INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 3, No. 8, p. 150-158, 2013

RESEARCH PAPER OPEN ACCESS

Effect of pretilachlor rate on grain yield and weed biomass in two rice cultivars

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Key words: Herbicide efficacy, weed interference, yield.

doi: http://dx.doi.org/10.12692/ijb/3.8.150-158 Article published on August 20, 2013

Abstract

This study was conducted at Rice Research Station of Tonekabon, Iran, in 2011. The objectives of this study were to evaluate the effect of different pretilachlor rates on grain yield of 'Hashemi' and 'Deylamani' rice cultivars, and to determine weed biomass and relative yield loss for both cultivars when pretilachlor was applied at below-label rates. The experimental design was a split plot where the whole plot portion was a randomized complete block with three replicates. Main plots were pretilachlor rates (0, 0.5, 1, 1.5, 2 liter ha^{-1}) and subplots were two traditional rice cultivars ('Hashemi' and 'Deylamani'). Result indicated that no significant differences were found in grain yield, yield components, relative yield loss, harvest index, rice biomass, weed biomass, and herbicide efficacy between 'Hashemi' and 'Deylamani' as averaged across herbicide rates. At the same time, 'Hashemi' was significantly taller than 'Deylamani'. In contrast, 'Deylamani' produced greater leaf area compared to 'Hashemi'. Regardless of rice cultivar, the highest grain yield, tiller number per m^{-2}, grain number per panicle, rice biomass, leaf area index, and herbicide efficacy were observed in plots received recommended rate (2 L ha^{-1}) of Pretilachlor, while the highest weed biomass and relative yield loss were found in plots received no herbicide. The results suggest that rice grain yield significantly reduces when pretilachlor is used at lower than recommended rates.

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Introduction

Rice is the staple food for more than half of the world's population. In Iran, the total area under rice cultivation is more than 600000 ha, and rice is grown in 15 provinces. However, more than 80% of rice area is distributed in Mazandaran (265000 ha) and Guilan (230000 ha) provinces. In the area, rice is transplanted during May and harvested from mid August to mid September depending on the cultivar, climate conditions, and availability of labour. From 1.8 million tonnes in the late 1980s, rice production in Iran increased to 3.21 million tonnes in 2011, with the average yield being 3000-3500 kg ha^{-1} (rough rice) for local and 5000-7000 kg ha^{-1} for improved cultivars (FAO, 2011). Nevertheless, as the demand and production of rice are still not balanced, Iran imports around 0.4 to 0.5 million tonnes of rice for domestic consumption. Therefore, it is essential to enhance rice production in the country.

Weeds are one of the major constraints to rice production in Iran. Weeds reduce rice grain yield up to the extent of 32% (Singh *et al.*, 2007) by competing for space, nutrients, water and light. Moreover, weeds are able to cause qualitative indirect damages due to crop yield reduction, contamination of seeds (Ashton and Monaco, 1991), slowing of tillage and harvesting practices. At the same time, some weeds serve as alternate hosts for pests and diseases. Most important grass weed species in paddy fields of Iran are *Echinochloa crus-galli* (L.) P. Beauv, and *Echinochloa oryzicola* Vasing, sedges are *Cyperus difformis* L., *Scirpus juncoides* Roxb., *Scirpus maritimus* L., *Scirpus mucronatus* L., and broad-leaved weed species are *Sagittaria trifolia* L., and *Alisma plantago-aquatica*

L. Chemical weed management is the most popular method of weed control in rice. Chemical weed control is cheaper and less time consuming than mechanical weed control. Pretilachlor[1] EC 50 is a pre-emergence selective herbicide for control of grasses, sedges and some broad leaf weeds in transplanted Rice fields. It has no harmful effect on rice crop and is absorbed mostly by the germinating shoots, and partly by the roots of weeds.

Many researchers reported that rice cultivars differ significantly in weed competitiveness, and cultivars with strong weed-competitive ability are a low-cost and safe tool for integrated weed management (Zhoa *et al.*, 2006a; Gealy *et al.*, 2003; Fischer *et al.* 2001; Garrity *et al.*, 1992). Weed competitiveness (WC) is the ability of a crop to suppress and tolerate weeds (Jannink *et al.*, 2000) which include; 1- weed-suppressive ability (WSA), or the crop's ability to suppress weeds, 2- weed tolerance (WT), or the ability of crop to maintain its yield with weed interference.
The objectives of this study were: (1) to evaluate the effect of different pretilachlor rates on grain yield of two rice cultivars, and (2) to determine weed biomass and relative yield loss for both cultivars when pretilachlor was applied at lower than recommended rate.

