Effect of Pretilachlor on Weedy Rice and Other Weeds in Wet-Seeded Rice Cultivation in South Vietnam

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Abstract: Wet-seeded rice is a common method of sowing in Vietnam. Weeds, including weedy rice, however, are a major problem in this establishment method. A study was conducted in a farmer's field to evaluate the effect of pretilachlor dose (0, 300, 600, and 900 g ai ha−1) on the management of weedy rice and other weeds in wet-seeded rice cultivation in the spring-summer, summer-autumn, and winter-spring seasons of 2012-13. The herbicide was applied 1 day after sowing. Weeds belonging to the grass, broadleaf, and sedge groups were effectively controlled by the lowest herbicide dose (300 g ha−1). Overall, weed control did not increase with increases in herbicide dose after 300 g ha−1, suggesting the optimum dose for pretilachlor in wet-seeded systems. The application of pretilachlor at 300 g ha−1 significantly reduced the number of weedy rice panicles (20 – 69%) and weedy rice biomass (15 – 26%). The highest pretilachlor dose (i.e., 900 g ha−1), however, was better than the lower doses in reducing the number of weedy rice panicles (47 – 80%) and weedy rice biomass (41 – 54%). The non-treated plots produced a rice grain yield of 210, 2000, and 1850 kg ha−1 in the spring-summer, summer-autumn, and winter-spring seasons, respectively. Compared with the non-treated plots, the lowest dose of pretilachlor improved grain yield. However, maximum yield was obtained by applying the highest dose of pretilachlor; 2690, 4490, and 5150 kg ha−1 in the spring-summer, summer-autumn, and winter-spring seasons, respectively. The results of our study suggest that a broad spectrum of weed flora can be easily managed by a lower dosage of pretilachlor in wet-seeded rice; however, the herbicide dose needs to be increased to 900 g ha−1 in order to decrease the weedy rice problem.

Key words: Biomass, Broadleaf, Grass, Pretilachlor, Sedge, Weedy rice, Wet-seeded rice.

Rice is a staple food in Vietnam, where more than 50% of the rice is established by wet-seeded culture. In wet-seeded rice cultivation, however, weed infestation, particularly weedy rice infestation is a serious problem that farmers encounter (Delouche et al., 2007; Azmi and Karim, 2008; Chauhan, 2013). In this establishment system, the suppressive effect of standing water is absent at the time of crop establishment as weeds and rice seedlings emerge simultaneously (Chauhan, 2012a, 2013). Therefore, the increase in infestation of weedy rice and other weeds in Vietnam and other Asian countries is closely associated with the increase in area under direct (wet or dry) seeding (Delouche et al., 2007; Azmi and Karim, 2008; Chauhan, 2013). The growing trend towards the adoption of direct seeding because of scarcity of labor and water is extending the area infested with weedy rice.

Weedy rice consists of the unwanted plants of Oryza sativa that infest and compete with cultivated rice and produce grains with distinctly colored pericarps (Delouche et al., 2007; Suh, 2008). In Vietnam, its infestation was first reported in 1994 (Chin et al., 2000; Chin, 2001). Important traits of weedy rice are early shattering of the grain and a persistent soil seed bank due to high dormancy (Delouche et al., 2007; Azmi and Karim, 2008; Chauhan and Johnson, 2010). In earlier studies, for example, weedy rice in Vietnam showed dormancy for a period of 20 – 65 days (Thanh et al., 1999). In other places, variable degrees of dormancy, ranging up to 300 days, have been reported in different weedy rice accessions (Suh, 2008). Weedy rice can markedly reduce rice yield. In an earlier study in Vietnam, a yield loss of 16% was observed due to weedy rice infestation (Chin, 2001). In Malaysia, a yield loss of about 1 t ha−1 was reported at a density of about 35 weedy rice panicles per square meter (Azmi et al., 2005). An earlier study in the United States suggested that the threshold infestation to prevent yield losses in rice was 1-3 plants per square meter of weedy rice (Smith, 1988). In conclusion, weedy rice increases the production cost and
reduces the farmers’ profit through less yield and lower rice quality at harvest (Mortimer et al., 2000; Chauhan, 2013).

