Research Paper

Determination of yield loss and economic threshold density of *Scirpus maritimus* in winter rice

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ABSTRACT

Rice is the staple food in Bangladesh. *Scirpus maritimus* infests rice heavily, causing enormous yield losses and threatening in the sustainability of the rice production system. Information on the interference and economic threshold (ET) of *S. maritimus* will be useful for the effective management of *S. maritimus* in rice. This will lead to the rationalization of herbicide use and the reduction of herbicide input into the environment. In this study, it was observed that the weed infestation levels of 80 or more *S. maritimus* plants per m² offered higher competition, leading to significant reductions in the growth (dry weight, height, crop growth rate, net assimilation rate and leaf area index) and yield of rice. The regression model was effective in simulating yield losses in relation to a wide range of *S. maritimus* dry matter. The weed dry matter–crop yield model was found to be effective in simulating rice yield losses in relation to a wide range of *S. maritimus* dry matter. The ET dry matter of *S. maritimus* were 18.39, 15.61 and 13.57 g/m² (4, 3 and 3 *S. maritimus* number m⁻², respectively) in first year at the 70, 80, and 90% control efficiencies, respectively, of the herbicide, Bensulfuron-methyl + Pretilachlor 6.6% GR. In the second year, the ET dry matter of *S. maritimus* were 15.06, 12.38 and 10.51 g/m² (3, 3 and 2 *S. maritimus* number m⁻², respectively) at the 70, 80, and 90% control efficiencies, respectively, of the herbicide. In rice cultivation, 10 to 18 g *S. maritimus* per m² (2 to 4 number m⁻²) could be allowed without economic yield loss.

Key words: Economic threshold, *Scirpus maritimus*, interference, rice, bensulfuron-methyl + pretilachlor 6.6% GR, weeds.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for half of the world’s population. About 90% of the world’s rice is grown in Asia (IRRI, 2006). Rice has a tremendous influence on agrarian economy of Bangladesh and constitutes 95% of the food grain production (Julfiquare et al., 1998). The average rice grain yield (3.40 t/ha) of Bangladesh is far below that of the world’s average (Anonymous, 2007).

Uncontrolled weeds cause rice grain yield losses ranging from 36 to 56% in the Philippines (Rao and Moody, 1994), 40 to 100% in South Korea (Kim and Ha, 2005) and 30 to 40% in Bangladesh (BRRI, 2006; Mamun, 1990). *Scirpus maritimus* is a perennial Cyperaceae weed (Holm et al., 1997) having 1 to 3 mm thick and ovoid tubers at nodes. Stems are erect, triangular in cross-section, smooth below the inflorescence and 15 to 180 cm tall at maturity. Upper leaves overtop the inflorescence. It is a serious weed of rice in Italy, Romania, Spain, Hungary and South Korea. Lieffers and Jennifer (1982) considered the plant to be the most important weed of wetland rice in the Philippines. Competition studies performed in rice crops in the Philippines found that *S. maritimus* occurring at 20 and 40 weeds/m² caused 80 to 100% yield loss if weeds were
present early in the rice growing period. *S. maritimus* exerted serious impacts on rice tiller, dry matter production and causes 40% yield loss (Lieffers and Jennifer, 1982). The presence of 45 to 250 *S. maritimus* plants per m² decreased rice yields by 7.7 to 65% in Russian (Lieffers and Jennifer, 1982).

Increasing the use of herbicides in agriculture is a primary concern today. Making appropriate decisions on weed management can result in a reduction in herbicide use (Das et al., 2010). The economies of herbicide use should be determined by a combination of weed control, yield loss, crop price, crop productivity, and herbicide and application costs. The weed's economic threshold (ET) is one of the main steps that are involved to develop a criterion for determining whether or not a chemical treatment against weed is necessary and economical (Cousens, 1987).

The ET of a weed is the density at which the cost of control measured equals the benefit that is obtained (Cussans et al., 1986). In general, the economic damage threshold is one of the important alternative weed management strategies in order to minimize the labor requirement for weeding operations and maximization of economic returns. The most weed ET levels are reported as a fixed number of plants. But, weed ET levels affected by several factors such as weed species, density and time of emergence, environment and management, crop variety and arrangement (O’Donovan, 1991; Cardina et al., 2000).

