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A replacement series evaluation of competition between rice (*Oryza sativa* L.) and rice barnyardgrass (*Echinochloa oryzicola* Vasing)

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To evaluate the competitive ability of two rice cultivars with rice barnyardgrass (ECPH), a pot experiment was carried out in a replacement series study. Treatments were arranged as a factorial with two cultivars (Hashemi, and Deylamani) and five rice: rice barnyardgrass mixture proportions (8:0, 6:2, 4:4, 2:6 and 0:8). The experiment was conducted as a randomized complete block design with three replications. Relative yield total of above ground dry weight, root dry weight and leaf area showed that rice cultivars and rice barnyardgrass were competing for the same resources. In general, replacement series curves and RCC values demonstrated that Deylamani was more competitive than rice barnyardgrass and rice barnyardgrass was more competitive than Hahsemi. This experiment confirmed that there are differences in weed competitiveness among rice cultivars.

Key words: Competitiveness, rice, rice barnyardgrass, relative yield total.

INTRODUCTION

Rice is one of the most cultivated cereals and it is grown all around the world. In Iran, the production of rice is concentrated in the northern areas (Guilan and Mazandaran provinces) where the land is fertile enough for producing rice. Weeds are one of the major biological constraints in rice production, which cause yield losses approximately 50% in transplanted rice (Ampong-Nyarko and Datta, 1991). Michael (1983) reported about 50 species of *Echinochloa* genus that are dispersed in worldwide, and most of them are the weeds as common name of barnyardgrass. Two main species of *Echonochloa* in rice paddy field of Iran are *Echinochloa crus-galli* (L.) P. Beauv.) and *Echinochloa oryzicola* Vasing (=*Echinochloa phyllopogon* Stapf ex Kessenko). Yaghoubi et al. (2006) reported that in rice paddy field of Iran, the dominant species of *Echinochloa* weeds in deep water rice is changing from *E. crus-galli* to *E. oryzicola* that has either mimicry or photoperiodic sensitivity and synchronizing to the rice, but has less competitive ability against rice than *E.cruss-galli*. Yabono (1966) reported that *E. oryzicola* is the most dominant and persistent weed in flooded rice of Japan.

Recently, increasing concerns to the environmental and health effects of, and resistant weed biotypes induced by herbicide application have motivated scientists to search for more environment-friendly approaches to dealing with weed problems (Zhao et al., 2006). Weed-competitive cultivars are an important element of these approaches. Some researchers reported that variation in competitive ability against weeds exists not only among crop species, but also among cultivars within species (Zand and Beckie, 2002; Gealy et al., 2003, 2005; Watson et al., 2006; Compiglia et al., 2010). Although a negative correlation between weed competitiveness and yield, have been reported by several researchers (Jennings and Jesus, 1968; Jennings and Herrera, 1968; Kawano

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Abbreviations: ECPH, Rice barnyardgrass; **RCC**, relative crowding coefficient; **RY**, relative yield; **RYT**, relative yield total; **CEC**, cation exchange capacity; **df**, degree of freedom; **LAI**, leaf area index.

et al., 1974),some researchers which has worked on rice (Garrity et al., 1992; Fischer et al., 1997, 2001; Johnson et al., 1998; Fofana and Rauber, 2000; Ni et al., 2000; Harding and Jalloh, 2011), and Barley (Watson et al., 2006), potato (Compiglia et al., 2010) and wheat (Cousens and Mokhtari, 1998) have suggested that competitive cultivars could be developed without substantially lowering yields. Difference in competitive index and ability to withstand competition was linked to plant height (Garrity et al., 1992), number of tillers (Fischer et al., 1997), early tiller production (Johnson et al., 1998), leaf area index (Dingkuhn et al., 1999; Harding and Jalloh, 2011), canopy ground cover (Audebert et al., 1999), specific leaf area (Audebert et al., 1999), early crop biomass (Ni et al., 2000), early vigor (Bertholdsson, 2005; Zhao et al., 2006), relative crop growth rate (Ryan et al., 2010), Allelopatic potential (Wu et al., 2003; Bertholdsson, 2010), plant density (Egbe et al., 2010) and seed size (Nik et al., 2011). The methods of investigating plant competition must consider density, spatial arrangement, and proportion (Radosevich, 1987). Radosevich (1987) classified these methods into additive, substitutive or replacement series, systematic, and neighborhood. The replacement method has been extensively used in many plant interference studies (De Wit and Van Den Bergh, 1965; Harper, 1977; Akey et al., 1991; Chaves and Gealy, 1999; Estorninos et al., 2002; Gealy et al., 2005). This method is most valuable for assessing the competitive effects of two species at a single total density and determining the relative effects of interferences within and between species (Radosevich, 1987). There is lack of data concerning the competitive ability of ECPH against rice cultivars. Therefore, the aim of this study was to evaluate the relative competitive ability of ECPH against two native rice cultivars, which intensively cultivated in north of Iran, in a replacement series study.