In some countries (e.g., the United States), herbicide-resistant rice cultivars are used to manage weedy rice. However, this option is not available in Vietnam. Because of the physical and physiological similarities of weedy rice to cultivated rice, it is difficult to control weedy rice in conventional rice cultivars. Recently, it was found that the herbicide pretichlor (with a safener) has the potential to reduce weedy rice infestation in wet-seeded rice systems (Shen et al., 2013). Pretichlor is a selective systemic herbicide and it is absorbed by the germinated shoots and roots. In the wet-seeded rice system, pre-germinated rice seeds are broadcast on the soil surface and pretichlor is applied 1 – 2 days after seeding. Most of the weedy rice seeds, however, are buried at different depths in the soil profile as pre-sowing tillage operations thoroughly mix weed and weedy rice seeds in the cultivated-soil profile. The safener mixed with the herbicide enhances herbicide tolerance in cultivated rice without affecting herbicidal susceptibility in the target weed species, including weedy rice. In Bangladesh, pretichlor was also found to be effective in controlling a broad spectrum of weed flora in wet-seeded rice, in which uncontrolled weeds caused more than 40% yield losses (Rashid et al., 2012). The information on the evaluation of the pretichlor dosage for controlling both weedy rice and other weeds is limited in wet-seeded rice cultivation in Vietnam. Therefore, a study was conducted in a farmer’s field in three consecutive seasons from 2012 to 2013 to evaluate the effect of pretichlor dosage on the management of weedy rice in wet-seeded rice cultivation. In addition, the effect of herbicide was also evaluated according to the type of weed: grass, broadleaf, and sedge.

Materials and Methods

A study was conducted in a farmer’s field during three consecutive rice-growing seasons (spring-summer 2012, summer-autumn 2012, and winter-spring 2012-13) in Long Hung village, O Mon district, Cantho city, Vietnam (10° 19’ N, 105° 39’ E), to evaluate the effect of pretichlor dosage on the management of weedy rice and other weeds in wet-seeded rice cultivation. The study was conducted in the same field during the three seasons and the preceding crop in the field was rice. The topography of the experimental field was uniform and leveled, and the soil was clay. The soil had sand:silt:clay contents of 2:37:61, a pH of 4.8, organic carbon of 2.18%, and total nitrogen of 0.12%.

The experimental field was prepared using two harrowing operations and then leveled using a wooden board. Rice (cv. IR50404) was sown at a seeding rate of 100 kg ha⁻¹ using a drum seeder with rows spaced 20-cm apart. Before sowing, rice seeds were soaked in water for 24 hours and then incubated in the dark for another 24 hours. The crop in was sown on March 26, 2012; June 26, 2012; and November 25, 2012. Recommended doses of nitrogen (100 kg N ha⁻¹), phosphorus (60 kg P₂O₅ ha⁻¹), and potassium (40 kg K₂O ha⁻¹) fertilizers were used.

The experiment in each season had four treatments and was arranged in a randomized complete block design with three replicates. The treatments comprised four doses of pretichlor 300 g l⁻¹ + fenclorim (safener) 100 g l⁻¹ (Sofit 300 EC): 0, 300, 600, and 900 g ai ha⁻¹. The herbicide was sprayed at 1 day after sowing (DAS) with a knapsack sprayer that delivered 320 L ha⁻¹ spray solution through flat-fan nozzles. Soil water condition was saturated for a week after seeding and a water-depth of 3 – 5 cm was maintained thereafter, except during the second (18 – 20 DAS) and third (38 – 40 DAS) fertilizer applications. Water was drained 2 – 3 days before fertilizer application and applied immediately after fertilizer application. In each season, the experimental plot size was 20 (5 × 4 m) m².

