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EFFECTS OF CROP DENSITY AND REDUCED RATES OF PRETILACHLOR ON WEED CONTROL AND GRAIN YIELD IN RICE

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ABSTRACT

Field experiments were conducted at Rice Research Station of Tonekabon, Iran, to determine if increased rice plant density improves weed control and reduces herbicide application rate. In both years, the experimental design was split plot where the whole plot design was a randomized complete block with four replicates. Main plots were herbicide rates (0, 0.5, 1, 1.5, and 2 L ha^{-1} of Pretilachlor) and subplots were plant densities (16, 25 and 33 plants m^{-2}). Results showed that at high rice density, rice grain yield increased significantly from 1927 kg ha^{-1} to 3217 kg ha^{-1} as the rate of pretilachlor increased from 0 to 1.5 L ha^{-1}, but there was no further increase in yield above this rate. At medium and low densities, grain yield increased significantly as the rate of pretilachlor increased from 0 to 2 L ha^{-1}. In plots treated with recommended rate of pretilachlor (2 L ha^{-1}), there were no significant differences for grain yield among the crop densities, whereas in untreated plots, the grain yield increased by 51% from low to high crop density. For the 0, 25%, 50%, and 75% of recommended rates, weed biomass decreased significantly with increasing rice density, while for the 100% of recommended rate, weed biomass was unaffected with increasing crop density. This study illustrated that planting rice at higher density can reduce herbicide rate by 25% without adverse effect on grain yield, and can be an important component of integrated weed management strategy in lowland rice systems.

Key words: chemical control, cultural control, crop density, integrated weed management.

ABBREVIATIONS: D, plant density; DAT, days after transplanting; GN, grain number per panicle; H, herbicide rate; HE, herbicide efficacy; LAI25 and LAI45, leaf area index for 25 and 45 days after transplanting, respectively; ThGW, 1000 grain weight; TN, tiller number/m^2; WB, weed biomass; Y, grain yield.

INTRODUCTION

Weeds are the greatest constraint to yield in rice production systems. Overall, *Echinochloa crus-galli* (L.) P. Beauv, *Cyperus difformis* L., *Scirpus juncoides* Roxb., *Scirpus maritimus* L., *Scirpus mucronatus* L., *Sagittaria trifolia* L., and *Alisma plantago-aquatica* L. are the most dominant weed species in rice paddy fields of northern Iran. Weeds compete with rice for space, nutrients, water and light. Yield reduction due to weeds competition has been reported to be up to 15% in rice (Baltazar and DeDatta, 1992), affecting both the number of fertile tillers/m^2, number of grains per panicle, and 1000-grain weight. Uncontrolled growth of weeds in paddy reduced the grain yield by 62.6% (Singh et al., 2005) or even 100% (Kropff, 1993) in transplanted rice. On the other hand, some weeds serve as alternate hosts for pests and diseases. Therefore, weed management is a key element in rice production systems.

Herbicides have been intensively used for weed control in many crops, especially rice. Pretilachlor 50% EC[1] is a selective systemic herbicide used as pre-emergence herbicide in transplanted rice fields for controlling grasses, broadleaf weeds, and sedges. It absorbed primarily by the germinating shoots, and secondarily by the roots, with translocation throughout the plant.

Recently, increasing environmental contamination, economic pressure, and the development of herbicide resistance have led to a reduction in herbicide use in conventional farming (Lemerle et al., 2001). On the other hand, hand-weeding is the main

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[1] -chloro 2'6'diethyl N (2-propoxyethyl) acetanilide

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mechanical weed control used by traditional rice farmers in Iran, but is high time-consuming and extensive labour-intensive. These highlighted the need for integrated weed management (IWM) programmes (Cowan et al., 1998).

Agronomic practices such as crop rotation, crop density, and spatial arrangement can be manipulated to reduce weed interference in some crop-weed associations. As crop density increases, the area occupied by weeds are lessened, the availability of growth resources to weeds reduced, and subsequently crop yield loss is reduced. Crop density can be manipulated to maximize the interception of photosynthetically active radiation (PAR) by a crop while minimizing PAR interception by weeds (Limon-Ortega et al., 1998). Mohler (2001) documented that crop density affected crop competition with weeds. Wilson et al. (1995) reported that increased wheat density not only reduced weed biomass but also reduced number and dry weight of weed seeds.