The threshold approach to weed management is successfully applied in Germany (Gerowitt and Heitefuss, 1990). However, the potential yield losses that can be inflicted by *S. maritimus* on rice have hardly been documented in Bangladesh or elsewhere. Therefore, this study was undertaken to appraise the interference effects of different densities of *S. maritimus* on the growth and yield of rice and to determine the ET of *S. maritimus* in winter rice.

**MATERIALS AND METHODS**

**Experimental site**

Two field experiments were conducted at research farm of Bangladesh Rice Research Institute, Gazipur of Bangladesh during winter season (November to May) in 2010 (year 1) and 2011 (year 2). Same field was used in both years (90° 33’ E longitude and 23° 77’ N latitude). The fields were characterized by different native weed species. The soil of the experimental field belongs to the Shallow Red Brown Terrace Soils. The soil was typical for the region, that is, loamy with pH 6.2 and 6.3 and organic matter content 1.4 and 1.5 in year 1 and 2, respectively. The region can be described as having a sub-tropical humid climate, with two distinct seasons: a winter season from November to May, and a summer season from June to October.

**Treatments**

The treatments consisted of 5, 10, 20, 40, 80 and 160 *S. maritimus* plants per m² as compared with weedy and weed-free check treatments. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. All weeds excluding *S. maritimus* were removed manually on their emergence at a regular interval through the crop cycle. Newly emerged weeds were uprooted to maintain desired number of *S. maritimus* m⁻².

**Rice variety and agronomic practices**

Land was ploughed one month before planting and then harrowed. Plot sizes were 1 m × 1 m. Ridge of 40 cm in height and 30 cm in width was constructed between plots. Rice (cv. RRRI dhan29, a semi-dwarf variety with growth duration of around 165 days, popular variety of Bangladesh) was planted on 15th and 17th January in year 1 and 2, respectively. Fertilizers such as nitrogen, phosphorus and potassium (N, P, and K) and sulphur (S) were applied at 120, 20, 50 and 10 kg/ha, respectively. The source of N, P, K and S were prilled urea, triple super phosphate (TSP), muriate of potash (MOP) and gypsum, respectively. Triple super phosphate, MOP and gypsum were applied at the time of final land preparation as basal and N was top dressed as three equal split at 20, 35 and 55 DATs. The plant spacing was 20 × 20 cm. Pesticides and herbicides were not applied during crop growth.

**Experimental measurements**

Height of all the weeds in 5 and 10 *S. maritimus* treatment plots; 10 *S. maritimus* and 10 rice plants in other treatments were measured at 10 days interval from 30 to 70 DAT. Then, relative weed height (RWH) was calculated. Weed samples were collected at 70 DAT and dry weight of weed was taken. The relative weed height (RWH) was calculated using following formula:

\[
RWH = \frac{\text{Weed height}}{\text{Crop height}}
\]  

\(1\)

**Determination of the physiological and agronomic parameters**

Rice crop growth rate (CGR) (g m⁻²) was calculated as follows:

\[
\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1}
\]  

\(2\)

Where, \(W_1\) and \(W_2\) are the dry weight of the plants per m².
(land area) at t₁ and t₂ DAT, respectively and t₂ > t₁.

The leaf area index (LAI) was calculated as follows:

\[ \text{LAI} = \frac{\text{leaf area of the plants (cm}^2/) \text{land area occupied by those plants (cm}^2) \times 100}{\text{}} \quad (3) \]

The net assimilation rate (NAR) (g m\(^{-2}\)) was calculated as follows:

\[ \text{NAR} = \frac{[W_2 - W_1 \ln L_2 - \ln L_1)] / ([t_2 - t_1] [L_2 - L_1])}{\} \quad (4) \]

Where, \(W_1\), \(W_2\), \(t_1\) and \(t_2\) are as defined earlier, \(L_1\) and \(L_2\) are the leaf area of the plants at \(t_1\) and \(t_2\) DAT, respectively, and \(\ln\) is the natural logarithm (Log₁₀).