Materials and methods

Experimental design, plant culture and management

Field experiment was conducted on a lowland rice field at Rice Research Station of Tonekabon (36° 51' N, 50° 46' E), Iran, in 2011. The previous crop was rice. Soil properties were determined at 0-30 Cm before experiment establishment (Table 1). Monthly weather data are shown in Table 2. The experimental design was a split plot where the whole plot portion was a randomized complete block with three replicates. Main plots were pretilachlor rates (0, 0.5, 1, 1.5, 2 liter ha^{-1}) (0, 25, 50, 75, and 100% of recommended rates, respectively) applied at six days after transplanting. The subplots were two traditional rice cultivars ('Hashemi' and 'Deylamani'). This cultivars are extensively cultivated in north of Iran. Subplot size was 7 rows × 4 m, and both cultivars were transplanted on May 19, 2012 at planting distance of 20 Cm × 20 Cm. Fertilizer was applied as a basal application of 25 kg N as urea, 70 kg P_2O_5 as triple super phosphate and 100 kg K_2O as KCl per hectare. Additional N was applied at 25 kg ha^{-1} as topdressing at 40 days after transplanting for both cultivars.

Plant sampling

Green leaf area was measured with a leaf area meter[1] at 25 and 45 days after transplanting. Leaf area index (LAI) was calculated as the ratio of green leaf area divided by the ground area. Plant height was measured from the soil surface to the tip of the panicle based on 12 individual measurements in each plot. At maturity stage, yield components of rice (Tiller number per m^2, grain number per panicle, and 1000-grain weight) were measured according to Gomez (1972). Rice grain yield, biological yield, and weed biomass were determined from 2.5 m^2 per plot. Grain yield was corrected to 140 g kg^{-1} grain moisture content. Biological yield and Weed biomass from each plot were dried at 70 °C for 96 h, and weighted. Relative yield loss (%) was calculated as fallowing:

Relative yield loss (%) = 100[(weed free yield – weedy yield)/ weed-free yield] [1]

Harvest index was calculated by dividing the dry weight of the grain by the dry weight of aboveground (biological yield). The herbicide efficiency was calculated from the following equation (Lesnik, 2003):

$$HE = [(W_{Un} - W_T)/ W_{Un}] \times 100 \quad [2]$$

Where HE is the herbicide efficiency, W_{Un} is weed biomass in untreated plot with herbicide; W_T is weed biomass in treated plot with herbicide. Meter

Statistical analyses

Analysis of variance was performed using SAS procedures (SAS Institute, 2004). Means were compared using fisher's protected LSD test at α=0.05. When interactions between factors were not significant, main effects were presented. Moreover, if the analysis of variance indicated a significant F value for herbicide rate, a linear, quadratic, or exponential function was fit to the herbicide rate data using regression functions present in the graphics program (SigmaPlot version 10, Systat Software, Inc., Point Richmond, CA). Standard errors were calculated for all means.

Results and discussion

Analysis of variance indicated that rice grain yield was significantly influenced by pretilachlor rate (table 3). Regardless of rice cultivar, grain yield increased significantly from 2442 to 3096 kg ha^{-1} as pretilachlor rate increased from 0 to 2 L ha^{-1} (Fig. 1). It seems that stronger competition between weeds and rice for nutrient reduced rice grain yields in plots which received herbicide at below-label rates. Cultivar had no significant effect on grain yield. Moreover, the interaction between cultivar and herbicide rate was also not significant at $P < 0.05$, indicating that both cultivars, 'Hashemi' and 'Deylamani', showed similar responses to pretilachlor rates for grain yield (Table 3). Similarly, the relative yield loss due to weed competition was significantly reduced as herbicide application rate increased. Grain yield reduced by 37.5% in untreated plots with herbicide, and reduced by 27.1%, 19.6%, and 16.5% in plots received 25, 50, and 75% of recommended rates of Pretilachlor, respectively. Contrary to yield response, weed biomass was significantly reduced as pretilachlor application rate increased from 0 to 2 L ha^{-1} (Fig. 2). The maximum (324.28 g m^{-2}) and minimum (33.98 g m^{-2}) weed biomass were observed in plots which received pretilachlor at the rate of 0 and 2 L ha^{-1}, respectively. The main effect of cultivar and the interaction of pretilachlor rate × cultivar were not significant for weed biomass and relative yield loss. Averaged across pretilachlor rates, relative yield loss (Table 4) was slightly greater for 'Hashemi' (21%) compared to 'Deylamani' (19%). This indicates that the cultivars did not significantly differ in competitive ability against weeds. Contrary to this result, Ni *et al.* (2000), Gealy *et al.* (2003), and Zhao *et al.* (2006a) found significant differences in weed competitive ability among rice cultivars. Moreover, differences between barley cultivars in their weed competitiveness have been reported by Dhima *et al.* (2010) and Watson *et al.* (2006).