Some researchers reported that weed biomass decreased and grain yield increased as crop density increased (Eslami et al., 2006; Olsen and Weiner, 2005).

At the same time, it was hypothesized that increased crop density can partially reduce herbicide application rate. Increasing crop density has been cited as a means to facilitate reduced herbicide use (Nazarko et al., 2005; Blackshaw et al., 2005). Walker et al. (2002) observed that maximum wheat yield and reduction in seed production of *Avena ludoviciana* was achieved with approximately 130 wheat plants m^{-2} and weeds treated with herbicide at 75% of recommended rate. Alternatively, this benefit was achieved by increasing wheat density to 150 plants m^{-2} applied with 50% herbicide rate (Walker et al., 2002).

There is little information on the effect of increased rice density on herbicide application rate in lowland rice systems.

Therefore, the objectives of this study were to investigate whether increased rice density improves weeds control, and whether there is a trade-off between crop density and herbicide rate.

MATERIAL AND METHODS

Experimental design, plant growth conditions, and sampling

Field experiments were conducted in 2011 and 2012 on a lowland rice field at Tonekabon’s Rice Research Station (36^{o} 51' N, 50^{o} 46' E), Iran. Monthly precipitation and temperature are shown in Table 1. Soil properties were 2.4% organic matter content, 30% clay, 45% silt, 25% sand, 6.9 PH. In both years, the experimental design was split plot where the whole plot design was a randomized complete block with four replicates. Main plots were herbicide rates (0, 0.5, 1, 1.5, and 2 L ha^{-1} of Pretilachlor) (0, 25, 50, 75, and 100% of recommended rate, respectively) applied at six days after transplanting (DAT). The subplots were plant densities (20, 25, and 33 plants m^{-2}, at planting distance of 20×25, 20×20, and 20×15 Cm, respectively). Main plots were 6 by 4 m; subplots were 2 by 4 m. Rice Cv. Daylamani seedlings were manually transplanted on May 20, 2011, and May 19, 2012. The plots were fertilized with a basal application of 25 kg N as urea, 70 kg P as triple super phosphate and 100 kg K as KCl per hectare; an additional topdressing of 25 kg N as urea was made at 40 DAT.At maturity stage, yield components of rice were measured according to Gomez (1972). Rice grain yield (based on 14% humidity) and weed biomass were determined from 2.5 m^{2} per plot. Weed biomass from each plot was dried at 70 °C for 96 h, and weighted.

Statistical analyses

The relationship between rice grain yield and herbicide rate was described using the following exponential model:

$$Y = a \exp (bx) \qquad [1]$$

Where Y is estimated grain yield as a function of herbicide rate (x), a is y intercept at 0 herbicide rate, and b is estimated regression parameter.

The relationship between weed biomass and herbicide rate was described using the following exponential model:

$$Y=a/(1+\exp(-(X-X0)/b)) \qquad [2]$$

Where y is estimated weed biomass as a function of herbicide rate (x), a is weed biomass in the absence of herbicide application, x_0 is the herbicide rate where 50% inhibition occurred, b is estimated regression parameter.

The herbicide efficacy was calculated from the following equation (Lesnik, 2003):

$$HE = \frac{W_{Un} - W_T}{W_{Un}} \qquad [3]$$

Where HE is the herbicide efficacy, W_{Un} is weed dry weight in non treated plot with herbicide; W_T is weed dry weight in treated plot with herbicide.

The relationship between the herbicide efficacy and herbicide rate was described using the following linear model:

$$Y= ax + b \qquad [4]$$

Where y is the herbicide efficacy as a function of herbicide rate (x), b is y intercept and a is estimated regression parameter.

Analyses of variance were conducted using SAS procedures (SAS Inst., 1990). Means were compared using Fisher's protected LSD test at $\alpha=0.05$. If the analysis of variance indicated a significant F value for herbicide rate, a linear or quadratic 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).