**Estimation of weed dry matter and yield loss**

The percentage of yield loss of each infested plot was calculated according to Gill and Vijayakumar (1969), which is as follows:

\[ Y_L(\%) = \frac{Y_{wf} - Y}{Y_{wf}} \times 100 \quad (5) \]

Where, \(Y_L\) is the observed yield loss, \(Y_{wf}\) is the grain yield in weed-free plots and \(Y\) is the grain yield from each infested plot.

**Simulation of rice grain yield and yield loss**

**Rice versus S. maritimus dry matter**

The crop yield–weed dry matter response was asymptotic (Cousens, 1985a); therefore, a rectangular non-linear hyperbolic regression model was used to analyze the relationship between the rice yield (\(Y\)) and the \(S. \) maritimus dry matter (\(d\)):

\[ Y = Y_{wf} \left[ 1 - \frac{id}{100 (1 + id/a)} \right] \quad (6) \]

Where, \(Y\) is the simulated rice yield in a particular weed dry matter, \(Y_{wf}\) is the estimated weed-free crop yield, \(i\) is the percentage yield loss per unit of weed dry matter (\(d\)), as \(d\)→0 and \(a\) is the asymptote value of maximum yield loss (%), as \(d\)→∞.

The data were fitted to non-linear equations and the aforementioned parameters were estimated. The data and fitted curves were presented in terms of the percentage yield loss (\(Y_L\)) by using equation 7:

\[ Y_L = \frac{id}{1 + id/a} \quad (7) \]

Where, \(Y_L\) is the predicted yield loss (%) and \(i, d\) and \(a\) are as defined earlier.

**Economic threshold (ET) of \(S. \) maritimus**

The ET of \(Sm\) was determined by using the quadratic equation, as suggested by Cousens (1987):

\[ 1 + (i/a)(2 - h - [y p a h / c]) T + (i/a)^2 (1 - h) T^2 = 0 \quad (8) \]

Where “\(i\)” and “\(a\)” are as defined earlier and were calculated from Equation 1; “\(y\)” is the weed-free rice yield, “\(p\)” is the unit price of rice, “\(h\)” is the efficiency of the herbicide, “\(c\)” is the cost of weed control, and \(T\) is the ET weed dry matter.

In this study, the values were: \(i = 0.1761 \%; a = 26.51\%; y = 8.52 t/ha in year 1 and i = 0.2479\%; a = 14.45\%; y = 7.08 t/ha in year 2; h = 70, 80 and 90\%; p = 180.00 $ t^{-1}; and c = 30.00 $ ha^{-1} in both years.

Mamun et al. (2011) reported that bensulfuron-methyl + pretilachlor 6.6% GR (Londex power 6.6% GR) (Petro. Chem., Dhaka, Bangladesh) is a selective pre-emergence herbicide that can control \(S. \) maritimus by 70 to 90%. The cost of controlling \(S. \) maritimus using bensulfuron-methyl + pretilachlor 6.6% GR was 30.00 $ ha⁻¹ which included herbicide plus the application cost. The minimum support price for rice that was declared by the Government of Bangladesh was taken as the price for rice.

**Statistical analysis**

The data on rice and weeds were subjected to an ANOVA for the Randomized Complete Block Design (RCBD) by using MSTAT-C software (CIMMYT, Mexico City, Mexico) and the significance was tested by a variance ratio (that is, F-value) at the 5% level (Gomez and Gomez, 1984). The coefficient of variation and the least significant difference were worked out for all the variables of the studied crops and weeds in order to compare the treatment means.

**RESULTS**

**Relative weed height**

Weed density exerted significant effect on relative weed height (RWH) through out the crop growing period except 30 DAT. Relative weed height increased gradually with the increases of weed densities and advances of crop growing period (Table 1). At 30 DAT, the RWH was maximum with 20 and 80 \(S. \) maritimus m⁻² and minimum with 160 \(S. \) maritimus m⁻² in both years. Weed population influenced RWH significantly at 40 DAT in both years. The highest RWH obtained from control and the lowest one in 20 weed m⁻².
Table 1. Relative weed height at 30, 40, 50, 60 and 70 days after transplanting (DAT).