Correlation analysis showed that rice grain yield was positively correlated with rice biological yield, Tiller number per m^{-2}, grain number per panicle, plant height, and leaf area index at 45 days after transplanting at $P < 0.001$ level, but negatively correlated with weed biomass ($P < 0.01$), and not correlated harvest index and leaf area index at 25 days after transplanting (Table 5). Similarly, Haefele *et al.* (2004), found grain yield was positively correlated to tiller density and LAI, whilePlant height was positively correlated to yield in the wet season but negatively in the dry season. They also reported a negative correlation between grain yield and weed biomass. There was a positive correlation ($r = 0.78^{***}$) between weed biomass and the relative yield reduction (Table 5). Similar result was reported by Zhao *et al.* (2006b). On the other hand, relative yield loss was negatively correlated with tiller number, grain number per panicle, plant height, leaf area index at 45 days after transplanting (Table 5). Similar result was reported by Haefele *et al.* (2004).

Table 1. Monthly precipitation and temperature from April to September in 2011 at Rice Research Station of Tonekabon.

Month	Precipitation (mm)	Temperature (°C)		
		Maximum	Minimum	Average
April	39.6	16.6	10.7	13.6
May	10.4	21.9	16.5	19.2
June	73.9	26.8	20.8	23.8
July	2.9	31.4	24.2	27.8
August	131.3	28.8	23.1	25.9
September	271.1	25.4	19.7	22.5

Table 2. Soil characteristics (0-30 cm depth) at the research location before transplanting.

OC (%)	pH	Sand (%)	Silt (%)	Clay (%)	CEC (me 100 g⁻¹)	Total N (%)	P (mg kg⁻¹)	K (mg kg⁻¹)
2.2	6.8	19	44	37	29.9	0.207	11	112

Tiller number was significantly influenced by only pretilachlor rate (Table 3). Tiller number increased significantly with increasing pretilachlor application rate (Fig. 3), as averaged across rice cultivars. The highest and lowest tiller numbers per m^{-2} were observed when pertilachlor applied at the rate of 0 and 2 L ha^{-1}, respectively. The main effect of pretilachlor was significant for grain number per panicle, but cultivar had no significant effect on grain number per panicle. At the same time, the interaction between herbicide rate and cultivar was significant, indicating that 'Hashemi' and 'Deylamani' showed different response to pretilachlor rate in terms of grain number per panicle (Table 3). As shown in Fig. 4, grain number per panicle for 'Deylamani' was significantly increased from 74 to 104 grain per panicle as pretilachlor application rate increased from 0 to 2 L ha^{-1}. In contrast, grain number per panicle for 'Hashemi' remained unchanged with increasing herbicide rate. The main effects of cultivar and herbicide rate were not significant for 1000-grain weight. This indicates that weed competition did not affect rice grain weight. Similarly, Haefele *et al.* (2004) and Zhao *et al.* (2006b) found that 1000-grain weight was not affected by weeds, but tiller number, and filled grain number decreased with weed competition. Moreover, the interaction between cultivar and herbicide rate was not significant for 1000-grain weight, indicating both cultivars showed similar response to herbicide rate for this trait.