Table 1. Monthly precipitation and temperature from April to September in 2011 and 2012 at Tonekabon's Rice Research Station

Month	Precipitation (mm)		Temperature (°C)					
			Maximum		Minimum		Average	
	2011	2012	2011	2012	2011	2012	2011	2012
April	39.6	7.2	16.6	19.4	10.7	11.8	13.6	15.6
May	10.4	29.2	21.9	25.3	16.5	18.3	19.2	21.8
June	73.9	115.8	26.8	27.5	20.8	20.5	23.8	24
July	2.9	127.4	31.4	29.1	24.2	22.8	27.8	25.9
August	131.3	86.1	28.8	30.9	23.1	24.2	25.9	27.5
September	271.1	81.9	25.4	26.3	19.7	20.7	22.5	23.5

RESULTS AND DISCUSSION

Grain yield and weed biomass

The ANOVA indicated that the effects of herbicide rate (H), and rice density (D) were highly significant ($P<0.001$) for grain yield and weed biomass (Table 2). The effect of year (Y) was significant ($P<0.001$) only for grain yield. Moreover, the interaction between herbicide rate and rice density was significant at 0.05 and 0.01 probability level for grain yield and weed biomass, respectively. On the other hand, the interaction effects of Y×H, Y×D, and Y×H×D were not significant (Table 2); thus means were presented as the average of two years for both grain yield and weed biomass. Grain yield was significantly lower in 2011 (2480 kg ha^{-1}) than 2012 (2249 kg ha^{-1}), because the weather was more rainy and cloudy during grain filling period in 2011 compared to 2012 (Table 1). Moreover, increases in rice lodging due to heavier rainfall in 2011 than 2012 also reduced rice grain yield. Rice grain yield increased significantly from 1927 kg ha^{-1} to 3217 kg ha^{-1} as the rate of pretilachor increased from 0 to 1.5 L ha^{-1}, but there was no further increase in yield above this rate (2 L ha^{-1}) at high rice density (Figure 1). In contrast, rice grain yield increased significantly as the rate of pretilachlor increased from 0 to 2 L ha^{-1} at medium and low rice densities. In other words, for plots with high rice density, the maximum grain yield (3217 kg ha^{-1}) was achieved by applying the rate of 1.5 L ha^{-1} of pretilachlor, whereas for plots with medium and low densities, the maximum grain yield (3387 and 3412 kg ha^{-1} for medium and low densities, respectively) was achieved by applying the rate of 2 L ha^{-1} of pretilachlor. It seems likely, that this was mainly due to increased weed suppression with applying the rate of 1.5 L ha^{-1} of pretilachlor at high crop density. Moreover, for the 0, 25%, 50%, and 75% pretilachlor rates, yields increased significantly with increasing rice density from 16 to 33 plants m^{-2} while, for the 100% pretilachlor rate, yield was either unaffected or slightly adversely affected with increasing rice density. Rice grain yield was 1.7, 2.1, and 2.6 times higher at high, medium, and low crop density, respectively, in plots receiving 2 L ha^{-1} of pretilachlor compared to the plots without herbicide. In plots treated with recommended rate of pretilachlor (2 L ha^{-1}), there were no significant differences for grain yield among the crop densities, whereas in untreated plots, the grain yield increased by 27% from low to medium density, 19% from medium to high density, and 51% from low to high density. In other words, in the presence of weeds, untreated plots or plots treated below recommended rates, highest grain yield was obtained under high rice density. If weeds are present and not abundant, plots treated with recommended rate, the effect of crop density on grain yield are small or nonexistent because plasticity in the growth of crop plants allows them to produce more tillers and to occupy all available space at low density (Weiner et al., 2001; Kristensen et al., 2008). Similar results were reported for wheat by Weiner et al. (2001), Walker et al. (2002) and Kristensen et al. (2008). Weed biomass over herbicide rate and crop density within each year was 199.7 g m-^{2} in 2012 and192.7 g m^{-2} in 2013. At each crop density, weed biomass did not significantly decrease as the rate of pretilachlor increased from 0 to 0.5 L ha^{-1}, but significantly decreased with further increases in pretilachlor rate (Figure 2).

