, RY=17.51+77.39/(1+abs(x/61.78)^2.66
R^2=0.982

Fig 4. Influence of weed interference on relative yield of rice under different saline conditions. Increasing duration of weed interference (►) data fitted to the logistic equation; increasing weed-free period (♦) data fitted to the Gompertz equation. The dots and the lines represent observed relative yield and fitted models, respectively.

(2006) found that the number of effective and total tillers decreased with onset of competition from 42 days until the crop harvest.

Number of filled grain panicle^{-1}

The filled grains of rice were significantly influenced by weed competition period under saline conditions. The maximum filled grains were produced in weed-free condition and less number was noted under weedy conditions (Table 1). Weed competition over different durations had significant influences on filled grains panicle^{-1} (Table 4). Under the non-saline conditions, the maximum number of filled grains panicle^{-1} (109.10) was recorded in the season-long weed-free treatment, while the lowest panicles (83.0) were observed in season-long weedy treatments. At 4 dS m^{-1}, the highest filled grains were obtained in the season-long weed-free treatments, but the lowest value was found in the season-long weedy treatments. Similar trend was observed at 8 dS m^{-1} salinity as well. The results suggested that the number of filled grains panicle^{-1} was significantly reduced with weed competition. Najib, (2009) observed that the filled grain panicle^{-1} of rice affected by weed competition period both in saturated and flooded conditions. Similarly, the reductions in the filled grains panicle^{-1} have been widely reported by different authors due to weeding duration and season long weed competition (Ekeleme et al., 2007; Begum et al., 2008).

Thousand grain weight

The 1000 grains weight of rice was influenced by weed competition period as compared to season-long weed free conditions but there was no significant difference treatments upto 60 DAT in weed-free and 30 DAT in weedy treatments (Table 1).

The effect of weed competition period showed that the highest 1000-grain weight (23.24 g) was observed in the season–long weed-free treatments, while the lowest value (21.11 g) was recorded in 75-day weedy treatment under non-saline conditions (Table 4). At 4 dS m^{-1}, the 75 day weed-free treatment produced the highest value (22.56 g) followed by the season-long weed-free, 60 day weed-free and 15 day weedy treatments. At 8 dS m^{-1}, the maximum value (21.48 g) was found in the season-long weed-free treatments, while the lowest value (19.04 g) was produced in the season–long weedy treatment. The results indicate that weed interference period influenced the grain weight at all salinity levels and the degree of influence varied with saline levels which might be due to unbalanced nutrition, water and air by competition of weeds (Table 4). Similarly, Begum et al. (2008) observed reduction of 1000-grain weight of rice by competition from the weed species of *F. milliaece*.

Grain yield hill^{-1} (g)

The yield was significantly decreased with the increasing span of weed interference but higher yield was recorded in season-long weed-free treatment and vice-varsa (Fig. 3). There was significant effect of weed competition period on the grain yield at different salinity levels (Table 5). The highest grain yield (14.34 g hill^{-1}) was observed at weed free treatment for season long at zero saline condition. The lowest grain yield (1.97 g hill^{-1}) was produced in weedy condition for season long at 8 dS m^{-1}.

At 4 dS m^{-1}, the highest yield produced in weed free condition for 75 days followed by weed free for season long period with grain yield of >11 g hill^{-1}, while the lowest yield (5.50 g hill^{-1}) was found in weedy treatments for season long. Under saline condition of 8 dS m^{-1}, the grain yield hill^{-1} was more affected by the weeding interval treatments. The maximum yield recorded in weed free treatment for season-long period followed by weedy for 15 days, weed free for 75 and weed free for 60 days with grain yield of >6 g hill^{-1}, while the minimum yield was found in weedy treatment for season-long and 75 days, and the other treatments produced intermediate results.

The result also indicated that the rice grain yield was reduced by the weed infestation and the scale of reduction was found according the duration of weed infestation. Increased biomass accumulation by weeds with the increasing span of weed interference period might also be a plausible cause of yield reduction in rice. As Woolley et al. (1993) stated, weed DM has been found to be highly correlated with crop yield loss. It has also been reported that grain yield significantly reduced by increasing the weed competition duration of *F. miliacea* (Begum et al., 2008). Similarly, Najib (2009) reported that rice grain yields were significantly affected by weeding interval treatments in both saturated and flooded conditions. Rice grain yield was drastically decreased in saturated condition as a consequence of increasing the weed infestations (Ekeleme et al. (2007). Chauhan and Johnson, (2011) reported as high as 95% yield reduction in rice due to weed competition throughout the rice growing season. These findings might be due to differences in rice variety, agro-climatic zone, soil moisture regimes and prevalent weed flora density among the experimental sites. Prolonged weed competition resulted in lower number of panicles, grains panicle^{-1}, filled grain panicle^{-1} and thousand grain weight which finally affected the grain yield.