Biological yield was significantly affected by only pretilachlor rate. Regardless of rice cultivars, biological yield was significantly increased as pretilachlor rate increased (Fig. 5). The greatest rice biomass was observed in plots received 2 or 1.5 L ha^{-1}, while the lowest biomass was recorded for plots received no herbicide. Harvest index was not significantly affected by the main effects. The interaction between cultivar and herbicide rate was also not significant for HI. These results indicate that grain and straw was equally affected by weed competition in both cultivars.

Table 3. ANOVA for plant height (Ph), grain yield (Y), relative yield loss (RYL), tiller number per m² (TN), grain number per panicle (GN), 1000-grain weight (ThGW), biological yield (BY), harvest index (HI), leaf area index at 25 and 45 days (LAI25 and LAI 45) after transplanting, weed biomass (WB), and herbicide efficacy (HE) as affected by herbicide rate (H), and cultivar (C)

Source of variance	df	Ph	Y	RYL	TN	GN	ThGW	BY	HI	LAI_{25}	LAI_{45}	WB	HE
Block (R)	2	170**	1748628**	202**	2401*	120*	0.55^{ns}	3747470**	1.94^{ns}	0.00002^{ns}	0.108^{ns}	378^{ns}	63^{ns}
Herbicide rate (H)	4	344***	1756946***	1154***	3702**	235*	1.05^{ns}	4532004**	0.84^{ns}	0.00033^{ns}	1.081***	97158***	8201***
Error (a)	8	8	31053	22	468	73	1.21	427043	4.29	0.00047	0.029	503	20
Cultivar (C)	1	313**	188052^{ns}	36^{ns}	213^{ns}	95^{ns}	0.81^{ns}	1756687^{ns}	4.96^{ns}	0.0085*	0.165***	172^{ns}	6^{ns}
H* C	4	21^{ns}	68134^{ns}	57^{ns}	789^{ns}	172**	0.20^{ns}	128334^{ns}	0.14^{ns}	0.00002^{ns}	0.001^{ns}	109^{ns}	6^{ns}
Error (b)	30	25	138126	83	274	35	1.03	1018353	6.7	0.00018	0.001	950	14

*, **, and ***: significant at the 0.05, 0.01, and 0.001 probability level, respectively.

ns, not significant at the 0.05 probability level.

Table 4. plant height (Ph), grain yield (Y), relative yield loss (RYL), tiller number per m² (TN), grain number per panicle (GN), 1000-grain weight (ThGW), biological yield (BY), harvest index (HI), leaf area index at 25 and 45 days (LAI25 and LAI 45, respectively) after transplanting, weed biomass (WB), and herbicide efficacy (HE) for 'Hashemi' and 'Deylamani' averaged across herbicide rates.

Cultivar \ Traits	Ph (Cm)	Y (kg ha^{-1})	RYL (%)	TN m^{-2}	GN per panicle	ThGW (g)	BY (kg ha^{-1})	HI (%)	LAI_{25}	LAI_{45}	WB (g m^{-2})	HE (%)
Hashemi	125.6 a	3048 a	21.2 a	218 a	88.2 a	27.4 a	4922 a	38.2 a	0.102 a	1.35 b	199.6 a	47.9 a
Deylamani	119.2 b	3206 a	19.0 a	212 a	84.6 a	27.7 a	5406 a	37.4 a	0.112 a	1.50 a	194.8 a	48.8 a
LSD (0.05)	4.1	302	7.4	13	4.8	0.8	821	2.1	0.011	0.03	25.1	3.1

Table 5. Pearson's correlation coefficients for measurements of rice as affected by herbicide rate, and cultivar (n=30).