The lowest weed biomass (24 g m^{-2}) was observed at the highest crop density and herbicide application rate. This is consistent with the results of Lemerle et al. (2001) and Kristensen et al. (2008), who found that weed biomass was reduced with increasing crop density. There was an average 62% reduction in weed biomass for plots which did not receive herbicide and had highest crop density compared to the plots with the same herbicide rate and lowest crop density. The reduction in weed biomass decreased to 60% in plots which received 2 L ha^{-1} of pretilachlor and had highest crop density compared to the plots with the same herbicide rate and lowest crop density. For the 0, 25%, 50%, and 75% pretilachlor rates, weed biomass decreased significantly with increasing rice density, while for the 100% pretilachlor rate; weed biomass was unaffected with increasing rice density. In untreated plots, weed biomass decreased by 22% from low to medium density, 21% from medium to high density, and 38% from low to high density.

Table 2. Mean squares from the combined analysis of variance for rice grain yield (Y), tiller number m^{-2} (TN), grain number panicle^{-1} (GN), 1000-grain weight (ThGW), weed biomass (WB), leaf area index for 25 and 45 (LAI25 and LAI 45) days after transplanting, and herbicide efficacy (HE) as affected by herbicide rate (H) and plant density (D)

Source	df	Y	TN	GN	ThGW	WB	LAI_{25}	LAI_{45}	HE
Year (Y)	1	1203349^{**}	513^{ns}	76^{ns}	0.009^{ns}	1090^{ns}	0.00128^{*}	0.75^{ns}	52.7^{ns}
R (Y)	4	404837^{**}	3757^{ns}	29^{ns}	0.277^{ns}	2556^{ns}	0.00030^{ns}	0.237^{**}	515.4^{***}
Herbicide rate (H)	4	39978034^{***}	83417^{***}	2793^{***}	2.340**	296815***	0.00044^{ns}	3.053***	25322.9***
H * Y	4	48280^{ns}	462^{ns}	6^{ns}	0.010^{ns}	614^{ns}	0.00002^{ns}	0.016^{ns}	27.0^{ns}
Density (D)	2	3569143^{***}	36780^{***}	1054^{***}	0.363^{ns}	76500***	0.03045***	1.149***	2120.4***
H * D	8	1568889^{*}	6042^{ns}	235^{**}	0.465^{ns}	4664 **	0.00004^{ns}	0.039^{ns}	314.4 ***
D * Y	2	7086^{ns}	656^{ns}	6^{ns}	0.016^{ns}	7^{ns}	0.00056^{ns}	0.001^{ns}	10.6^{ns}
H * D * Y	8	39769^{ns}	745^{ns}	2^{ns}	0.323^{ns}	248^{ns}	0.00005^{ns}	0.007^{ns}	13.2^{ns}
Error	40	78156	697	74	0.458	1495	0.00033	0.031	57.16

*, **, ***: significant at the 0.05, 0.01, and 0.001 probability levels, respectively;
ns, not significant at the 0.05 probability level.

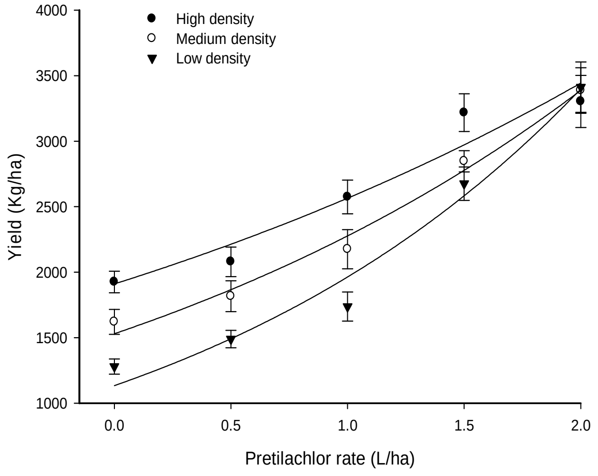

Figure 1. Effect of pretilachlor rate on grain yield averaged over two years at high (●), medium (○), and low (▼) rice density [Vertical bars represent ± 1 SE of means

Fitted lines are based on the equations: $y = 1910.00 \exp(0.29x)$, $R^2 = 0.93$ (high crop density); $y = 1529.82 \exp(0.39x)$, $R^2 = 0.98$ (medium crop density); $y = 1133.62 \exp(0.54x)$, $R^2 = 0.97$ (low crop density)]