Critical period of weed-crop competition under saline condition

The Gompertz and Logistic equations were fitted to the relative yield data and the critical periods of the weed-crop competition for each salinity level were determined (Tables 6 and 7). The predicted and observed relative yields at different salinity levels are shown in the Fig. 4.

The result shows that the beginning of the CPWC at 5% yield loss were 14, 12, and 7 DAT and at 10% yield loss were 36, 32 and 23 DAT, respectively at 0, 4 and 8 dS m^{-1} salinity levels. The end of the CPWC for salinity levels 0, 4 and 8 dS m^{-1} were 55, 64 and 80 DAT at 5% and 45, 48 and 64 DAT at 10% yield loss levels, respectively.

Therefore, the duration of the critical periods of weed competition for salinity levels of 0, 4 and 8 dS m^{-1}were 14–55, 12–64 and 7–80 DAT for 5% yield loss and were 36–45, 32–48 and 23–64 DAT for 10% yield loss levels, respectively. Juraimi et al. (2009) estimated the critical period for direct seeded rice under flooded irrigated system and the values were 15 to 75 days after sowing (DAS) and 25–51 DAS, respectively for 5 and 10% yield loss levels. Begum et al. (2008) concluded that the critical period of weed-crop competition was between 14–28 days after sowing at a 5% yield loss level. The present study showed that the length of critical period is longer at 5% than 10% yield loss in all the salinity levels. It was revealed that the duration of critical period for weed removal increased with the increasing in salinity levels.

The result also indicated that the longer weed free period should be maintained for getting higher yield under higher salinity levels. Since 5% yield loss level would not be practical from economic view point but 10% yield loss may be considered excellent in terms of economic return and this

Table 5. Interaction effect of weed competition and salinity levels on rice grain yield (g) per hill of rice.

Weed competition period	Salinity levels (dS m^{-1})		
	0	4	8
Weed-free until 15 DAT	9.64 d	7.93 i	3.45 g
Weed-free until 30 DAT	11.22 c	9.33 g	4.38 f
Weed-free until 45DAT	13.15 ab	10.45 d	5.78 d
Weed-free until 60 DAT	13.66 ab	10.98 c	6.03 c
Weed-free until 75 DAT	13.84 ab	11.12 b	6.23 bc
Weed-free check	14.34 a	11.69 a	6.66 a
Weedy until 15 DAT	13.85 ab	11.13 b	6.32 b
Weedy until 30DAT	12.94 ab	10.02 e	5.61 d
Weedy until 45 DAT	12.57 bc	9.54 f	4.67 e
Weedy until 60 DAT	11.15 c	8.69 h	4.21 f
Weedy until 75 DAT	9.31 d	6.71 j	3.01 h
Weedy check	6.91 e	5.50 k	1.97 i

Means with the same letter in a column do not differ significantly at P=0.05 (LSD test).

level can be achieved by early post-emergence application of herbicide or weeding between 36–45, 32–48 and 23–64 DAT at salinity levels of 0, 4 and 8 dS m^{-1} followed by a post emergence application or weeding between 20–40 DAT. Nevertheless, weed management can be extended beyond that period if the objective is not only to have higher yield but also to avoid weed seed grain to prevent build-up of the weed seed bank, which is of major concern for long-term sustainability of weed management under saline condition. Evans et al. (2003) reported that application of nitrogen reduced the critical period of weed-crop competition in corn. They explained that the application of higher amount of nitrogen (120 kg vs 60 kg ha^{-1}) increased the tolerance of corn to the presence of weeds as the higher corn growth at the early stage is likely to be increased with higher nitrogen rates. Although higher nitrogen rate did not increase yield, it aids in more timely corn leaf expansion and improving the resiliency of corn leaf nitrogen content to the effects of weed interference. Thus, the differences in the beginning of the CPWC at different salinity levels could be attributed primarily to differences in the greater growth of weeds compared to rice at the higher salinity levels.

Weed density had a significant effect on the beginning of the critical period. The greater the weed density, the shorter the time the crop could tolerate the early-season weed competition (Dillehay et al., 2011). Martin et al. (2001) reported that the end of the critical period was less affected by the weed density than the beginning of the critical period since the crop became more competitive at the later growth stages.

