Rice Grain Yield and Weed Growth as Affected by Plant Density and Pretilachlor Rate

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Increasing crop density has been suggested as a method to apply herbicides at below-recommended rates. A field experiment was conducted at the Rice Research Station of Tonekabon, Iran, to determine the effects of crop density and herbicide application rate on rice grain yield and weed growth. The experimental design was randomized complete block with split-plot arrangement and three replicates. Main plots were pretilachlor rates (0, 0.5, 1, 1.5 and 2 L ha⁻¹ of pretilachlor) and subplots were plant densities (25 and 33 plants per m²). Results showed that averaged across crop density, rice grain yield was significantly increased from 1394 to 3050 kg ha⁻¹ as herbicide rate increased from 0 to 2 L ha⁻¹. Tiller number per m² or grain number per panicle was significantly increased as pretilachlor rate increased from 0 to 1.5 L ha⁻¹, whereas there was no further increase in tiller number per m² or grain number per panicle above this rate. Rice grain yield increased by an average of 11% with increasing crop density from 25 to 33 plants per m², whereas there were no significant differences in tiller number per m², grain number per panicle and thousand-grain weight between crop densities. Weed biomass was significantly reduced from 293.1 to 31.3 g m⁻² as pretilachlor rate increased from 0 to 2 L ha⁻¹, and was significantly less in high crop density compared to low crop density. Herbicide efficacy was significantly increased from 12 to 90% as herbicide rate increased from 0.5 to 2 L ha⁻¹. Therefore, this experiment illustrated that the combination of high plant density with reduced rates of pretilachlor may not be an effective weed management strategy in transplanting rice system.

Key Words: herbicide, integrated weed management, rice

Abbreviations: D – plant density; GN – grain number per panicle; H – herbicide rate; HE –herbicide efficacy; LAI25 and LAI45 – leaf area index at 25 and 45 d after transplanting, respectively; ThGW – 1000-grain weight; TN – tiller number per m²; WB – weed biomass; Y – grain yield

INTRODUCTION

Rice (Oryza sativa L.) is the main staple food for more than half of the world’s population. In 2011, worldwide rice production exceeded 672 million mt. Iran ranked 20th in terms of rice production in the world (FAO 2011). Weeds are one of the most troublesome pests in rice production systems throughout the world. In northern Iran, rice fields contain a complex of weeds such as Echinochloa crus-galli (L.) P. Beauv., Scirpus juncoides Roxb., Scirpus maritimus L., Scirpus muconatus L., Cyperus difformis L., Alisma plantago-aquatica L. and Sagittaria trifolia L. that reduce grain yield if a proper weed management strategy is not applied. Yield reduction due to sub-optimal weed management in lowland rice was estimated at 16–68% (Kropff 1993).

Chemical control is still the predominant type of weed control in rice fields. Pretilachlor [2-Chloro-N-(2,6-diethylphenyl)-N-(2-propoxyethyl) acetamide] 50% EC, a selective systemic herbicide, is applied as pre-emergence in transplanted rice field for controlling grasses, sedges and some broadleaf weeds (Shim et al. 1990). It is absorbed principally by the germinating shoots, and partially by the roots. In Iran, this herbicide is extensively used by farmers for controlling weeds in rice fields.

Repeated use of herbicides in rice fields has already led to the evolution of resistance in the weed species to herbicides (Rao et al. 2007). Moreover, extensive use of herbicides can adversely affect nontarget organisms, including humans, and the environment. These conditions highlighted the need for integrated weed management
(IWM) programs (Hill et al. 1994). The aim of IWM is to use a combination of chemical, mechanical, biological and cultural methods to maintain weed densities at acceptable levels.

Using cultural methods such as increased crop density can reduce the amount of growth resources (light, water, nutrients, etc.) in weeds, which, in turn, reduces their competitive ability and seed production. O’Donovan (2006) reported that increasing the wheat density (through increasing seeding rate) reduced the biomass and seed production of wild oat. Likewise, manipulating row spacing in crops such as transplanted rice and corn that are generally planted as row crops also has potential to affect weed control. Blackshaw et al. (2000) documented that increasing plant density (through reducing row spacing) increased bean yield and improved weed control. Paynter and Hills (2009) reported that crop density influenced the competition between Barley and rigid ryegrass (Lolium rigidum).

