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# Effect of flooding depth and pretilachlor rate on emergence and growth of three rice weeds: junglerice (*Echinochloa colona*), smallflower umbrella sedge (*Cyperus difformis*), and ludwigia (*Ludwigia hyssopifolia*)

**Sangay Dorji[1], Bhagirath S. Chauhan[2*], Aurora. M. Baltazar[1], and David Johnson[2]**

[1]University of the Philippines, Los Baños 4031, Philippines
[2]International Rice Research Institute, Los Baños 4031, Philippines
[*]Corresponding author's email address: b.chauhan@irri.org

**Abstract**
The effects of intermittent flooding and pretilachlor rates on emergence and early growth of three common weeds of lowland rice were assessed in a screenhouse study. These species were junglerice (*Echinochloa colona*), smallflower umbrella sedge (*Cyperus difformis*), and ludwigia (*Ludwigia hyssopifolia*). The weeds were treated with pretilachlor at 0.075 to 0.3 kg a.i. $ha^{-1}$ at 3 d after seeding, and subjected to alternate flooding (0, 2, 4, and 6 cm water depth) and draining that commenced 2 d after herbicide treatment. Intermittent flooding to 6 cm decreased the emergence of all three weed species. Smallflower umbrella sedge growth was not affected by flooding alone, but was completely suppressed by pretilachlor application. Growth of junglerice was reduced more by pretilachlor when application was followed by flooding. Our results suggest that emergence and seedling growth of these three weeds can be suppressed with pretilachlor and, further, the effect was increased when combined with flooding. Pretilachlor appears to be a useful management option on tropical lowland rice farms and particularly for the control of junglerice, for which farmers can combine an appropriate application rate with subsequent flooding of fields.

**Keywords:** Direct seeding; wet-seeded rice; submergence tolerance; alternate wetting and drying

Rice (*Oryza sativa* L.), the staple food for more than half of the world's population, is still largely established by transplanting, yet, in many Asian countries, farmers are changing to direct seeding due to scarcities of labor and water (Chauhan 2012; Chauhan *et al.* 2012b). Weeds pose a major threat to yields in direct-seeded rice systems and high yields are dependent on successful weed control. In Asia, direct seeding with pregerminated rice seeds sown onto puddled soil, called wet seeding, is commonly practiced in Thailand, Malaysia, the Philippines, Sri Lanka, and Vietnam. Once seedlings have established, soil may be flooded to suppress weed growth. If weeds have established by this time or if flooding is intermittent, if irrigation water is not available, or if rainfall is inadequate, weed growth can be a serious constraint to the production of direct-seeded rice (Chauhan 2012; Chauhan and Johnson 2010; Chauhan *et al.* 2012b; Holm *et al.* 1977).

Manual weeding in broadcast-sown rice, which is most common, is time-consuming and impractical and mechanical weeding is not an option in this system. Farmers therefore rely largely on the use of herbicides. The similar growth stage between weeds and rice seedlings, however, often limits the "window of application" and results in poor selective weed control (Baltazar and De Datta 1992). Further, the reliance solely on herbicides is likely to hasten the development of herbicide-resistant weeds (Chauhan 2012; Mortimer *et al.* 2005; Mortimer 1997).

Although flooding has been long established as an effective and widespread cultural means of controlling rice weeds, irrigation water is becoming scarce in some areas due to competition from other sectors. By 2025, it is estimated that 15 to 20 million ha of irrigated rice may suffer from water scarcity (Tuong and Bouman 2003). Hence, the continuous flooding of rice fields to control weeds may not be possible in the near future. There is also uncertainty for farmers reliant on rainfall and only rarely can flooding be maintained throughout the crop. Water-saving management approaches to improve water use are being developed, including non-flooded systems and alternate wetting and drying (AWD); however, non-flooded systems or those with only intermittent flooding present challenges for weed control (Tuong *et al.* 2005). In such systems, farmers are likely to be increasingly relying on herbicides in combination with intermittent flooding. Little is known, however, about the opportunities for lower herbicide rates when applied in combination with flooding. The available evidence is promising and it was found that pretilachlor applied at 50% of the recommended rates controlled smallflower umbrella sedge (*Cyperus difformis* L.), gooseweed (*Sphenoclea zeylanica* Gaertn.), and ammannia (*Ammannia baccifera* L.), irrespective of whether soil was saturated, intermittently flooded (as in AWD), or continuously flooded (Janiya and Johnson 2005). However, no information is available on the effects of pretilachlor combined with intermittent flooding on weed seedling emergence and early growth of other weed species that infest wet-seeded rice. Of particular interest to farmers may be whether it is possible to reduce the rates of herbicides, vis-à-vis those of non-flooded systems, if herbicide use is integrated with intermittent flooding.

The objective of this study was to evaluate the effects of different rates of pretilachlor combined with alternate flooding and draining on emergence and early growth of weeds. Three widespread and common weeds of rice were selected: a grass – junglerice [*Echinochloa colona* (L.) Link], a broadleaf – ludwigia [*Ludwigia hyssopifolia* (G. Don) Exell], and a sedge – smallflower umbrella sedge.

## Materials and Methods

### *Location of the study and general conditions.*

All experiments were conducted in a screenhouse (a framed chamber made of 2-mm iron mesh and overhead transparent PVC cover to prevent rain damage) at the International Rice Research Institute, Los Baños, Philippines, from September to November, 2010. Seeds of junglerice, smallflower umbrella sedge, and ludwigia were collected from fields around Los Baños, Philippines, which had been in rice cultivation for several years. Prior to use, the germination of each species was tested by placing 300 seeds in Petri dishes lined with moist filter papers and counting the germinated seeds after 7 and 14 d.