At 14 DAS, rice plants in four randomly selected rows, 1 m each, were counted and the number converted to rice plants per square meter. Density and biomass of the grass, broadleaf, and sedge group of weeds were measured at 28 and 56 DAS from two randomly selected quadrats of 50 × 50 cm. For biomass measurements, plant samples were placed in an oven at 70°C for 72 hours and weighed. At crop maturity, the number of weedy rice panicles in an area of 1 square meter was counted and harvested to determine weedy rice biomass. From the same area, rice yield-attributing components (number of tillers and panicles per square meter, number of filled grains per panicle, and 1000-grain weight) were measured. Rice grain yield in an area of 5 square meters was determined and the value was adjusted to kg ha⁻¹ at 14% moisture content. After crop harvest (but, before tillage), soil samples were taken using metal cores of 7.5 cm in diameter. In each plot, 10 soil cores to a depth of 5 cm were randomly sampled. The soil samples were soaked in water and weedy rice seeds were collected, counted, and converted to number per square meter.

Data were analyzed using analysis of variance (ANOVA) to evaluate the differences between treatments by GenStat 8.0 (VSN International Ltd., Oxford, U.K.). The means were separated using least significant difference (LSD) at the 5% level of significance. Non-transformed data on weed density and biomass were used for analysis because transformation did not improve the homogeneity of variance. The relationship between grain yield (kg ha⁻¹) and rice panicles (number m⁻²) was assessed using linear regression. Because of differences among seasons, data are presented separately for different seasons.
Rice plant density was not influenced by pretilachlor dose in all three growing seasons (data not shown). Rice plant density ranged from 80 to 95 plants m$^{-2}$ in the spring-summer, 80 to 84 plants m$^{-2}$ in the summer-autumn, and 80 to 87 plants m$^{-2}$ in the winter-spring seasons.

As the main objective of our study was to evaluate the effect of pretilachlor on weedy rice, we did not include data on other weed species. However, we grouped the weed species into grass, broadleaf, and sedge groups. The dominant weed species in the experimental plot were *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees, *Cyperus iria* L., *Fimbristylis miliacea* (L.) Vahl, and *Ludwigia hyssopifolia* (G. Don) Exell.

In all three consecutive growing seasons, density of the grass, broadleaf, sedge, and total weeds at 28 DAS was highest in the non-treated plots (Table 1). Herbicide treatments reduced weed density; however, there was no significant reduction in density with increases in pretilachlor dose beyond 300 g ha$^{-1}$. Similarly, compared with the non-treated plots, herbicide-treated plots had lower biomass of grass, broadleaf, sedge, and total weeds at 28 DAS (Table 2). Herbicide doses from 300 to 900 g ha$^{-1}$, however, had a similar effect, suggesting the effectiveness of pretilachlor even at low doses.

At 56 DAS, the density (Table 3) and biomass (Table 4) of grass, broadleaf, sedge, and total weeds were highest in the non-treated plots in all three growing seasons. In the spring-summer season, however, the density and biomass were significantly reduced by the herbicide treatments. However, in the summer-autumn and winter-spring seasons, there was no significant difference in weed density and biomass among the treated and non-treated plots.

### Table 1. Effect of pretilachlor on grass, broadleaf, sedge, and total weed density at 28 days after sowing in different growing seasons.

| Pretilachlor dose (g ai ha$^{-1}$) | Spring-summer 2012 | Summer-autumn 2012 | Winter-spring 2012-13 |
|-----------------------------------|---------------------|---------------------|----------------------|
|                                   | G       | BL      | S       | Total   | G       | BL      | S       | Total   | G       | BL      | S       | Total   |
| 0                                 | 581.5   | 13.0    | 783.5   | 1378.0  | 149.5   | 15.5    | 104.5   | 269.5   | 243.5   | 9.0     | 125.0   | 377.5   |
| 300                               | 10.0    | 0.0     | 11.0    | 21.0    | 4.0     | 0.0     | 2.2     | 6.2     | 6.0     | 0.0     | 18.0    | 24.0    |
| 600                               | 22.5    | 0.0     | 4.4     | 27.0    | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| 900                               | 0.0     | 0.0     | 1.5     | 1.5     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| LSD                               | 71.0    | 6.5     | 111.5   | 90.0    | 51.7    | 11.0    | 35.0    | 54.7    | 57.8    | 3.1     | 43.9    | 58.7    |

LSD, least significance difference at 5% level of significance; G, grass; BL, broadleaf; S, sedge.