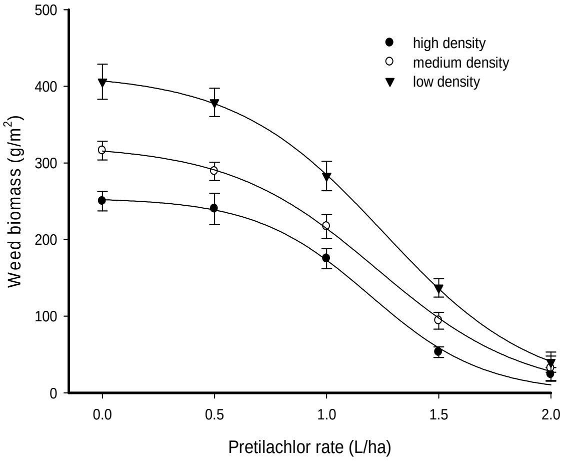

Figure 2. Effect of pretilachlor rate on weed biomass at high (●), medium (○), and low (▼) rice density. Actual data are averaged over two years. [Vertical bars represent ± 1 SE of means. Fitted lines are based on the equations: $y = 256.45/(1 + \exp(-(x - 1.27)/-0.31))$, $R^2 = 0.99$ (high crop density); $y = 322.14/(1 + \exp(-(x - 1.34)/-0.36))$, $R^2 = 0.99$ (medium crop density); $y = 411.94/[1 + \exp(-(x - 1.39)/-0.35)]$, $R^2 = 0.99$ (low crop density)]

O'Donovan et al. (2006) determined that wild oat biomass after the use of reduced herbicide rates was lower when wheat seeding rates were higher than normal. Rice grain yield was positively correlated with tiller number per m^2, grain number per panicle, leaf area at 25 and 45 DAT, but negatively correlated with weed biomass (Table 3). The negative correlation between grain yield and weed biomass has been repeatedly demonstrated by other researchers (Lemerle et al., 2001; Weiner et al., 2001; Walker et al., 2002; Kristensen et al., 2008; Safdar et al., 2011).

Table 3. Correlation coefficients for grain yield (Y), tiller number/m^2 (TN), grain number per panicle (GN), 1000-grain weight (ThGW), weed biomass (WB), leaf area index for 25 and 45 (LAI25 and LAI45) days after transplanting, and herbicide efficacy (HE) as influenced by herbicide rate and plant density averaged across two years

Parameters	Y	TN	GN	ThGW	WB	LAI25	LAI45
TN	0.81***						
GY	0.76***	0.59***					
ThGW	0.12^{ns}	0.17^{ns}	0.14^{ns}				
WB	-0.88***	-0.76***	- 0.76***	- 0.15^{ns}			
LAI 25	0.31**	0.47**	0.07^{ns}	0.21*	- 0.31**		
LAI 45	0.95***	0.81***	0.67***	0.18^{ns}	- 0.83***	0.41***	
HE	0.95***	0.70***	0.70***	0.18^{ns}	- 0.93***	0.23*	0.78***

*, **, and *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively;
ns: non significant.

Tiller number

Herbicide rate (H) and rice density (D) had significant ($P<0.001$) effects on tiller number /m^2, but all 2- and 3-way interactions were not significant at 0.05 probability level (Table 2). Regardless of rice density and year, tiller number followed a positive linear relationship as pretilachlor application rate increased from 0 to 2 L ha^{-1} (Figure 3).

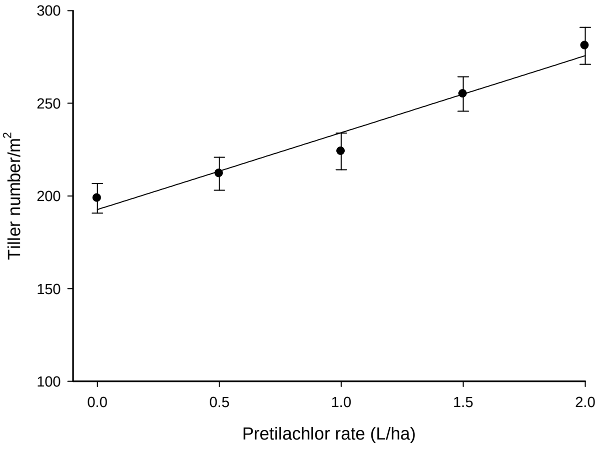

Figure 3. Effect of pretilachlor rate on tiller number per m^2 as averaged across rice densities and years (Vertical bars represent ± 1 SE of means. Fitted lines are based on the equations: $y = 192.6 + 41.5\ x$, $R^2 = 0.94$)

In plots which received no herbicide or lower than recommended rate, tiller number was significantly reduced due to weed competition. Nutrient limitation, especially nitrogen, is an important factor for reducing the tiller number under weedy conditions (due to reduced herbicide rates).