Materials and methods

Experimental Site and soil characteristics

The experiment was conducted in pots (33cm diameter × 23 cm height) during June to November 2011 at the glasshouse of the Universiti Putra Malaysia ((3◦00′21.34″N, 101◦4′ 15.06″ E, 37m elevation).

The average daily minimum and maximum temperatures were 28.2 to 32^{0}C and 37.4 to 41.3^0 C, respectively while the light intensity was 26.7 to 365.8 µmol$m^{-2}s^{-1}$ prevailing during the experimental period. The experimental soil collected from the rice fields of Tanjung Karang, Kuala Selangor.

The experimental soil was loamy clay in texture (18.3% sand, 43.7% silt, 38% clay) and acidic in reaction (pH 6.1) with 1.02% organic carbon, EC-1.56 dSm^{-1}. The soil nutrient status was 0.19% total N, 11.12 ppm available P, 122 ppm available K, 620 ppm Ca, 290 ppm, 7.63 ppm S and 0.96 ppm Zn.

Plant materials

A rice variety MR232, was sourced from Malaysian Agriculture Research and Development Institute (MARDI) and used as plant material in this study. The rice variety MR232 was selected as the plant material because it performed well under saline conditions in previous study (Hakim et al., 2010). The characteristics of rice variety MR232: plant height–93 to 105 cm, tiller/m^2–491, panicle length–25.7cm, sterility%–36, spikelet length–10.22cm, spikelet breadth–2.36cm, thousand grain weight–23.95 g, Maturation period–103 to 113, yield– 7 to 8 t/ha, texture–soft. Three salt tolerant weed species (*Ehinochloa colona, Cyperus iria* and *Jussia linifolia)* were also studied in this experiment.

Experimental treatments and design

The experiment was laid out as the factorial fashion with the treatments arranged in the randomized complete block design with four replications. The experimental factors consisted of a quantitative series of both the increasing duration of weed interference and the length of the weed free period and three salinity levels viz. 0, 4 and 8 dS m^{-1}. Timing of weed removal was based on the number of days after transplanting.

To determine the beginning of the CPWC, the first component, increasing length of weed-free period, was established by maintaining weed-free condition for 15, 30, 45, 60 and 75 days after transplanting (referred to as weed-free plots) before allowing subsequent emerging weeds to compete for the remainder of the growing season.

To evaluate the end of the critical period of the CPWC, the second component, increasing duration of weed interference, was established by allowing the weeds to compete with the rice for 15, 30, 45, 60 and 75 days after transplanting (referred to as weedy plots) after which, plots were maintained weed-free until harvest. In addition, season long weedy check and weed-free check were included as control. No herbicide was used as through weed control was accomplished by hand weeding.

Methodology

Rice seeds of the variety MR232 were soaked in water for 24 hours followed by incubation for 12 hours to allow sprouting and then sown in a well prepared wet seedbed. The pots were

Table 6. Parameter estimates with standard errors of the Gompertz and Logistic models used to determine the critical timing of weed removal for three salinity levels. (The models were fit to relative yield of rice (expressed as the percentage of the weed-free control) as a function of increasing length of weed-free period and duration of weed interference, respectively. Refer to text (equations 1 and 2) for model description).

	Parameter estimates				
Salinity levels(dS m^{-1})	y0	a	b	x0	R^2
			Gompertz equation		
0	66.01(SE)	32.45	11.50	29.62	0.992
4	50.83	48.75	21.03	16.24	0.993
8	46.54	50.02	14.0	29.38	0.986
			Logistic equation		
0	42.66	51.96	4.05	72.20	0.991
4	39.41	53.85	3.20	65.53	0.972
8	17.51	77.39	2.66	61.78	0.982

Table 7. Critical period of weed interference in rice for 5 and 10% yield losses under different levels of soil salinity.

	5% yield loss level		10% yield loss level	
Salinity levels (dS m^{-1})	Start of critical period (DAT)	End of critical period (DAT)	Start of critical period (DAT)	End of critical period (DAT)
0	14	55	36	45
4	12	64	32	48
8	7	80	23	64

filled with the prepared soil. The soil was mixed thoroughly with urea, triple supper phosphate (TSP), muriate of potash (MOP) and gypsum at the rate of 57 kg N, 80 kg P_2O_5 and 150 kg K_2O ha^{-1}, respectively before fill into the pots. Water was applied into the pot to maintain saturated condition at transplanting. Five-week-old rice seedlings were transplanted, allocating three hills per pot giving one seedling per hill. Thirty seeds of each of the three weed species (*Ehinochloa colona*, *Cyperus iria* and *Jussia linifolia*) based on the results of the laboratory experiment with tolerant and moderately tolerant status (Hakim et al., 2011) were sown in each pot on the same day of rice seedling transplantation. Eight pots were prepared for each treatment to get two sets of pots, one for recording data on growth parameters and another for yield related parameters.