### Table 2. Effect of pretilachlor on grass, broadleaf, sedge, and total weed biomass at 28 days after sowing in different growing seasons.

| Pretilachlor dose (g ai ha$^{-1}$) | Spring-summer 2012 | Summer-autumn 2012 | Winter-spring 2012-13 |
|-----------------------------------|---------------------|---------------------|----------------------|
|                                   | G       | BL      | S       | Total   | G       | BL      | S       | Total   | G       | BL      | S       | Total   |
| 0                                 | 86.8    | 0.7     | 107.2   | 194.7   | 25.1    | 1.2     | 6.7     | 32.9    | 32.3    | 0.8     | 15.0    | 48.0    |
| 300                               | 3.6     | 0.0     | 4.6     | 8.1     | 0.3     | 0.0     | 0.1     | 0.3     | 0.9     | 0.0     | 4.0     | 4.9     |
| 600                               | 6.6     | 0.0     | 1.9     | 8.4     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| 900                               | 0.0     | 0.0     | 0.5     | 0.5     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| LSD                               | 16.5    | 0.2     | 41.0    | 32.4    | 17.7    | 0.8     | 1.7     | 17.3    | 8.6     | 0.2     | 3.0     | 6.7     |

LSD, least significance difference at 5% level of significance; G, grass; BL, broadleaf; S, sedge.

### Table 3. Effect of pretilachlor on grass, broadleaf, sedge, and total weed density at 56 days after sowing in different growing seasons.

| Pretilachlor dose (g ai ha$^{-1}$) | Spring-summer 2012 | Summer-autumn 2012 | Winter-spring 2012-13 |
|-----------------------------------|---------------------|---------------------|----------------------|
|                                   | G       | BL      | S       | Total   | G       | BL      | S       | Total   | G       | BL      | S       | Total   |
| 0                                 | 94.5    | 2.0     | 302.0   | 398.5   | 123.5   | 9.0     | 151.0   | 283.5   | 163.0   | 9.0     | 349.0   | 521.0   |
| 300                               | 11.5    | 0.5     | 37.5    | 49.5    | 0.0     | 0.0     | 0.0     | 0.0     | 8.0     | 0.0     | 62.0    | 70.0    |
| 600                               | 0.0     | 0.0     | 11.5    | 11.5    | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| 900                               | 0.0     | 0.0     | 1.5     | 1.5     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| LSD                               | 38.5    | NS      | 87.4    | 62.2    | 18.0    | 5.5     | 45.4    | 57.9    | 25.0    | 3.1     | 70.0    | 288.0   |

LSD, least significance difference at 5% level of significance; G, grass; BL, broadleaf; S, sedge; NS, nonsignificant.

### Results

Rice plant density was not influenced by pretilachlor dose in all three growing seasons (data not shown). Rice plant density ranged from 80 to 95 plants m$^{-2}$ in the spring-summer, 80 to 84 plants m$^{-2}$ in the summer-autumn, and 80 to 87 plants m$^{-2}$ in the winter-spring seasons.

As the main objective of our study was to evaluate the effect of pretilachlor on weedy rice, we did not include data on other weed species. However, we grouped the weed species into grass, broadleaf, and sedge groups. The dominant weed species in the experimental plot were *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees, *Cyperus iria* L., *Fimbristylis miliacea* (L.) Vahl, and *Ludwigia hyssopifolia* (G. Don) Exell.
of broadleaf weeds did not differ with the dose of pretilachlor. This response was not because of poor herbicide efficacy but because of the very low density and biomass of broadleaf weeds in the non-treated plots.