MATERIALS AND METHODS

The experiment was conducted outdoors in plastic pots at Rice Research Station in Tonekabon (36° 54' N, 40° 50' E; 20 m above sea level), north of Iran from June to September in 2010. The experiment was arranged as a two-factor factorial in a randomized complete block design with three replications. The two factors included two native rice cultivars, (Hashemi and Deylamani) and five rice: ECPH ratios (100:0, 75:25, 50:50, 25:75 and 0:100). Actual plant numbers per pot for each mixture were 8:0, 6:2, 4:4, 2:6 and 0:8, respectively. Pots (35 cm average diameter by 30 cm deep) were arranged in a rectangular grid pattern with approximately 40 cm between edges of adjacent pots. Pots were filled to a depth of 25 cm with clay loam soil from the Tonekabon Rice Research station Farm. Soil properties were 2.2% organic matter content, 37% clay, 44% silt, 19% sand, 6.8 pH, 29.9 cation exchange capacity (CEC) (meg 100 g). Rice seeds were disinfected with thiophanate-methyl pesticide in 2 per 1000 dose and subsequently were sown in the nursery on 1 April, 2010. According to rice: ECPH ratio in each pot, Three seedlings of the appropriate cultivar or one germinated ECPH seed were transplanted (or planted) in hills with a square arrangement, with hills equidistant from the sides of the pot and from each other, on 1 June, 2010.

Recommended rate of nitrogen (100 kg ha^{-1}), phosphorous (100 kg ha^{-1}) and Potassium (150 kg ha^{-1}) were applied. One-third amount of nitrogen and whole phosphorous and Potassium were applied as a basal dose at transplanting stage. The Remaining two-thirds of nitrogen were utilized in two split doses, 30 days after transplanting (tiller stage) and panicle initiation stage. Consistent with the lowland paddy field practices in north of Iran, a permanent flood 5 cm deep was maintained from approximately 7 day after transplanting until 20 day before harvesting stage. Moreover, during the growing season, all unwanted weeds except the planted ECPH were hand weeded. At maturity stage, Plant height (from the soil surface to the top of the main panicle) was measured. Plants were harvested by hand-cutting at the soil surface and subsequently aboveground biomass of rice and ECPH were separated, and tillers of each species were counted. Leaf area was measured with a leaf area meter[1]. Roots of rice and ECPH were washed gently and thoroughly to remove soil particles so that the root tissues remained intact and subsequently were separated. Rice or ECPH aboveground and belowground (root) biomass from each pot was placed in separate paper bags, dried at 72°C for 96 h, and weighted. Relative yield (RY) and relative yield totals (RYT) for aboveground dry weight, root dry weight, leaf area and tiller number were calculated according to the following equations (Harper, 1977):

$$RY_r = (Yrb/Yrr) \quad \text{or} \quad RY_b = (Ybr/Ybb) \qquad (1)$$

Where Yrb (or Ybr) = yield per pot of rice (or ECPH) when grown with ECPH (or rice) and Yrr (or Ybb) = yield per pot of rice (or ECPH) in monoculture.

$$RYT = RY_r + RY_b \qquad (2)$$

Harper (1977) advocated that RYT can be used to describe the mutual relationships of pairs of species that may or may not be making demands on the same resources in the environment. RYT equal to 1 indicate that species A and B are making demands on the same limiting resources. RYT greater than 1 indicate that the two species make different demands on resources, so competition is avoided. Values less than 1 indicate that there is a mutual antagonism between species A and B.