<table>
<thead>
<tr>
<th>Weeds (no/m²)</th>
<th>30 DAT</th>
<th>40 DAT</th>
<th>50 DAT</th>
<th>60 DAT</th>
<th>70 DAT</th>
<th>30 DAT</th>
<th>40 DAT</th>
<th>50 DAT</th>
<th>60 DAT</th>
<th>70 DAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.52</td>
<td>0.72bc</td>
<td>0.77bc</td>
<td>0.90b</td>
<td>1.03ab</td>
<td>0.48</td>
<td>0.71bc</td>
<td>0.76bc</td>
<td>0.90b</td>
<td>1.03ab</td>
</tr>
<tr>
<td>10</td>
<td>0.53</td>
<td>0.70bc</td>
<td>0.72c</td>
<td>0.90b</td>
<td>1.07ab</td>
<td>0.52</td>
<td>0.69bc</td>
<td>0.71c</td>
<td>0.89b</td>
<td>1.08ab</td>
</tr>
<tr>
<td>20</td>
<td>0.61</td>
<td>0.63b</td>
<td>0.79bc</td>
<td>0.90b</td>
<td>1.03b</td>
<td>0.58</td>
<td>0.62b</td>
<td>0.78bc</td>
<td>0.89b</td>
<td>1.04ab</td>
</tr>
<tr>
<td>40</td>
<td>0.57</td>
<td>0.66b</td>
<td>0.86b</td>
<td>0.95b</td>
<td>1.10b</td>
<td>0.54</td>
<td>0.65ab</td>
<td>0.86b</td>
<td>0.95b</td>
<td>1.10b</td>
</tr>
<tr>
<td>80</td>
<td>0.61</td>
<td>0.76ab</td>
<td>0.91b</td>
<td>0.95b</td>
<td>0.98b</td>
<td>0.58</td>
<td>0.75ab</td>
<td>0.90b</td>
<td>0.95b</td>
<td>0.98b</td>
</tr>
<tr>
<td>160</td>
<td>0.49</td>
<td>0.69ab</td>
<td>0.89b</td>
<td>1.08a</td>
<td>1.15a</td>
<td>0.45</td>
<td>0.68ab</td>
<td>0.88b</td>
<td>1.09a</td>
<td>1.16a</td>
</tr>
<tr>
<td>Control</td>
<td>0.58</td>
<td>0.82a</td>
<td>1.07a</td>
<td>1.06a</td>
<td>1.10b</td>
<td>0.55</td>
<td>0.82a</td>
<td>1.07a</td>
<td>1.06a</td>
<td>1.10b</td>
</tr>
<tr>
<td>CV (%)</td>
<td>16.82</td>
<td>14.85</td>
<td>10.55</td>
<td>6.69</td>
<td>7.68</td>
<td>18.91</td>
<td>15.63</td>
<td>10.98</td>
<td>7.04</td>
<td>8.03</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>NS</td>
<td>0.16</td>
<td>0.13</td>
<td>0.09</td>
<td>0.12</td>
<td>NS</td>
<td>0.016</td>
<td>0.14</td>
<td>0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>SE</td>
<td>0.042</td>
<td>0.053</td>
<td>0.065</td>
<td>0.069</td>
<td>0.075</td>
<td>0.040</td>
<td>0.052</td>
<td>0.065</td>
<td>0.069</td>
<td>0.076</td>
</tr>
</tbody>
</table>

In a column, mean values followed by the same letter are not significantly different at 5% in DMRT (p ≤ 0.05), control = no weeding and NS = not significant.

Statistically, similar RWH was found from 5 to 160 weed m⁻² in both years except 20 weed m⁻² in the second year. More than one RWH was measured from control at 50 DAT. The second highest RWH was found in 80 weed m⁻² which was statistically identical with that of 40 to 160 weed m⁻². The RWH at 5 to 20 weed m⁻² were statistically similar in both years. At 60 DAT, the highest RWH was gotten from 160 weed m⁻² which was statistically identical with the control. The RWH obtained from 5 to 80 weed m⁻² were statistically similar.