Parameter	Grain yield	Relative yield loss	Tiller number	Grain number	1000 grain weight	Biological yield	Harvest index	LAI_{25}	LAI_{45}	Weed biomass
Relative yield loss	-0.94***	1								
Tiller number	0.68***	-0.67***	1							
Grain number	0.56***	-0.55***	0.11^{ns}	1						
1000 grain weight	0.28^{ns}	-0.31^{ns}	0.33^{ns}	0.18^{ns}	1					
Biological yield	0.92***	-0.88***	0.61***	0.50**	0.34^{ns}	1				
Harvest index	0.08^{ns}	- 0.09^{ns}	- 0.04^{ns}	0.02^{ns}	- 0.24^{ns}	-0.43**	1			
LAI_{25}	0.24^{ns}	-0.18^{ns}	0.38*	0.10^{ns}	0.07^{ns}	0.34^{ns}	0.08^{ns}	1		
LAI_{45}	0.77***	-0.80***	0.57***	0.56***	0.17^{ns}	0.69***	-0.22^{ns}	0.39*	1	
Weed biomass	-0.66***	0.78***	-0.53**	-0.52**	- 0.14^{ns}	-0.58***	-0.03^{ns}	-0.26^{ns}	-0.89***	1
Herbicide efficacy	0.68***	-0.79***	0.58***	0.53**	0.20^{ns}	0.61***	0.02^{ns}	0.32^{ns}	0.89***	-0.65***
Plant height	0.75***	-0.75***	0.71***	0.33^{ns}	0.23^{ns}	0.64***	0.01^{ns}	0.10^{ns}	0.66***	-0.96***

*, **, and ***: significant at the 0.05, 0.01, and 0.001 probability level, respectively.

ns, not significant at the 0.05 probability level.

LAI25 and LAI45; Leaf area index at 25 and 45 days after transplanting, respectively.

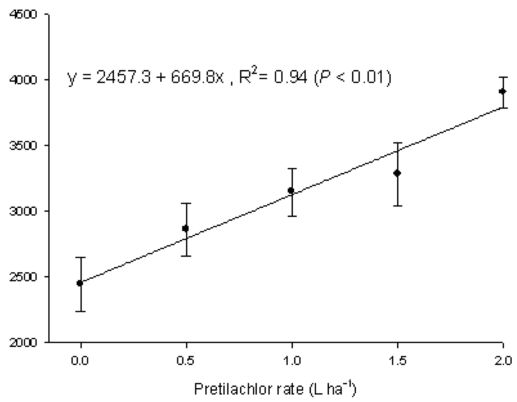

Fig. 1. Rice grain yield (kg ha^{-1}) as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual rice grain yield. Line represents grain yield estimate from the equation y = a + bx, where y = estimated grain yield, x = herbicide rate, a = y intercept (grain yield at zero herbicide rate), and b = estimated regression parameters that describe the slope of the line.

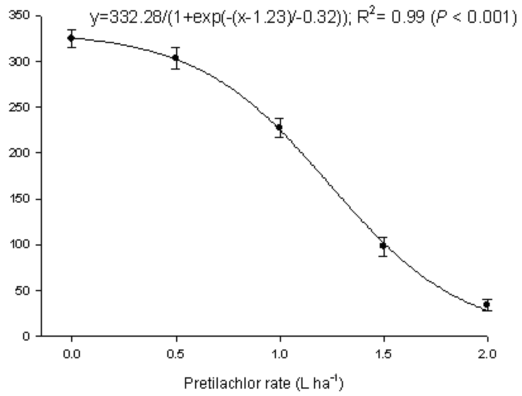

Fig. 2. Weed biomass as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual weed biomass. Line represents weed biomass estimate from the equation $y = a/(1+\exp(-(x-x_0)/b))$, y = estimated weed biomass x = herbicide rate, a = weed biomass (g m^{-2}) with no herbicide treatment, x_0 = the effective dose required to reduce weed biomass by 50%, and b = estimated regression parameter.

Main effect of herbicide rate (H), and cultivar were significant for plant height (Ph). Averaged across cultivars, plant height of rice was significantly increased as herbicide application rate increased from 0 to 2 L ha^{-1} (Fig. 6). This is probably due to better weed suppression at recommended rate of pretilachlor (2 L ha^{-1}). The reduction in plant height of rice due to weed competition was reported by earlier researchers (Begum *et al.*, 2008; Begum, 2006). Similarly, Chauhan and Johnson (2010) noted that the reduction in plant height of rice was increased in higher weed density. 'Hashemi' cultivar was significantly taller than 'Deylamani' (126 Cm vs. 119 Cm) as averaged across herbicide rates (Table 4).