The RCC method is a measurement of the competitive ability of one component to obtain limiting resources when grown in mixtures with another component compared with its ability to use those resources when grown in a pure culture. RCC values of approximately 1 indicate that the two species are equal competitors and values greater than 1 or less than 1 indicate that a species is more or less competitive, respectively, than another species. The RCC values were calculated according to the following equation (Novak et al., 1993):

$$RCC = (((Wr75{:}25/Wb75{:}25) + (Wr50{:}50/Wb50{:}50) + (Wr25{:}75/Wb25{:}75))/3)/ (Wr100{:}0/Wb100{:}0) \qquad (3)$$

Where Wr n:n is aboveground or root dry weight, leaf area and tiller number of rice at a ratio of n:n and Wbn:n is aboveground or root dry weight, leaf area and tiller number of ECPH at a ratio of n:n. The larger the RCC value, the greater the competitiveness with the other species. All data were subjected to analysis of variance (ANOVA), and means were separated using Fisher's Protected LSD at the 0.05 level. All statistical analyses were conducted by using SAS (SAS Institute, Inc, 2002). To determine whether RYT differed significantly from 1.0 or not, the following equation was used (Gealy et al., 2005):

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[1] - LI-3000A Leaf Area Meter (Li-Cor, USA)

Table 1. Above ground dry weight, root dry weight, leaf area, tiller number and height of deylamani and Hashemi rice cultivars as influenced by 8:0, 6:2, 4:4 and 2:6 rice: ECPH mixture proportions.

Rice cultivar	Rice: ECPH ratio	Above ground dry weight (gr $plant^{-1}$)	Root dry weight (gr $plant^{-1}$)	Leaf area (Cm^2 $plant^{-1}$)	Tiller no $plant^{-1}$	Plant height (Cm)
Deylamani	8:0	25.88	7.1	1013	11.01	82.68
	6:2	27.40	6.8	1064	13.42	80.38
	4:4	29.98	7.8	1034	13.61	79.96
	2:6	35.76	13.9	1389	16.86	76.18
Hashemi	8:0	24.83	5.9	798	15.91	64.50
	6:2	20.50	6.5	613	14.72	61.91
	4:4	19.98	6.7	661	12.00	55.31
	2:6	17.36	6.1	565	10.20	50.04
LSD (0.05)	-	3.37	2.1	196	0.84	4.73

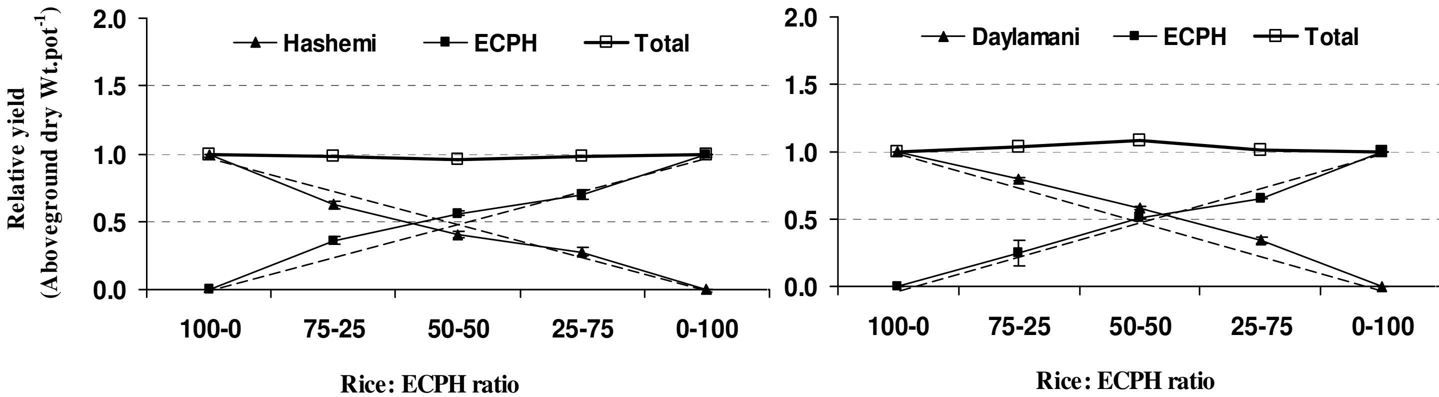

Figure 1. Relative aboveground dry weights of rice (▲) and rice barnyardgrass (ECPH). (■), and relative yield totals (RYT) (□) as influenced by rice: ECPH mixture proportions in a replacement series. The two straight dashed lines in each frame indicate the theoretically expected responses for two equally competitive species, which intersect at the point of equivalency (Harper, 1977).