At crop harvest, the highest number of weedy rice panicles was observed in the non-treated plots in all three seasons (Table 5). The application of pretilachlor at 300 g ha\(^{-1}\) significantly reduced (20 – 69%) the number of weedy rice panicles. The highest pretilachlor dose (i.e., 900 g ha\(^{-1}\)), however, was better than the lower rates in reducing the number of weedy rice panicles. Depending on the season, compared with the non-treated plots, pretilachlor at 300 g ha\(^{-1}\) suppressed weedy rice biomass by 15 – 26% (Table 5). Increasing the herbicide dose to 900 g ha\(^{-1}\) further decreased biomass by 41 – 54% compared with the non-treated control. In the non-treated plots, weedy rice added 510 – 820 seeds m\(^{-2}\) in the soil (Table 5). The use of pretilachlor markedly decreased the size of the seed bank; however, the reduction was more at the highest dose in all three herbicide treatments compared with the non-treated control. Pretilachlor at 300 g ha\(^{-1}\), for example, reduced weedy rice seed in the soil by 24 – 31%. The decrease at 900 g ha\(^{-1}\) was 62 – 73%.

The herbicide dose strongly affected the yield of cultivated rice (Table 6). In all the growing seasons, non-treated plots produced the lowest grain yield. In the spring-summer season, the yield was 208 kg ha\(^{-1}\), compared with 2004 kg ha\(^{-1}\) in the summer-autumn season and 1850 kg ha\(^{-1}\) in the winter-spring season. The use of pretilachlor at 300 g ha\(^{-1}\) increased the yield by 12% in the spring-summer season, 17% in the summer-autumn season, and 28% in the winter-spring season. However, the increase was not statistically significant (LSD = 177 kg ha\(^{-1}\)).
summer season, the non-treated plots yielded only 210 kg ha$^{-1}$. In the other two seasons, however, the non-treated plots yielded 1850 – 2000 kg ha$^{-1}$. The lowest dose of pretilachlor improved grain yield vis-à-vis the non-treated plots. However, the maximum yield (2090, 4490, and 5150 kg ha$^{-1}$ in the springsummer, summer-autumn, and winter-spring seasons, respectively) was obtained with the highest dose of pretilachlor. Because of very low yield in the non-treated plots in the spring season, the yield increments with the herbicide application were more than 10 times. In the summer-autumn season, pretilachlor at 300, 600, and 900 g ha$^{-1}$ improved rice yield by 77, 91, and 124%, respectively, vis-à-vis the non-treated plots. In the winter-spring season, these values were 107, 122, and 178%, respectively. Irrespective of the pretilachlor dose, rice grain yield was highly correlated ($P < 0.001$) with rice panicle number (data not shown). There was a positive and linear relationship between rice grain yield and rice panicle number, with 84, 84, and 78% of the variation in grain yield explained by the relationship in the spring-summer, summer-autumn, and winter-spring seasons, respectively.

**Discussion**

Weeds, including weedy rice, are becoming an important problem in wet-seeded rice cultivation in Vietnam. In this study, we evaluated the effect of different doses of pretilachlor on weedy rice and other weeds. Pretilachlor at the lowest dose (300 g ha$^{-1}$) provided effective control of grass, broadleaf, and sedge weeds. In many Asian countries, pretilachlor is used to manage weeds in wet-seeded rice systems. In Sri Lanka, for example, different application methods (e.g., sand mixture or spray) for pretilachlor effectively controlled the major grasses, broadleaves, and sedges associated with wet-seeded rice (Abeysekera et al., 2005). Similarly, in a previous study in Vietnam, pretilachlor was one of the most effective herbicides against grass weeds in wet-seeded rice (Tuat and Son, 2005). In a recent study in Sri Lanka, pretilachlor plus pyribenzoxim provided greater than 90% control of all weeds (Chauhan et al., 2013). Results of a study in Bangladesh revealed that, to effectively control associated weeds and obtain optimal wet-seeded rice productivity, pretilachlor at 250 or 375 g ha$^{-1}$ can be used as an alternative to hand weeding thrice (Rashid et al., 2012). In dry-seeded rice systems, however, pretilachlor at 600 g ha$^{-1}$ was not found effective in controlling weeds, especially on *Eclipta prostrata* (L.) L. and *Eleusine indica* (L.) Gaertn. (Chauhan and Abugho, 2013). Pretilachlor is effective where soil moisture is maintained at saturation to achieve high efficacy and therefore this herbicide is widely used in wet-seeded rice systems.