Averaged across years and pertilachlor application rates, tiller number m^{-2} increased from 210 to 259, as plant density increased from 20 to 33 plants m^{-2} (Table 4). A significant and negative correlation ($P<0.001$, $r=-0.76$) was observed between Tiller number/m^2 and weed biomass (Table 3). Based on the findings of this correlation analysis, tiller number appears to be a trait that improves crop competitiveness against weeds. In contrast, it has been reported that competitiveness of barley cultivars did not relate to tiller number (Paynter and Hills, 2009).

Grain number per panicle

There were strong effects of herbicide rate, crop density ($P<0.001$) and their interactions ($P<0.007$) on grain number. In contrast, the main effect of year (Y) and the interaction effects of Y×H, Y×D, and Y×H×D were not significant (Table 2). Grain number per panicle increased more sharply at low crop density than at medium and high densities as pretilachlor rate increased from 0 to 2 L ha^{-1} (Figure 4).

At each crop density, maximum and minimum grain numbers were obtained when herbicide was applied at 0 and 100% of the recommended rates, respectively. In plots treated with recommended rate of pretilachlor (2 L ha^{-1}), grain number per panicle was significantly higher for low and medium densities than for high density. When the herbicide was applied at 75% of the recommended rate, grain number per panicle was not affected by crop density. On the other hand, grain number per panicle was significantly higher for high and medium densities than for low density when herbicide was applied at 0 and 50% of recommended rates (Figure 4).

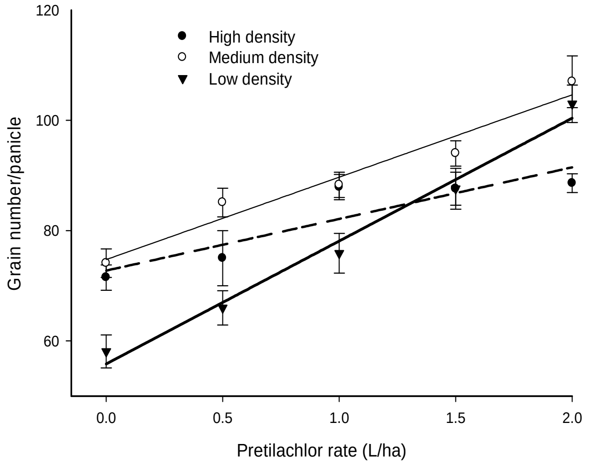

Figure 4. Effect of pretilachlor rate on grain number per panicle at high (●), medium (○), and low (▼) rice density. Actual data are averaged over two years. [Vertical bars represent ± 1 SE of means. Fitted lines are based on the equations: $y = 72.7 + 9.3\ x$, $R^2 = 0.75$ (high crop density); $y = 74.7 + 14.9\ x$, $R^2 = 0.94$ (medium crop density); $y = 55.8 + 22.2\ x$, $R^2 = 0.97$ (low crop density)]

Table 4. Effect of rice density on tiller number, LAI at 25 days after transplanting (LAI 25), and LAI at 45 days after transplanting (LAI45) as averaged across pretilachlor rates and years

Density	Traits		
	Tiller number (No/m)	LAI25	LAI45
High density	259	0.16	1.78
Medium density	233	0.12	1.53
Low density	210	0.09	1.39
LSD (0.05)	14	0.01	0.10

Thousand-grain weight

Thousand-grain weight was significantly affected by herbicide rate. Other main effects and all interactions were not significant (Table 2). Thousand-grain weight was significantly increased from 27.2 g to 28.1 g as the rate of herbicide increased from 0 to 1 L ha^{-1}, but it was significantly reduced at the highest herbicide application rate (Figure 5). The reduction in thousand-grain weight at high weed density (due to low herbicide application) was likely caused by interspecific competition for light and nutrients during grain filling period. Specially, some weeds such as barnyardgrass being taller than the rice plants (Yamasue, 2001) resulted in a reduction in rice plant photosynthesis in grain filling period.