$$\text{Cutoff} = 1 \pm (t^* \times \text{standard error of the mean}) \quad [4]$$

where t* = the two-sided critical value from the t-table with degree of freedom (df) equal to df associated with the term used as the error term in the F-test. To assess the competitiveness of either cultivar against ECPH, the four models for interference, proposed by Harper (1977) and adapted by Fleming et al. (1988), were used. These models described the possible outcomes of the interaction of two species when grown in a replacement series (Oberg et al., 1996; Radosevich, 1987). Replacement series diagrams were constructed for the response of aboveground dry weight, root dry weight, leaf area and tiller number to species proportion.

RESULTS AND DISCUSSION

Aboveground dry weight

Aboveground dry weight (g $plant^{-1}$) for Hashemi reduced as rice: ECPH ratio decreased (Table 1). The highest aboveground dry weight for Hashemi was obtained when grown alone. In contrast, aboveground dry weight (g $plant^{-1}$) for Deylamani increased as rice: ECPH ratio decreased (Table 1). The highest aboveground dry weight for Deylamani was obtained when grown at 2:6 rice: ECPH mixture proportion (Table 1). These results suggested that Deylamani grew better with intraspecific than with interspecifice competition. Fleming et al. (1998) also reported that the more aggressive species in the mixture increased in dry weight with increased proportions of the less aggressive species. Replacement series diagrams based on relative aboveground dry weights illustrated competitive effects between two rice cultivars and ECPH. As shown in the Figure 1, Hashemi and ECPH lines intersect to the left of the 50:50 mixture proportions. In other words, the curve representing Hashemi cultivar was concave and the curve for ECPH was convex. This indicates that ECPH was more

Table 2. Aboveground dry weight, root dry weight, leaf area, tiller number and height of rice barnyardgrass (ECPH) as influenced by 8:0, 6:2, 4:4 and 2:6 rice: ECPH mixture proportions.

ECPH grows in mixture with	ECPH: rice ratio	Aboveground dry weight (gr plant^{-1})	Root dry weight (gr plant^{-1})	Leaf area (Cm^2 plant^{-1})	Tiller no plant^{-1}	Plant height (Cm)
Deylamani	8:0	30.15	5.94	1691	15.62	83.44
	6:2	26.49	6.87	1443	13.17	76.96
	4:4	30.66	6.65	1694	12.46	66.89
	2:6	29.65	5.89	1504	11.31	60.19
Hashemi	8:0	30.15	5.54	1691	15.62	83.44
	6:2	28.03	6.51	1718	14.33	79.44
	4:4	33.74	6.57	2466	15.69	78.37
	2:6	42.83	11.66	3098	19.56	79.72
LSD (0.05)	-	3.01	1.10	359	1.28	1.86

Table 3. Mean comparison for the effect of rice cultivars and rice barnyardgrass (ECPH) on relative crowding coefficient (RCC) for aboveground dry weight, root dry weight, leaf area and tiller number**.**

Species in mixture	Relative crowding coefficient (RCC)			
	Above ground	Root	Leaf area	Tiller number
Deylamani	1.249	0.921	1.233	1.001
Vs. ECPH	0.808	1.116	0.906	1.004
Hashemi	0.807	0.962	0.702	0.925
Vs. ECPH	1.291	1.220	1.544	1.095
LSD (0.05)	0.353	0.789	0.479	0.231

competitive than Hashemi cultivar and gained resources at the expense of the cultivar.

On the other hand, the lines for Deylamani and ECPH intersect at the right of the 50:50 mixture proportion (point of equivalency of the expected yield), indicating that Deylamani was more competitive than ECPH. The RYT for aboveground dry weight ranged from 0.96 to 1.08, but all of them were not significantly different from 1, on the basis of the cutoff of not > 1.09 or <0.91. This indicates that rice cultivars and ECPH were competing for the same resources. This result was in agreement with some previous studies (Gealy et al., 2005; Estorninos et al., 2002). The RCC value for Deylamani was significantly greater than that for ECPH while for Hashemi, it was significantly lower than that for ECPH (Table 3). These data indicate and also confirm results of RY for aboveground dry weight that Deylamani was superior competitor compared to ECPH. Fischer et al. (2000) reported that when competing for limited resources, the species with the greater RCC in the mixture is the stronger competitor. Also, Gealy et al. (2005) reported that Lemont rice cultivar had lower RCC than BYG, while PI 312777 had similar RCC with BYG. Moreover, the greater RCC of Deylamani over Hashemi indicates the aggressiveness of Deylamani against Hashemi in aboveground dry weight. Some researchers reported that differences in WC exist between and within rice cultivars (Gealy et al., 2003; Fofana and Rouber, 2000; Ni et al., 2000; Fischer et al., 1997, 2001; Johnson et al., 1998; Garrity et al., 1992).