Each weed density except 80 weed m⁻² gave more than one RWH at 70 DAT. The highest RWH was calculated from 160 weed m⁻² in both years. The second highest RWH was found from control which was statistically identical with RWH of 5 to 40 weed m⁻² in both years. The lowest RWH was obtained from 80 weed m⁻². The relative weed height was increased by 10 and 13% at 30 DAT, 12 and 13% at 40 DAT, 28 and 27% at 50 DAT, 15 and 15% at 60 DAT and 6 and 6% at 70 DAT in control over 5 weeds m⁻² in year 1 and 2, respectively.

Weed dry matter production

Weed density exerted significant effect on dry matter production in both years. Weed dry matter production increased gradually with the weed density. *S. maritimus* produced more dry matter m⁻² in the first year than that of the second year (Figure 1). In the first year, dry matter production was not significant from 5 to 20 weeds m⁻². Five *S. maritimus* m⁻² produced 48.44 g while 422.33 g of unweeded control. More than 42% higher dry matter was obtained from 40 to 20 *S. maritimus* m⁻². Production of weed dry matter increased greatly from 40 to 160 *S. maritimus* m⁻². But dry matter recorded from unweeded control plot was dramatic. It was 46% higher than that of 160 *S. maritimus* m⁻².

In the second year, weed dry matter production increased slowly to 160 *S. maritimus* m⁻² and sharply in control. Three times higher dry matter was found in 10 to 5 *S. maritimus* m⁻². Only 7.44 g dry matter was found in 5 *S. maritimus* m⁻² while 199.03 g of unweeded control. Weed dry matter production in 20 and 40 *S. maritimus* m⁻² and 80 and 160 were statistically similar. About double dry matter was recoded from control than 160 *S. maritimus* m⁻² (Figure 1).

Rice growth

Weed density exerted significant effect on leaf area index (LAI) of rice in both years. Reduction of LAI occurred with the increases of weed population density (Figure 2a). The highest LAI was recorded from weed-free control (WFC) plot whereas lowest one from unweeded (UWC) control. Statistically identical LAI was found in WFC and 5 *S. maritimus* m⁻² in the first year but LAI reduced by 13% in 5 *S. maritimus* m⁻² compared to WFC in the second year. Similar LAI was obtained in 10 and 20 *S. maritimus* m⁻² in both years. Significant reduction on LAI occurred in 40 and 80 *S. maritimus* m⁻² in year 1 and 2.

Significant reduction of crop growth rate (CGR) was observed due to increment of weed population density. Crop growth rate was faster in year 1 compared to year 2 (Figure 2b). Significantly, the highest CGR was recorded from WFC which is identical with 5 *S. maritimus* m⁻² in both years. Crop growth rate was statistically similar at 10 and 20 *S. maritimus* m⁻² in year 1 and 2. No significant reduction on CGR was observed in 40, 80 and 160 *Sm* m⁻² in both years. Unweeded control plot gave the lowest CGR.
Net assimilation rate (NAR) in both years affected significantly was due to weed population density. Similar reduction trend was observed in year 1 and 2 (Figure 2c). The highest NAR was found in WFC and the lowest from UWC in both years. About 18% less NAR was calculated from 5 S. maritimus m⁻² in year 1 compared to WFC but identical in year 2. Similar NAR was found in 10, 20 and 40 S. maritimus m⁻² in year 1 and 2. Significant reduction of NAR was found in 80 and 160 S. maritimus m⁻² in both years.
Rice yield and yield attributes

The highest number of panicles m⁻² was recorded from weed free plots in both years (367 in year 1 and 279 in year 2). The number of panicles m⁻² gradually decreased with the weed density in both seasons. The lowest number of panicles m⁻² was recorded in the control plots for both years (217 in year 1 and 235 in year 2). The numbers of grains panicle⁻¹ were significantly affected by the weed density in both years (Table 2). The significant highest number of grains panicle⁻¹ was recorded from weed free plots in both years (129 in year 1 and 125 in year 2). The lowest number of grains panicle⁻¹ was recorded from control for both years. Weed density exerted significant influence on 1000-grain weight in year 1. The highest 1000-grain weight was recorded from 20 S. maritimus m⁻² in year 1 and in WFC in year 2.