Desired salinity levels were created as per treatment specification by applying salt solutions to each pot after two weeks of transplanting. To avoid osmotic shock, salt solutions were added in three equal instalments on the alternate day until the expected conductivity was reached. Conductivity of soil was compared with the conductivity meter (model: ECTestr, Spectrum Technologies, Inc.).

Weed and crop measurements

Leaf area $hill^{-1}$ of rice was measured by the leaf area mater (MODEL: LI-3100 AREA METER, USA) at 75 DAT. The SPAD values of leaves were measured with a chlorophyll meter (SPAD-502, Minolta Camera Co, Osaka, Japan) at 60 DAT, a non-destructive, quick and simple method for determining the leaf chlorophyll content (Peng et al., 1993). The crop was harvested at the full maturity (when 90% grains became golden yellow) and the grain yield was adjusted at 12% moisture basis. The data on plant height, crop DM and different yield components namely number of effective tillers $hill^{-1}$, filled grains $panicle^{-1}$, 1000-grain weight and grain yield $hill^{-1}$ were also recorded from the three hills pot^{-1} at maturity. The rice plant samples were then oven-dried at 70 ^{0}C for 72 hours and DM was recorded. At the end of each interference period, weeds were harvested, oven-dried for 72 hours at 65 ^{0}C, and weed DM was determined.

Critical period determination

Non-linear equations were used to describe crop yield response against weed interference. The Gompertz equation (Hall et al., 1992; Knezevic et al., 2002 and Johnson et al., 2004) was used to describe the effect of increasing duration of weed-free period on rice yield:

RY=y0+a*exp [-exp (-(x-x0)/b)] ………………….. [i]

Where, RY is the relative yield (% season-long weed-free yield), *y0* is the lower limit, *a* is the upper limit, *x0* is the days to give 50% yield, *x* is the number of days and b is the slope.

A logistic equation was used for describing the effect of increasing the length of weed interference on relative yield (Hall et al., 1992; Knezevic et al., 2002 and Johnson et al., 2004):

RY=y0+a/ (1+abs(x/x0) ^b)………………………….. [ii]

Where, *RY*= relative yield (% season-long weed-free yield), *y0*= lower limit, a upper limit, *x0*= days given 50% yield, *x* = days and *b* = slope

Using the derived Gompertz equation, the critical duration of weed-free period in days after transplant (DAT) was calculated for the yield loss levels of 5 and 10% for each salinity level. Similarly, using the derived logistic equation, the critical length of weed-infested period was calculated for yield loss level at 5 and 10% (Martin et al., 2001; Kiani and Faravani, 2003). The relationship between rice seed yield loss and weed dry weight was also obtained using the linear regression model. The Gompertz and logistic equations was fitted with the Sigma plot software.

Statistical analyses

Data on the growth and the yield parameters were analysed using the Analysis of Variance (ANOVA) technique and the mean separation was done with the Least Significant Difference (LSD) test at 5% probability level using the computerized Statistical Analysis System Software (SAS version 9.0). The logistic equation was used to determine the beginning of the CPWC, and the Gompertz equation was used to determine the end of the CPWC for yield loss levels of 5 and 10% chosen arbitrarily (Hall et al., 1992; Martin et al., 2001).

Conclusion

Weed composition and critical period of weed-crop competition are affected by salinity levels. The grain yield, straw yield, plant height, number of tillers, number of filled grain, 1000 grain weight, chlorophyll content and leaf area were reduced with increased weed competition period as well as elevated salinity levels. The critical period of weed-crop competition also increased with the raise in salinity level. The critical period for weed-crop competition under 5% yield loss at the 0, 4 and 8 dS m^{-1} were 14–55, 12–64 and 7–80 days after transplanting, respectively. At the 10% yield loss level, the estimated critical period for rice at the 0, 4 and 8 dS m^{-1} were 36–45, 32–48 and 23–64 days after transplanting, respectively. The present study concludes that more intensive weed management operations may be needed under saline environments than the non-saline conditions.

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