Root dry weight

Root dry weight of Deylamani increased dramatically at 2:6 rice: ECPH mixture proportion, but in the other mixture proportions did not vary statistically (Table 1). On the other hand, root dry weight of Hashemi did not vary statistically among the different mixture proportions (Table 1). Root biomass of ECPH was constant when grown with Deylamani among the different mixture proportions, but root dry weight of ECPH was significantly increased when grown at 2:6 ECPH: Hashemi mixture proportion (Table 2). Replacement series diagrams for relative root dry weight (Figure 2) showed that the lines for both cultivars and ECPH intersect almost at the point of equivalency of the expected yield, demonstrating that the cultivars and the weed have relatively similar

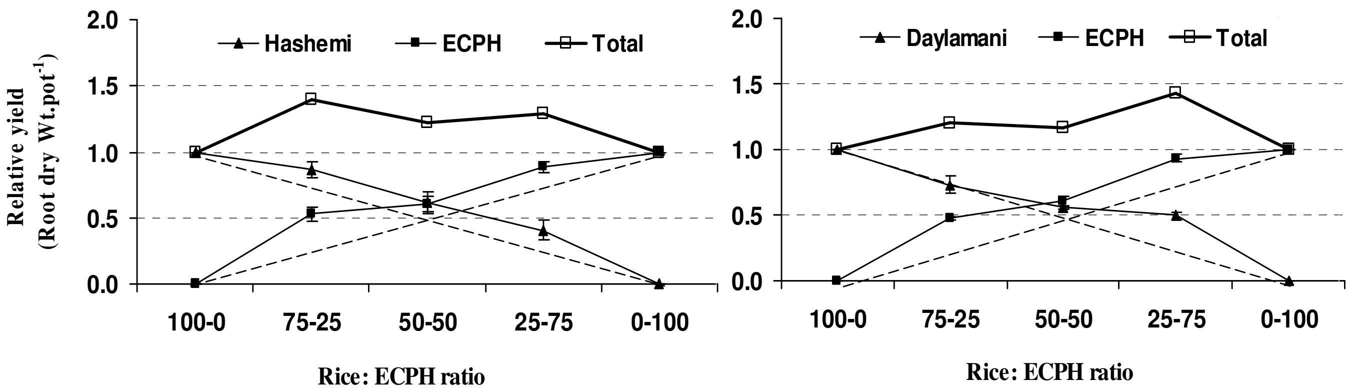

Figure 2. Relative root dry weights of rice (▲) and rice barnyardgrass (ECPH) (■), and relative yield totals (RYT) (□) as influenced by rice: ECPH mixture proportions in a replacement series. The two straight dashed lines in each frame indicate the theoretically expected responses for two equally competitive species, which intersect at the point of equivalency (Harper, 1977).