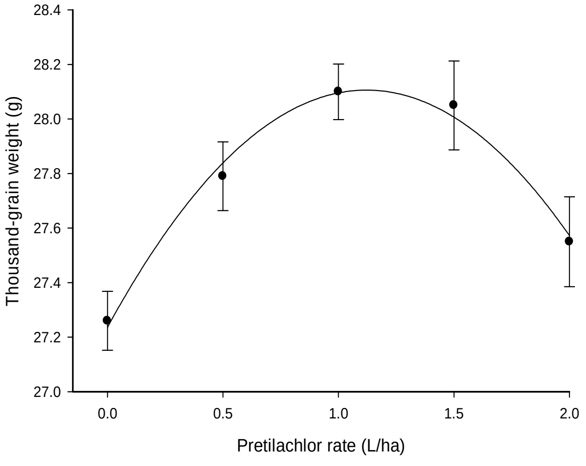

Figure 5. Effect of pretilachlor rate on 1000 grain weight as averaged across rice densities and years (Vertical bars represent ± 1 SE of means. Fitted lines are based on the equation: $y = 27.2 + 1.55x - 0.69x^2$, $R^2 = 0.97$)

Yang (1995) reported that 1000-grain weight was significantly reduced in rice cultivars under weedy conditions (due to reduced herbicide rates). In contrast, some researchers (Heafele et al., 2004; Zhao et al., 2006) demonstrated that weeds had no significant effect on 1000 grain weight.

Leaf area index at 25 and 45 days after transplanting

Leaf area index at 25 DAT (LAI25) was significantly influenced only by plant density, while Leaf area index at 45 DAT (LAI45) was significantly affected by plant density and herbicide rate (Table 2). This indicates that the severe competition did not occur between rice and weeds until 25 DAT, and therefore leaf area index of rice was unchanged with increasing herbicide application rate. In contrast, the severe competition between rice and weeds at 45 DAT caused a reduction in rice LAI in plots which received no herbicide or lower than recommended rates. All interaction effects were not significant for LAI at 25 and 45 DAT. LAI at 25 and 45 DAT were significantly increased with increasing plant density; which were the highest (0.16 and 1.78 at 25 and 45 DAT, respectively) and lowest (0.09 and 1.39 for 25 and 45 DAT, respectively) for 33 and 16 plants m^{-2}, respectively (Table 4).

With increasing herbicide application rate from 0 to 2 L ha^{-1}, LAI45 was significantly increased from 1.12 to 2.10 (Figure 6). It seems that herbicide application at recommended rate strongly suppressed weeds, which in turn alleviated the competition between rice and weeds and increased rice leaf area index. The reduction in LAI due to weed competition was also found by other researchers (Johnson et al., 1998; Karimmojeni et al., 2010; Aminpanah et al., 2012). Leaf area at 25 and 45 DAT exhibited significant negative correlation with weed biomass. It is obvious that an increase in LAI at higher crop density is associated with great reduction in weed biomass as a consequence of reduced light transmittance. At the same time, Ballare et al. (1990) stated that leaf area can also influence the transmitted radiation qualitatively by changing the red/far-red ratio.

So, the possibilities of changes of this ratio under high crop density are apparent and may also influence the results of weed:crop competition (Korres and Froud-Williams, 2002). In contrast, Paynter and Hills (2009) reported that competitiveness of barley cultivars did not appear to be strongly related to morphological traits that affect light interception such as canopy closure, plant height, and tiller number.