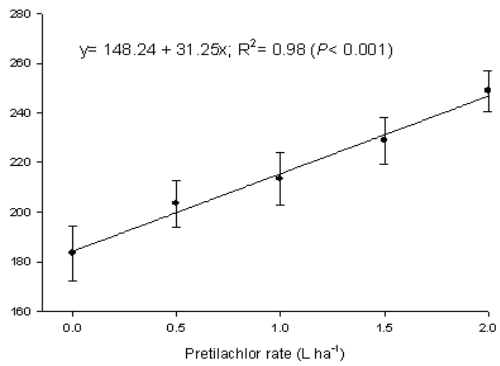

Fig. 3. Tiller number per m^2 as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual tiller number. Line represents tiller number estimate from the equation y = a + bx, where y = estimated tiller number x = herbicide rate, a = y intercept (tiller number at zero herbicide rate), and b = estimated regression parameters that describe the slope of the line.

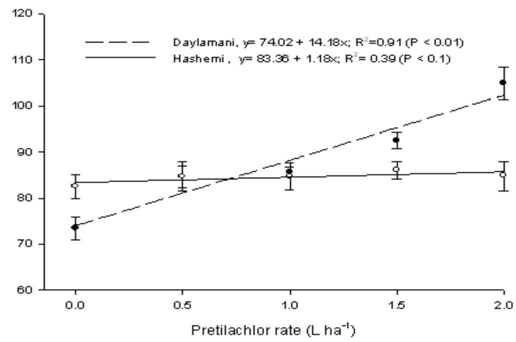

Fig. 4. Relationship between pretilachlor rate and grain number per panicle for Dylamani (dash line) and 'Hasehemi' (solid line). Symbols (± standard errors) represent actual grain number per panicle. Lines represent grain number estimates from the equation y = a + bx, y = estimated grain number x= herbicide rate, a = y intercept (grain number at zero

herbicide rate) and b = estimated regression parameter that describe the slope of the line.

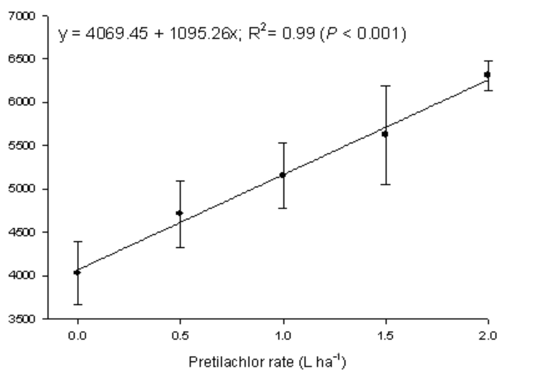

Fig. 5. rice biological yield as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual biological yield (kg ha^{-1}). Line represents rice biological yield estimate from the equation y = a + bx, where y = estimated biological yield x= herbicide rate, a = y intercept (biological yield at zero herbicide rate) and b = estimated regression parameter that describe the slope of the line.

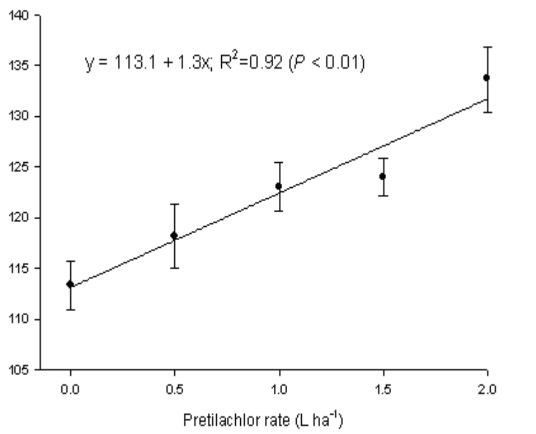

Fig. 6. plant height as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual plant height (Cm). Line represents plant height estimate from the equation y = a + bx, where y = estimated plant height x= herbicide rate, a = y intercept (plant height at zero herbicide rate) and b = estimated regression parameter that describe the slope of the line.

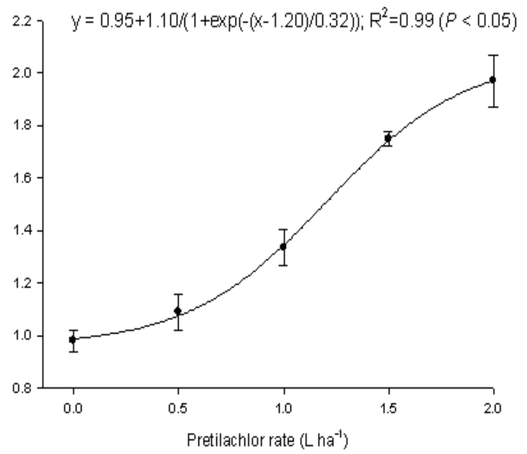

Fig. 7. Leaf area index at 45 days after transplanting (LAI45) as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual LAI45. Line represents weed biomass estimate from the equation y = a/(1+exp(-(x-xo)/b)), y = estimated LAI45, x = herbicide rate, a = LAI45 with no herbicide treatment, xo = the effective dose required to reduce LAI45 by 50%, and b = estimated regression parameter.