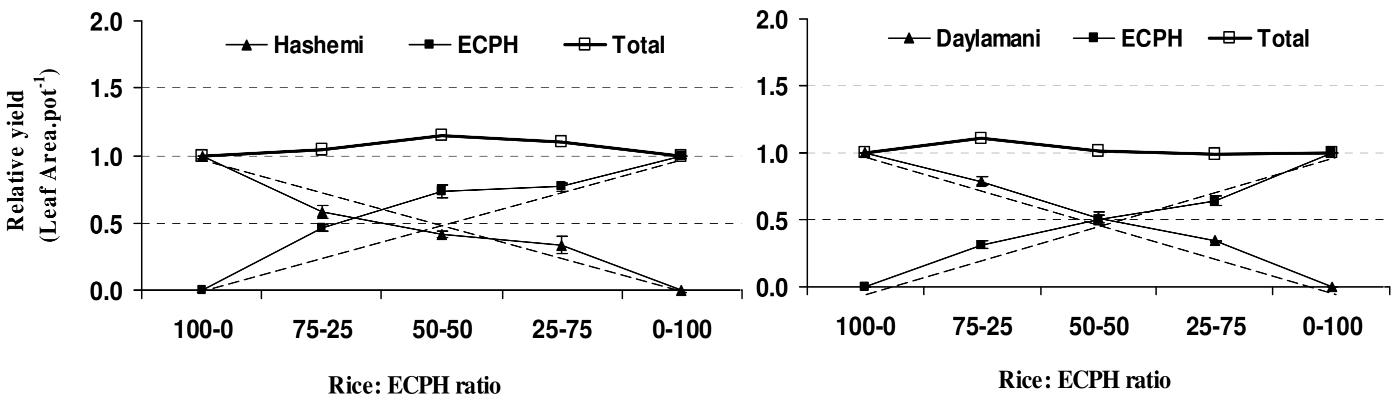

Figure 3. Relative leaf area of rice (▲) and rice barnyardgrass (ECPH) (■), and relative yield totals (RYT) (□) as influenced by rice: ECPH mixture proportions in a replacement series. The two straight dashed lines in each frame indicate the theoretically expected responses for two equally competitive species, which intersect at the point of equivalency (Harper, 1977).

(Table 2). The RY of the leaf area versus the proportion of Hashemi and ECPH were concave for Hashemi and convex for ECPH (Figure 3). This indicates that ECPH was more competitive than Hashemi cultivar. On the other hand, the intersection between Deylamani and ECPH was almost in the middle, indicating that Deylamani and ECPH were equally competitive. Moreover, this result showed that Deylamani was more competitive than Hashemi cultivar. The RYT for leaf area of both rice cultivar and ECPH ranged form 0.99 to 1.14 and based on the cutoff values (< 1.20 or > 0.80), they were not significantly higher or lower than it (Figure 3).

This indicates that rice and ECPH are likely competing for the same resources. This result was consistent with the report of Gealy et al. (2005). The RCC based on leaf area showed the aggressiveness of one species toward another (Table 3). The greater RCC of ECPH over Hashemi supports the aggressiveness of the weed against the rice cultivar in leaf area. Fischer et al. (2000) reported that when competing for limited resources, the species with the greater RCC in the mixture is the stronger competitor. On the other hand, the RCC value for leaf area did not significantly differ between Deylamani and ECPH, indicating equal competitiveness between them. Moreover, the greater RCC of Deylamani over Hashemi indicates the aggressiveness of Deylamani against Hashemi in leaf area production. Drews et al. (2009) reported that the more competitive cultivars Astron and Pegassos were taller than the less competitive cv. Greif had higher ground cover and light interception, presumably induced by planophile leaf inclination and partly, in the case of cv. Astron, because of higher leaf area index (LAI).

Tiller number

Deylamani had lower tiller density when planted as

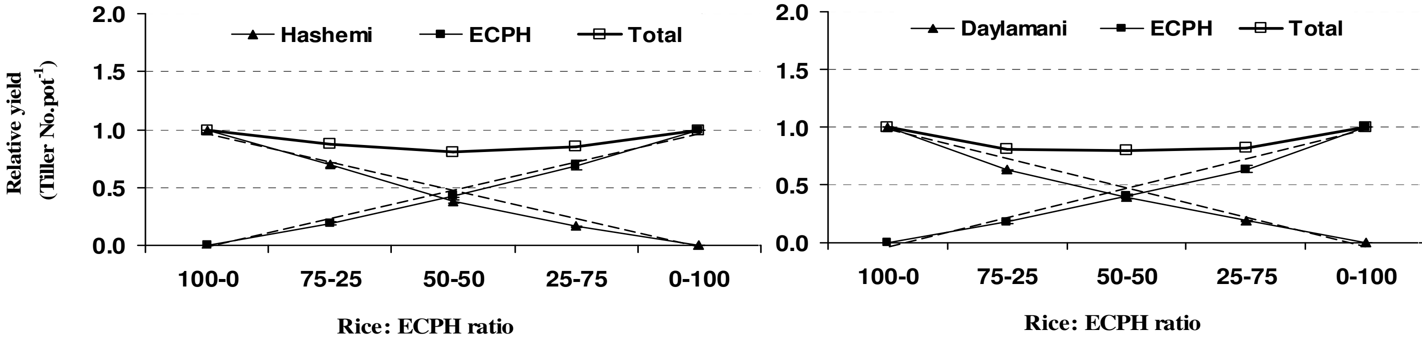

Figure 4. Relative tiller number of rice (▲) and rice barnyardgrass (ECPH) (■), and relative yield totals (RYT) (□) as influenced by rice: ECPH mixture proportions in a replacement series. The two straight dashed lines in each frame indicate the theoretically expected responses for two equally competitive species, which intersect at the point of equivalency (Harper, 1977).