It has been reported that crop production practice that reduces weed populations over time is important to the successful use of reduced herbicide doses. Increasing crop density has been suggested as a method to apply herbicides at below-recommended rates (Nazarko et al. 2005; Blackshaw et al. 2000; Blackshaw et al. 2005). Salonen (1992) reported that decreased suppression of weeds with reduced herbicide rates was partially compensated by increased crop seeding rates. At the same time, reduced herbicide rates have been documented as a means of slowing the development of herbicide resistance in weeds (Beckie and Kirkland 2003).

Extensive research has been conducted on the effect of increased crop density on herbicide application rate in various crops (Salonen 1992; Nazarko et al. 2005; Blackshaw et al. 2000; Blackshaw et al. 2005), but there is little information about the influence of this factor on herbicide application rate in lowland rice fields. Therefore, the objective of this study was to determine the effects of crop density and herbicide application rate on rice grain yield and weed growth.

MATERIALS AND METHODS

Experimental Design, Plant Culture and Management

Field experiment was conducted on a lowland rice field at the Rice Research Station of Tonekabon (36°51’N, 50°46’E), Iran, in 2011. Total monthly precipitation and maximum, minimum, and average air temperatures during rice growing period are presented in Table 1. Soil properties were 2.4% organic matter content, 30% clay, 45% silt, 25% sand, and 6.9 pH.

The experimental design was randomized complete block with split-plot arrangement and three replicates.

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation (mm)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>39.6</td>
<td>16.6</td>
</tr>
<tr>
<td>May</td>
<td>10.4</td>
<td>21.9</td>
</tr>
<tr>
<td>June</td>
<td>73.9</td>
<td>26.8</td>
</tr>
<tr>
<td>July</td>
<td>2.9</td>
<td>31.4</td>
</tr>
<tr>
<td>August</td>
<td>131.3</td>
<td>28.8</td>
</tr>
<tr>
<td>September</td>
<td>271.1</td>
<td>25.4</td>
</tr>
</tbody>
</table>

Main plots were pretilachlor rates (0, 0.5, 1, 1.5, and 2 L ha⁻¹ representing 0, 25, 50, 75 and 100% of the recommended rate, respectively) and subplots were plant densities (25 and 33 plants per m², at planting distance of 20 cm × 20 cm and 20 cm × 15 cm, respectively). Individual subplots were 2 m wide by 4 m long. Pretilachlor was applied at 6 d after transplanting (DAT) in accordance with the manufacturer’s recommendation. Before final land preparation, 25, 75 and 100 kg ha⁻¹ N (as urea), P (as triple super phosphate), and K (as KCl), respectively, were broadcasted and incorporated into the soil by a traditional wooden leveler. Rice cv. Hashemi was manually transplanted on May 19, 2011. At 40 DAT, 25 kg N ha⁻¹ was top dressed.

Statistical Analyses

Analyses of variance were conducted using SAS procedures (SAS INSTITUTE 2004). Means were compared using Fisher’s protected LSD test at α=0.05. 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).

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

\[ y = a + bx + cx^2 \] [1]

where y is estimated grain yield as a function of herbicide rate (x), a is the y intercept (grain yield at zero herbicide rate) and b and c are estimated regression parameters that describe the slope of the line.
The relationship between weed biomass and herbicide rate was described using the following exponential model:

\[ Y = \frac{a}{1 + \exp\left(-\left(X - X_0\right)/b\right)} \]  \[ \text{(2)} \]

where \( Y \) is estimated weed biomass as a function of herbicide rate \( (X) \), \( a \) is weed biomass \( \text{(g m}^{-2}\text{)} \) with no herbicide treatment, \( X_0 \) is the effective dose required to reduce weed biomass by 50\%, and \( b \) is estimated regression parameter.

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

\[ HE = \frac{(W_{Un} - WT)}{W_{Un}} \]  \[ \text{(3)} \]

where \( W_{Un} \) is weed dry weight in nontreated plot with herbicide; \( W_T \) is weed dry weight in treated plot with herbicide.

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

\[ Y = ax + b \]  \[ \text{(4)} \]

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

RESULTS AND DISCUSSION

Yield and Yield Components

Analysis of variance showed that the main effect of herbicide rate was significant \((P<0.05)\) for grain yield, tiller number per \( \text{m}^2 \) and grain number per panicle, but not for 1000-grain weight (Table 2). On the other hand, the main effect of crop density was also found to be significant \((P<0.05)\) for grain yield, but not for the yield components. Interaction between herbicide rate and crop density was not significant for yield and yield components.