The rice grain yield was significantly affected by the weed number m⁻² in both years. Rice grain yield decreased with the weed number m⁻² in both years. Significantly, the highest rice grain yields of 8.52 and 7.08 t/ha were recorded from weed free plots which were 38 and 22 % higher than that of control in year 1 and 2, respectively. Grain yield obtained from weed free was similar with that of 5 weed m⁻² in year 1 but higher in year 2. More than 6 t/ha grain yield was found in 40 and 80 weed m⁻² in year 1 and 2, respectively. The lowest grain yield was recorded from control in both seasons.

Rice yield loss simulation and economic threshold

The percentage deviation between the observed and predicted yield loss were 0, +2.73, +3.05, + 3.38, +4.86, +6.29, +7.06 and +8.73 in year 1 (Figure 3) and 0, +0.75, + 1.87, +2.68, +2.88, +3.41, 4.11 and 5.27 in year 2 (Figure 3) through a weed density crop yield model for 0 (WFC), 5, 10, 20, 40, 80, 160 and UWC S. maritimus m⁻², respectively. The simulation was assumed to be a good fit (R²= 0.96 and 0.97 in year 1 and 2, respectively). The quadratic regression equations that were derived using Equation 8 revealed that ET dry matter of S. maritimus were 18.39, 15.61 and 13.57 g/m² (4, 3 and 3 S. maritimus m⁻², respectively) in year 1 and 15.06, 12.38 and 10.51 g/m² (3, 3 and 2 S. maritimus/m², respectively) in year 2 at the 70, 80, and 90% efficiencies of bensulfuron-methyl + pretilachlor 6.6% GR, respectively (Table 3).

DISCUSSION

Weed height and dry matter production

The growth of weeds in control treatment was more vigorous than other treatments and weed growth was rapid because of absence of competition from rice. The RWH was less than 1 higher up to 60 DAT because 40 days old seedlings were transplanted. But more than 1 RWH was found at 70 DAT because weeds were grown faster than rice plant after 60 DAT. Higher weed dry matter was obtained from higher density weed population. Weeds faced more competition from rice in year 2 than in year 1.

At lower weed density up to 20 S. maritimus /m² dry matter production was similar because of less intraspecies competition. The S. maritimus plants, due to their lower density, experienced minimum intraspecies competition, which might have been much lower compared to both interspecific competitions in the treatments where weed density was more. As a result, individual plant growth was not affected in the treatment of lower weed plants m⁻² and the plants could collectively accumulate a dry weight that was relatively higher.

This corroborates that, for weed interference in a crop, although, it is dependent on the weed density (Cussens et al., 1986; Cousens, 1987; Zimdahl, 2004; Tadesse et al., 2010; Hazra et al., 2011), the weed dry weight is a more reliable estimate (Das, 2008; Das et al., 2010). Sometimes, a moderate infestation of weeds is as serious as a heavy infestation of weeds, which was substantiated by Akobundu (1987).

In addition, the increase in the dry weight of S. maritimus was not as proportionate as the increase in its density. The density increased thirty two folds (from 5 to 160 S. maritimus /m²), but the increase in dry weight was only nearly fivefold (from 48.44 to 230.44 g/m², respectively). A reduction in the dry weight of individual plants, probably related to intraspecific and interspecific competition at higher densities, might be responsible (Zimdahl, 2004; Das, 2008; Hazra et al., 2011).

Rice growth and yield

The degree of weed interference is highly dependent on the weed population and dry weight, ultimately being reflected by the yield of a crop (Das and Yaduraju, 1999). The yield reductions are generally in proportion to the amount of light, water, or nutrients that weeds use at the expense of a crop (Zimdahl, 2004). In this study, the interference effects were prominent, but variable.