Leaf area index at 25 days after transplanting (LAI25) was significantly affected by only cultivar, while Leaf area index at 45 days after transplanting (LAI45) was significantly influenced by cultivar and herbicide rate. Regardless of pretilachlor rates, 'Deylamani' had significant greater leaf area index compared to 'Hashemi' both at 25 and 45 days after transplanting (Table 4). Strong weed competition in plots which receive herbicide at below-label rates significantly reduced leaf area at 45 days after transplanting. Averaged across rice cultivars, leaf area index at 45 days after transplanting was significantly increased as pretilachlor rate increased, and was 2.1 times greater in plots received recommended rates of herbicide compared to those received no herbicide (Fig. 7). It seems that strong competition between rice and weeds in plots which received herbicide at lower than recommended rates reduced leaf area index at 45 days after transplanting. The reduction in rice LAI due to weed competition has been reported by Johnson *et al.* (1998) and Haefele *et al.* (2004), who declared that competition from weeds, decreased LAI of rice cultivars. Leaf area index at 45 days after transplanting was negatively correlated weed biomass. This result is similar to those reported by Korai and Morita (2003) and Garrity *et al.* (1992).

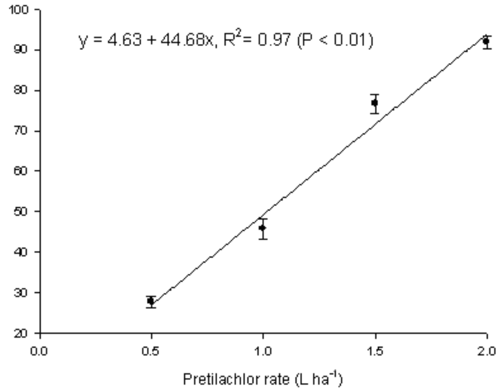

Fig. 8. Herbicide efficacy as a function of pretilachlor rate across rice cultivars. Symbols (± standard errors) represent actual Herbicide efficacy. Line represents Herbicide efficacy estimate from the equation y = a + bx, where y = estimated Herbicide efficacy, x= herbicide rate, a = y intercept (Herbicide efficacy at zero herbicide rate) and b = estimated regression parameter that describe the slope of the line.

Herbicide efficacy was the same for both cultivars over pretilachlor rates (Tables 3 & 4). Averaged across rice cultivars, herbicide efficacy was significantly increased with increasing the rate of pretilachlor (Fig. 8). Herbicide efficacy was positively correlated with grain yield, plant height, tiller number, and LAI45, but negatively correlated with weed biomass, and relative yield loss (Table 5). Application of pretillachlor at recommended rate enhanced weed suppression, which in turn increases leaf area index. This resulted in grater herbicide efficacy.

Conclusions

This experiment illustrated that regardless of rice cultivars, the highest grain yield, tiller number per m^{-2}, grain number per panicle, rice biomass, leaf area index, and herbicide efficacy were recorded in plots received recommended rate (2 L ha^{-1}) of Pretilachlor, while the highest weed biomass and relative yield loss were found in plots received no herbicide. Moreover, no significant differences were found in grain yield, yield components, relative yield loss, harvest index, rice biomass, weed biomass, and herbicide efficacy between 'Hashemi' and 'Deylamani' as averaged across herbicide rates. 'Hashemi' was significantly taller than 'Deylamani', while 'Deylamani' produced greater leaf area compared to 'Hashemi'. The results suggest that rice grain yield significantly reduces when pretilachlor is used at lower than recommended rates.

Acknowledgment

Thanks to the Islamic Azad University, Rasht Branch for their financial support.

References

Ashton FM, Monaco TJ. 1991. Weed Science, Principles and Practices, 3rd Ed., John Wiley and Sons.