In addition to other weeds, pretilachlor at the lowest dose (i.e., 300 g ha$^{-1}$) reduced weedy rice infestation compared with no herbicide application. However, the greatest suppression of weedy rice was observed at the highest pretilachlor rate of 900 g ha$^{-1}$. This herbicide rate, however, did not cause any phytoxicity in rice as the number of rice plants was similar in all the treatments. As the pretilachlor used in our study had a safener in it, no phytoxic effects were observed. Safeners are used to enhance herbicide tolerance in selected monocot crops without affecting herbicidal susceptibility of the target weed species (Davies and Caseley, 1999; Shen et al., 2013). In a recent study in China, the pretilachlor herbicide applied at 1350 g ha$^{-1}$ reduced rice fresh weight by only 7% (Shen et al., 2013). However, in our study, the maximum rate of pretilachlor was only 900 g ha$^{-1}$, which did not cause any toxicity. In Vietnam, the recommended rate of pretilachlor in the wet-seeded rice system is 300 g ha$^{-1}$, however, farmers use higher rate to control weeds.

In our study, pretilachlor used at the highest rate (900 g ha$^{-1}$) reduced the number of panicles and biomass of weedy rice and this response was consistent in all three consecutive growing seasons. In addition, the herbicide at this application rate contributed to reducing the weedy rice seed bank in the soil. These results clearly suggest that the application of higher pretilachlor dosage can effectively reduce weedy rice infestation in cultivated rice fields. An increase in weedy rice control with higher pretilachlor dosage in the wet-seeded rice cultivation system was also reported in other Asian countries (Shen et al., 2013). In southern China, for example, an application of pretilachlor at 900 g ha$^{-1}$ at 2 DAS increased weedy rice control efficiency in the precise hill-direct-seeded rice system (Shen et al., 2013). In Malaysia, pretilachlor applied just before or after tillage under standing water reduced the weedy rice seed bank (Azmi et al., 2004). In our study, compared with the non-treated plots, pretilachlor application, especially at the highest rate, reduced the weedy rice seed bank.

Pretilachlor application resulted in a significant increase in grain yield compared with the non-treated control. In the springsummer season, grain yield in the non-treated plot was only around 200 kg ha$^{-1}$. Such a low yield was mainly because of the high weed pressure in this season. In general, lower yield was obtained in the spring-summer season than other two seasons, which could be due to higher temperature in this season. Irrespective of the herbicide dose, grain yield was positively correlated with rice panicle number. In previous studies, pretilachlor application resulted in more rice panicles per unit area (Rashid et al., 2012). This response was observed mainly due to less crop-weed competition in the pretilachlor-treated plots. An increase in rice grain yield with pretilachlor usage in wet-seeded rice was also reported in other Asian countries. In Bangladesh, for example, pretilachlor from 250 to 500 g ha$^{-1}$ significantly increased
rice grain yield compared with the unweeded check (Rashid et al., 2012). Grain yield was increased because pretilachlor application resulted in a higher number of rice panicles per unit area and rice grains per panicle than in the unweeded check. In southern China, pretilachlor at 900 g ha\(^{-1}\) significantly increased cultivated rice yield compared with the control plots (Shen et al., 2013). In Thailand, the application of pretilachlor maximized the overall rice yield potential in wet-seeded rice cultivation by controlling weedy rice and *Leptochloa* spp. (Allard et al., 2005).

In summary, the results of our study suggest that a broad spectrum of weed flora can be easily managed by a lower dosage of pretilachlor in wet-seeded rice. To manage weedy rice, however, we need to increase the herbicide dose to 900 g ha\(^{-1}\). Although the highest dose of herbicide significantly reduced weedy rice biomass, it did not provide complete control. To achieve more effective control in conventional rice cultivars, we need to integrate pretilachlor use with various cultural weed management strategies (Chauhan, 2012b, 2013). These strategies can include the use of clean seeds, the stale seedbed practice, rotation of different rice establishment methods, and early flooding (Chauhan, 2013; Chauhan et al., 2014).

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