Infestation levels of S. maritimus offered considerable interference and caused reductions in the LAI, CGR and NAR and yield of rice. The level of interference was more prominent in 160 S. maritimus /m² and control treatment. The probable reasons already have been explained. There are reports of similar interference of a single weed species (Shurtleff and Cole, 1985; Hayden and Martin, 1986; Regnier and Stoller, 1989; Grichar, 1993; Punia et al., 2004) or of composite weeds (Chhonkar et al., 1997; Gaikwad and Pawar, 2002; Hazra et al., 2011). Increasing weed density reduced the number of panicle m⁻² of rice plants in both years.
Table 2. Rice grain yield and yield contributing characters at harvest.

<table>
<thead>
<tr>
<th>Weeds (no/m²)</th>
<th>Year 1</th>
<th></th>
<th>Year 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Panicles (no/m²)</td>
<td>Grains (no/pan)</td>
<td>1000-grain wt. (g)</td>
<td>Grain yield (t/ha)</td>
</tr>
<tr>
<td>0</td>
<td>367&lt;sup&gt;a&lt;/sup&gt;</td>
<td>129&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.52&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.52&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>340&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>111&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.74&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>8.15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>343&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>107&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.54&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>317&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>122&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.26&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>40</td>
<td>258&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>119&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.73&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.60&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>80</td>
<td>286&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>113&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.60&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>5.76&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>160</td>
<td>318&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>117&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.71&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>217&lt;sup&gt;d&lt;/sup&gt;</td>
<td>84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>5.31&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>CV (%)</td>
<td>10.86</td>
<td>10.66</td>
<td>3.22</td>
<td>10.36</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;0.05&lt;/sub&gt;</td>
<td>56.09</td>
<td>20.35</td>
<td>1.08</td>
<td>1.20</td>
</tr>
</tbody>
</table>

In a column, mean values followed by the same letter are not significantly different at 5% in DMRT (p<0.05); 0= weed free, control= no weeding, no. = number, pan= panicle, wt. = weight and NS= not significant.

Sultana (2000) observed about 52% reduction in tillers due to competition from weeds. Fazlul et al. (2003) also observed significantly highest number of total tillers produced in weed-free treatments. Begum et al. (2009) found that significantly higher percentage of fertile grains per panicle was produced in weed free plots and weed density of 250 m<sup>2</sup> compared with the rest of weed density treatments.

Similar result was observed for other species for example, red rice density of 5 plants m<sup>2</sup> were not effective to reduce fertile rice grain, but weed densities to 108 and 215 plants m<sup>2</sup> reduced fertile rice grain (Diarra et al., 1985). The 1000-grain weight is a genetic character widely used in yield estimation and varietal selection in rice (Iqbal et al., 2008). The highest 1000-grain weight was obtained in weed-free, while 1000-grain weights were significantly lowered in the treatments with higher weed densities. Islam et al. (1980) also reported variation in 1000- grain weight due to weed infestation, while Rao and Moody (1992) reported that weed competition did not affect the grain index of the rice.

**Yield loss simulation and economic threshold**

This experiment was based on additive series. A model of density-yield (Cousens, 1985a, b) was used to simulate rice yield losses across the *S. maritimus* densities. There was no deviation between the observed and predicted yield losses for any of the *S. maritimus* densities. These results indicate that the model is effective and can operate on a wide range of *S. maritimus* densities. This model is widely accepted and frequently used (Cousens, 1985a), but certain parameters of the model can vary because of the effect of other factors.
on the interference processes, such as the date of weed emergence relative to the crop (Kropff and Spitters, 1991). In comparison to counting the number of weeds, this method is quite cumbersome, especially, in the fields. Variations in the regression equation and ET (Table 3), due to the varying efficiency of herbicide, also were observed in this study, indicating that the ET, like the period threshold (that is, the critical period of weed interference), is a dynamic concept (Das, 2008). The mean ET was approximately 15.61 and 12.38 g/m² at the 80% efficiency of bensulfuron-methyl + pretilachlor 6.6% GR in year 1 and 2, respectively (Table 3). If we consider nearly 5% yield loss than we could allow 21.21 and 18.22 g S. maritimus dry matter per m² (Figure 3), the yield loss approximately turns out to be 4% at 14.21 and 14.15 g S. maritimus dry matter per m² in year 1 and 2, respectively. Thus, the simulation could foretell that even a 4% yield loss by a dry matter of 14 g S. maritimus per m² is an economic loss. This is mainly related to the lower cost, but higher efficiency, of the herbicide and the higher price for rice.