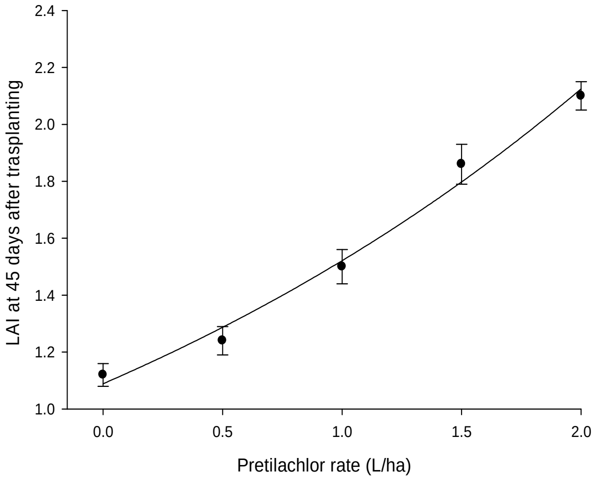

Figure 6. Effect of pretilachlor rate on LAI at 45 days after transplanting (DAT) as averaged across rice densities and years
(Vertical bars represent ± 1 SE of means. Fitted lines are based on the equation: $y = 0.33 + 1.08\ x$, $R^2 = 0.98$)

Herbicide efficacy

There were significant effects of herbicide rate (H) and crop density (D) on herbicide efficacy (Table 2). Moreover, the interaction between herbicide rate and crop density was also significant ($P<0.001$). In contrast, the main effects of year (Y), and the interaction effects of Y×H, Y×D, and Y×H×D were not significant (Table 2).

For each crop density, the relationship between herbicide rate and herbicide efficacy was fitted by a linear curve averaged across years. Herbicide efficacy was significantly increased from 38 to 93% (at high density), from 27 to 92% (at medium density), and from 5 to 90% (at low density) as herbicide rate increased from 0.5 to 2 L ha^{-1} (Figure 7).

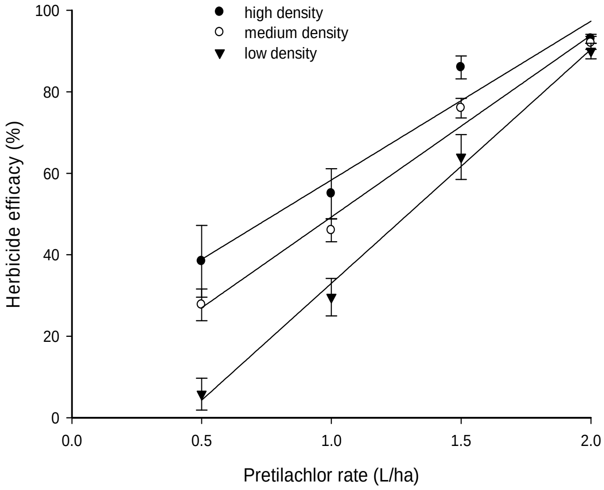

Figure 7. Effects of pretilachlor rate on herbicide efficacy at high (●), medium (○), and low (▼) rice density. Actual data are averaged over two years. [Vertical bars represent ± 1 SE of means. Fitted lines are based on the equations: $y = 19.4 + 38.9\ x$, $R^2 = 0.92$ (high crop density); $y = 4.7 + 44.5\ x$, $R^2 = 0.97$ (medium crop density); $y = -24.4 + 57.4\ x$, $R^2 = 0.99$ (low crop density)]

Application of pretilachlor at recommended rate increased weed suppression and decreased weed biomass, thus herbicide efficacy increased. This result is consistent with result from a previous study that documented that reduction in herbicide dose always caused a significant reduction in herbicide efficiency (Lesnik, 2003). When the herbicide was applied at 25 and 50% of the recommended rates, herbicide efficacy was significantly greater for high and medium densities than for low density. At 75% of recommended rate, herbicide efficacy was significantly greater at high crop density (86%), followed by medium crop density (76%), and then low crop density (64%). When the herbicide was applied at 100% of the recommended rate, there was no significant difference for herbicide efficacy among crop densities (Figure 7).

This finding is similar to the result of Lesnik (2003), who reported that herbicide efficacy increased with increasing crop density. Correlation analysis (Table 3) showed that herbicide efficacy was positively correlated with grain yield (P<0.001), tiller number/m^2 ($P<0.001$), grain number/panicle ($P<0.001$), Leaf area index at 25 DAT ($P<0.05$) and Leaf area index at 45 DAT ($P<0.001$) and negatively correlated with weed biomass ($P<0.001$).

CONCLUSIONS

This study highlighted that at high crop density (33 plants m^{-2}), there was no significant difference in grain yield between applying the herbicides at 75 and 100% of the recommended rate, but reducing rates below 75% of the recommended rate always resulted in lower grain yield, even at higher plant density.

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