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

Begum M. 2006. Biology and Management of Fimbristylis miliacea (L.) vahl. PhD Thesis. University Putra Malaysia.

Chauhan BS, Johnson DE. 2010. Relative importance of shoot and root competition in dry-seeded rice growing with jungle rice (Echinochloa colona) and ludwigia (Ludwigia hyssopifolia). Weed Science **58**, 295–299. http://dx.doi.org/10.1614/WS-D-09-00068.1

Dhima K, Vasilakoglou I, Gatsis T, Eleftherohorinos I. 2010. Competitive interactions of fifty barley cultivars with *Avena sterilis* and *Asperugo Procumbens*. Field Crops Research **117**, 90–100. http://dx.doi.org/10.1016/j.fcr.2010.02.004

FAO (Food and Agriculture Organization of the United Nations). 2011. FAOSTAT statistical database. [Online]. Available at http://faostat.fao.org/site/339/default.aspx

Fischer AJ, Ramirez H, Gibson KD, Pinheiro BDS. 2001. Competitiveness of semidwarf upland rice cultivars against palisadegrass (*Brachiaria brizantha*) and signalgrass (*B. decumbens*). Agronomy Journal, **93**,967-973. http://dx.doi.org/10.2134/agronj2001.935967x

Garrity DP, Movillon M, Moody K. 1992. Differential weed suppression ability in upland rice cultivars. Agronomy Journal **84**, 586-591. http://dx.doi.org/10.2134/agronj1992.00021962008400040009x

Gealy RD, Wailes EJ, Leopoldo E, Estorninos Jr, Chavez RSC. 2003. Rice cultivar differences in suppression of barnyardgrass (*Echinochloa crus-galli*) and economics of reduced propanil rates. Weed Science **51**, 601–609. http://dx.doi.org/10.1614/0043-1745(2003)051[0601:RCDISO]

Gomez KA. 1972. Techniques for field experiment with rice. International Rice Research Institute, Los Banos, 48P.

Haefele SM, Johnson DE, M'Bodj D, Wopereis MCS, Miezan KM. 2004. Field screening of diverse rice genotypes for weed competitiveness in irrigated lowland ecosystems. Field Crops Research **88**, 39–56. http://dx.doi.org/10.1016/j.fcr.2003.11.010

Jannink JL, Orf JH, Jordan NR, Shaw RG. 2000. Index selection for weedsuppressive ability in soybean. Crop Science, **40**, 1087-1094. http://dx.doi.org/10.2135/cropsci2000.4041087x

Korai A, Morita H. 2003. Evaluation of the suppression ability of rice (Oryza sativa) on Monochoria vaginalis by measuring photosynthetic photon flux density below rice canopy. Weed Biology and Management **3**, 172–178. Doi: http://dx.doi.org/10.1046/j.1445-6664.2003.00104.x

Lesnik M. 2003. The impact of maize stands density on herbicide efficiency. Plant, Soil and Environment **49(1)**, 29–35.

Ni H, Moody K, Robles RP, Paller EC, Lales JS. 2000. *Oryza sativa* (L.) plant traits conferring competitive ability against weeds. Weed Science **48**, 200-204.

SAS, version 9.1.3. 2004. SAS Institute. Cary, NC, USA.

Singh I, Ram M, Nandal DP. 2007. Efficacy of new herbicides for weed control in transplanted rice under rice-wheat system. Indian Journal of Weed Science **38**, 28-31.

Watson PR, Derksen DA, Van Acker RC. 2006. The ability of 29 barley cultivars to compete and withstand competition. Weed Science **54**, 783–792. http://dx.doi.org/10.1614/WS-05-020R3.1

Zhao DL, Atlin GN, Bastiaans L, Spiertz JHJ. 2006. Comparing rice germplasm for growth, grain yield, and weed-suppressive ability under aerobic soil conditions. Weed Research **46**, 444-452. http://dx.doi.org/10.1111/j.1365-3180.2006.00529.x

Zhao DL, Atlin GN, Bastiaans L, Spiertz JHJ. 2006b. Cultivar weed competitiveness in aerobic rice: Heritability, correlated traits, and the potential for indirect selection. Crop Science **46**, 372-380. http://dx.doi.org/10.2135/cropsci2005.0192