The quadratic regression model describing the response of rice grain yield to herbicide rate was significant at the 0.01 probability level \((r^2 = 0.96)\). Averaged across crop density, rice grain yield was significantly increased from 1394 to 3050 kg ha\(^{-1}\) as herbicide rate increased from 0 to 2 L ha\(^{-1}\) (Fig. 1). In other words, grain yield increased by 2.1 times in plots that received the recommended rate of pretilachlor compared with the plots that received no herbicide. This increase in yield was mainly due to better weed suppression at 100\% of the recommended application rate of pretilachlor.

The relationship between grain yield and weed biomass is expressed by a linear regression model (Fig. 2). Rice grain yield decreased with increasing weed biomass. This result clearly suggests that increasing weed growth could adversely affect crop grain yield most likely due to competition for nutrients and light. The negative correlation between grain yield and weed biomass was repeatedly reported by other researchers (Lemerle et al. 2001; Weiner 2001; Walker 2002; Kristensen et al. 2008). In contrast, grain yield increased with increasing herbicide efficacy (Fig. 3). Regression models describing the effects of herbicide rate on tiller number per \( \text{m}^2 \) and grain number per panicle were significant at 0.01 and 0.05 probability levels, respectively.

Tiller number per \( \text{m}^2 \) or grain number per panicle was significantly increased as pretilachlor increased from 0 to 1.5 L ha\(^{-1}\), whereas there was no further increase in tiller number per \( \text{m}^2 \) or grain number per panicle above this rate (Fig. 4 and 5). As grain yield in cereals such as rice is a function of tiller number per \( \text{m}^2 \) and grain number per panicle, therefore, increases in tiller number per \( \text{m}^2 \) and grain number per panicle at recommended rates of pretilachlor increased rice grain yield. Rice grain yield increased by an average of 11\% with increasing crop density from 25 to 33 plants per \( \text{m}^2 \), whereas there were no significant differences in tiller number per \( \text{m}^2 \), grain number per panicle and thousand-grain weight between crop densities (Table 2). This result supports the hypothesis that increases in crop density can increase grain yield. Similarly, Olsen et al. (2005) observed that wheat grain yield increased with increasing crop density. In contrast, Murphy et al. (2002) reported that wheat grain yield was relatively insensitive to increasing crop density.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Y</th>
<th>TN</th>
<th>GN</th>
<th>ThGW</th>
<th>LAI(_{25})</th>
<th>LAI(_{45})</th>
<th>WB</th>
<th>HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block (R)</td>
<td>2</td>
<td>340135†</td>
<td>178†</td>
<td>76 ns</td>
<td>2.1†</td>
<td>0.00020 ns</td>
<td>0.049 ns</td>
<td>773 ns</td>
<td>34.4 ns</td>
</tr>
<tr>
<td>Herbicide rate (H)</td>
<td>4</td>
<td>2725112‡</td>
<td>5137*</td>
<td>217‡</td>
<td>2.1‡</td>
<td>0.00018 ns</td>
<td>1.161***</td>
<td>86552***</td>
<td>9394.6***</td>
</tr>
<tr>
<td>Error (a)</td>
<td>8</td>
<td>35329</td>
<td>1132</td>
<td>33</td>
<td>6.9</td>
<td>0.00020</td>
<td>0.027</td>
<td>332</td>
<td>30.6</td>
</tr>
<tr>
<td>Density (D)</td>
<td>1</td>
<td>390336</td>
<td>2444 ns</td>
<td>120 ns</td>
<td>4.8 ns</td>
<td>0.01680***</td>
<td>0.552 ns</td>
<td>13167***</td>
<td>625.6*</td>
</tr>
<tr>
<td>H * D</td>
<td>4</td>
<td>555257‡</td>
<td>75 ns</td>
<td>170 ns</td>
<td>4.3 ns</td>
<td>0.00009 ns</td>
<td>0.029 ns</td>
<td>649 ns</td>
<td>85.9 ns</td>
</tr>
<tr>
<td>Error (b)</td>
<td>10</td>
<td>58964</td>
<td>1449</td>
<td>153</td>
<td>3.3</td>
<td>0.00051</td>
<td>0.044</td>
<td>594</td>
<td>44.3</td>
</tr>
</tbody>
</table>

\( ^* \text{and} ^{**} \text{and} ^{***} \text{– significant at the 0.05, 0.01, and 0.001 probability level, respectively.} \\
ns \text{– not significant at the 0.05 probability level.} \)
Leaf Area Index at 25 and 45 Days after Transplanting

As shown in Table 2, LAI25 was significantly affected \((P < 0.001)\) only by crop density \((D)\), while LAI45 only by the separate effects of herbicide rate \((H)\) and \(D\) (Table 2). LAI25 was significantly lower in low than in high crop density (Table 3). The quadratic regression model provided a better description for the relationship between LAI45 and herbicide rate (Fig. 6). LAI45 did not affect
Plant Density and Pretilachlor Rate on Rice Grain Yield

Table 3. Main effect of plant density on grain yield (Y), leaf area index at 25 (LAI 25) and 45 (LAI 45) d after transplanting, weed biomass (WB) and herbicide efficacy (HE).