The governmental price for rice was used. Bensulfuron-methyl + pretilachlor 6.6% GR, being marketed by a single company, has almost a fixed cost all over Bangladesh. Therefore, this ET could be useful to a large extent in other parts of Bangladesh. The farmers of the developed countries with high technical skills and with access to improved methods of weed control (for example, herbicides) might not be ready to lose even a 4% yield, whereas the reverse could be true for the farmers of the developing countries.

### Implication or application of ET

The ET concept was first adopted by entomologists in the 1970s (Wilkerson et al., 2002). Its use for weed management came much later. Therefore, this method appears to be more rational and useful as the other factors influence the ET (Thornton and Fawcett, 1993; Cheema and Akhtar, 2006). The ET generally is based on a consideration of the likely profits and losses in the current year. Certain benefits that accrue from adopting an ET are not considered.

The benefits in subsequent years from the herbicide and/or control measures that are adopted which affect future weed populations by preventing a build-up of their seed might bank in the soil also are ignored (Cussans et al., 1986; Norris, 1992). In order to ascertain the need of a weed-control measure, the impact of weed interference should be predicted as early as possible. The ET provides that baseline information for making weed-control decisions, based on the economics of a given situation (Cussans et al., 1986; Cousens, 1987), and plays an important role in setting up an integrated weed management program. It will help farmers to determine whether or not a treatment against weeds is necessary and economical. Weed scientists have made a few such general assumptions (Das, 2008); for example, the first one-quarter to one-third period of the total growing duration of a crop (Kasasian and Seejave, 1969) as the period threshold for weed interference.

### Conclusion

The density of 80 or more S. maritimus individuals per m² is competitive to rice. The weed infestation levels of 80 or more S. maritimus plants per m² offered higher competition, leading to significant reductions in the growth and yield of rice. The regression model was equally effective in simulating yield losses in relation to a wide range of S. maritimus dry mater. The ET dry mater of S. maritimus were 18.39, 15.61 and 13.57 g/m² in first year at the 70, 80, and 90% control efficiencies, respectively, of the herbicide, bensulfuron-methyl + pretilachlor 6.6% GR. In the second year, the ET dry mater of S. maritimus was 15.06, 12.38 and 10.51 g/m² at the 70, 80, and 90% control efficiencies, respectively, of the herbicide. In rice cultivation, 10 to 18 g S. maritimus per m² could be allowed without economic yield loss.

### Table 3. Economic threshold (ET) level of Scirpus maritimus (no. of plants per m²) in rice simulation through a model across the herbicide efficiencies.

<table>
<thead>
<tr>
<th>Years</th>
<th>Herbicide efficiency (%)</th>
<th>Regression equation*</th>
<th>ET level of Scirpus maritimus (g/m²)</th>
<th>ET level of Scirpus maritimus (no/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>70</td>
<td>0.000013 T² − 0.05438 T + 1 = 0</td>
<td>18.39</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0.000009 T² − 0.06405 T + 1 = 0</td>
<td>15.61</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>0.000005 T² − 0.07371 T + 1 = 0</td>
<td>13.57</td>
<td>3</td>
</tr>
<tr>
<td>Year 2</td>
<td>70</td>
<td>0.000088 T² − 0.06641 T + 1 = 0</td>
<td>15.06</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0.000059 T² − 0.08079 T + 1 = 0</td>
<td>12.38</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>0.000030 T² − 0.09518 T + 1 = 0</td>
<td>10.51</td>
<td>2</td>
</tr>
</tbody>
</table>

* Derived from equation 8: 1 + (i/a) (2 − h − [yp a h / c])T + (i /a)² (1 − h)T² = 0.
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