interspecific effects on root dry weight of the other. The RYT for root dry weight of both rice cultivars and ECPH ranged form 1.16 to 1.43. In most cases, they were significantly higher than cutoff value (< 1.16 or >0.84). This response probably occurred primarily because of the reduced interference in mixtures in relation to the monocultures due to the differences in paths of resource acquisition by C_3 rice plants and C_4 BYG plants, respectively (Fischer et al., 2000). The RCC value for root dry weight did not significantly differ among rice cultivars and ECPH (Table 3), indicating that neither species were dominant in root biomass production.

Leaf area

Leaf area (Cm^2 plant^{-1}) for Hashemi reduced when the proportion of rice: ECPH decreased (Table 1). The highest leaf area for Hashemi was obtained when grown alone. In contrast, leaf area (Cm^2 plant^{-1}) for Deylamani increased when the proportion of rice: ECPH decreased (Table 1). The highest leaf area for Deylamani was obtained when grown at 2:6 rice: ECPH mixture proportion (Table 1). On the other hand, leaf area of ECPH did not significantly vary among the different mixture proportions when grown with Deylamani, but it was significantly increased when grown with Hashemi monoculture than when grown at the different rice: ECPH mixture proportions, whereas Hashemi did not (Table 1).

This indicates that Hashemi responded more to interspecific competition than Deylamani. Tiller number of ECPH was significantly reduced when grown with Deylamani, but it was significantly increased at 2: 6 ECPH: Hashemi ratio (Table 2). This indicates that rice cultivar with high-tillering ability was affected more than low-tillering rice cultivar by ECPH. This result agrees with the result of Gealy et al. (2005) and Harding and Jalloh (2011), but is in contrast to other findings that greater tiller production is one of the factors consistent with the weed suppression (Estorninos et al., 2002; Gealy et al., 2003). The competitive ability of each cultivar against ECPH on the basis of the relative tiller production was evaluated using a replacement series diagram (Figure 4). Both cultivars and ECPH lines intersect almost at the 50:50 rice: ECPH ratio. These results suggested that Hashemi and Deylamani were as competitive as ECPH in tiller production. The RYTs for tiller number of each rice cultivar and ECPH (ranging from 0.79 to 0.88) were lower than the cutoff values (0.96 to 1.04). Harper (1977) suggested that RYT value less than 1 imply mutual antagonism. The RCC value for tiller density did not significantly differ among rice cultivars and ECPH (Table 3). This indicates that neither species were dominant in tiller production.

Plant height

In monoculture, Deylamani was taller than Hashemi. Hashemi height was reduced significantly when grown at 6:2, 4:4 and 2:6 rice: ECPH ratios, whereas that of Deylamani was not significantly affected at 6:2 and 4:4 rice: ECPH ratios, but at 2:6 rice: ECPH ratio, Deylamani height was also reduced significantly (Table 1). Our finding that the shorter cultivar was affected more than the taller cultivar by weeds was in contrast to Estorninos et al. (2002) and in agreement with Garrity et al. (1992) and Drews et al. (2009) findings. On the other hand, ECPH height was also reduced when it grown either with Hashemi or Deylamani (Table 2). Moreover, ECPH was shorter when grown together with rice at all mixture proportions than when planted alone. This indicates that ECPH responded to interspecific competition more than intraspecific competition. Moreover, ECPH height when grown with Deylamani was shorter than that when grown with Hashemi at different rice: ECPH ratios.

Conclusion

Integrated weed management combines several weed management techniques such as physical, chemical, biological and cultural controls, so that the reliance on any one weed control technique is reduced. The results of this experiment indicated that there are differences in weed competitiveness among rice cultivars. Deylamani was more competitive than rice barnyardgrass and rice barnyardgrass was more competitive than Hahsemi. Based on the results of this experiment, competitive cultivars could be an important component of integrated weed management strategies.

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