<table>
<thead>
<tr>
<th>Density</th>
<th>Traits</th>
<th>Y (kg ha(^{-1}))</th>
<th>LAI 25</th>
<th>LAI 45</th>
<th>WB (g m(^{-2}))</th>
<th>HE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>2208</td>
<td>0.149</td>
<td>1.62</td>
<td>156.6</td>
<td>47.8</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>1978</td>
<td>0.102</td>
<td>1.35</td>
<td>198.5</td>
<td>38.6</td>
</tr>
</tbody>
</table>

**F-test**

<table>
<thead>
<tr>
<th>Density</th>
<th>Traits</th>
<th>Y (kg ha(^{-1}))</th>
<th>LAI 25</th>
<th>LAI 45</th>
<th>WB (g m(^{-2}))</th>
<th>HE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**,** *** – significant at 0.01 and 0.001 probability levels, respectively

![Graph](image.png)

**y = 0.96 + 0.42x + 0.04x^2, R^2=0.96, P < 0.01**

Weed Biomass and Herbicide Efficacy

For the main effects of herbicide rate (H) and crop density (D), their interaction was not significant for weed biomass and herbicide efficacy (Table 2). The relationship between weed biomass and pretilachlor rate was described by an exponential model (Fig. 7).

Regardless of crop density, weed biomass was significantly reduced from 293.1 to 31.3 g m\(^{-2}\) as pretilachlor rate was increased from 0 to 2 L ha\(^{-1}\) (Fig. 7). Averaged across pretilachlor application rates, weed biomass was significantly less in low crop density compared with high crop density, as an increase from low to high density resulted in 27% less weed biomass (Table 3).

A linear regression model described the relationship between herbicide rate and herbicide efficacy. Herbicide efficacy was significantly increased from 12 to 90% as herbicide rate was increased from 0.5 to 2 L ha\(^{-1}\) (Fig. 8). Application of pretilachlor at recommended rate increased weed suppression and decreased weed biomass, thus herbicide efficacy increased.

A negative linear relationship was observed between herbicide efficacy and weed biomass (Fig. 9). Herbicide efficacy was significantly greater in high crop density compared with low crop density (Table 3), indicating that weed biomass was reduced with increasing crop density. Lemerle et al. (2001) declared that at relatively low crop densities, crop cover at early growing season is low, leaving a larger amount of resources (water, nutrients and light) available for the weeds, thus enabling them to establish and grow quickly. Therefore, application of pretilachlor at recommended rate and increased plant density decreased weed competition. As weed competition decreased, the crop canopy expanded more rapidly (through greater tillering and greater leaf area production), more radiation was intercepted by the crop and, finally, more crop dry matter was produced. This finding is similar to the results of Lesnik (2003), O’Donovan et al. (2004), Walker et al. (2002) and O’Donovan et al. (2001), who reported that increasing the crop density can be a dependable means for improving the efficacy of herbicides applied at reduced rates. Herbicide efficacy was positively correlated with grain yield (r = 0.90***), tiller number (r = 0.59**), LAI25 (r = 0.39) and herbicide efficacy (r = 0.88***), but negatively correlated with weed biomass (r = −0.97***). A greater LAI due to higher crop density increased shading by rice canopies, increased weed suppression and decreased weed biomass, and subsequently enhanced herbicide efficacy (Weaver 1991). At the same time, as herbicide efficacy is, in part, weed density dependent (Sikkema et al. 2005; Belles et al. 2000), therefore shading the soil surface can decrease weed seed germination and enhance herbicide efficacy. These reduced the competition (interference) between rice and weeds and subsequently increased rice grain yield.

CONCLUSION

This study highlighted that at crop densities of 25 and 33 plants per m\(^2\), rice grain yield was significantly reduced when pretilachlor was applied at rates below the recommended (2 L ha\(^{-1}\)). However, rice grain yield was significantly increased (11%) with increasing crop density from 25 to 33 plants per m\(^2\).
REFERENCES CITED