### *Effect of herbicide rate and flooding depth on emergence and early growth.*

For each of the three weed species, 25 seeds were broadcast sown on the soil surface in small plastic trays (8 cm x 8 cm x 5.5 cm) and covered with a thin (2 mm) layer of sterilized lowland soil. All trays were kept in saturated soil moisture conditions. Trays containing the seeds were placed inside larger plastic trays (15 cm diameter and 12 cm high) to maintain water levels. The arrangement allowed any weed seed that floated during flooding to be retained inside the container. The larger trays were marked to indicate flooding depth.

At 3 d after seeding (DAS), pretilachlor (with fenclorim as a safener) was sprayed at 0.075, 0.150, 0.225, and 0.300 kg a.i. $ha^{-1}$ using a hydraulic knapsack sprayer with a flat fan nozzle at 260 L $ha^{-1}$ spray volume. The recommended rate of pretilachlor in wet-seeded rice is 0.3 kg $ha^{-1}$. Untreated trays served as controls. At 5 DAS, or 2 d after herbicide treatment, the trays were flooded with 2, 4, and 6 cm water depths. Saturated conditions were maintained in trays that served as the nonflooded controls (0 cm water). At 5 d after flooding, trays were drained for a period of 5 d before flooding again to the treatment depth for a further 5-d interval as the flooding/draining cycle was repeated. At 20 DAS, trays were drained and the seedlings that emerged from the soil were counted. Roots were washed free of soil, cut, and separated from shoots. Shoots were oven-dried at 70 C for 72 h and dry weights were recorded. Data were expressed as percent seedling emergence, total dry weight of the seedlings per tray, and percent reduction in shoot dry weight. Percent seedling emergence was calculated based on the total number of seeds (25) sown. Percentage reduction in seedling emergence or dry weight was based on the emergence or dry weight of the untreated (control) plants.

### *Experimental design and statistical analyses.*

The trays were arranged in a 5 x 4 factorial (pretilachlor rates: 0, 0.075, 0.150, 0.225, and 0.300 kg a.i. $ha^{-1}$ and flooding depths: 0, 2, 4, and 6 cm) complete block design with four complete replications. The experiment was conducted twice. The analysis of variance (ANOVA) indicated no significant difference between the two experiments (“runs”) and no significant interactions between the experimental runs; therefore, the data were pooled over the experiment runs and subjected to ANOVA using CropStat 7.2. Treatment means were compared using least significant difference (LSD) at $P = 0.05$. Data for each species were analyzed separately.

## Results and Discussion

Seeds of junglerice had 80% germination, smallflower umbrella sedge had 65% germination, and ludwigia had 58% germination. In the untreated trays, about 80% of the junglerice seedlings emerged when the soil was saturated (0 cm) or flooded to 6 cm (Figure 1a). Seedling emergence declined with increased rates of pretilachlor and when combined with intermittent flooding. In the saturated soil, pretilachlor at 0.075 to 0.225 kg $ha^{-1}$ reduced junglerice emergence to 40 to 60% of the untreated trays and to about 15% at 0.3 kg $ha^{-1}$ of pretilachlor. No seedlings emerged when junglerice was treated with 0.3 kg $ha^{-1}$ pretilachlor and then flooded to 6-cm depth.

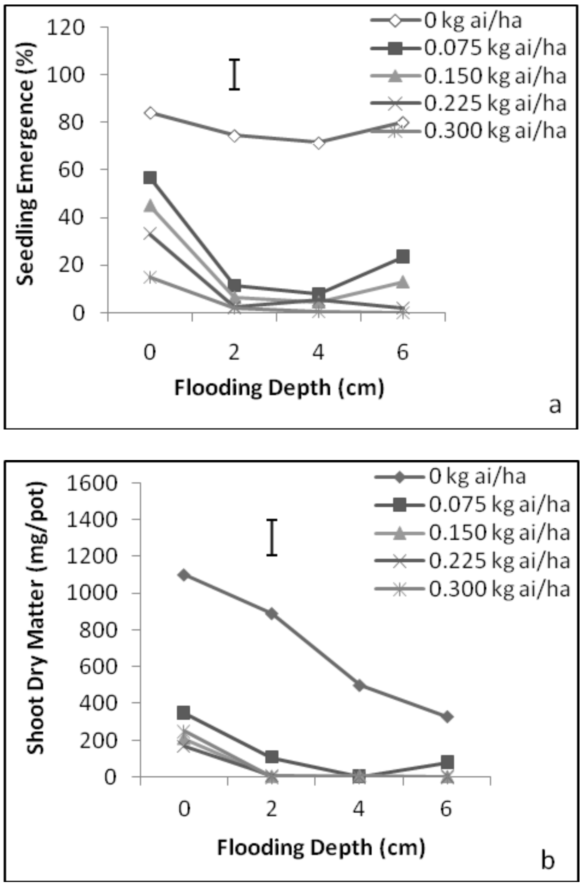


**Figure 1.** Seedling emergence (a) and shoot dry matter (b) of junglerice treated with different rates of pretilachlor and subjected to alternate flooding (0 to 6 cm water) and draining and grown for 20 d. Vertical bars indicate LSD at P = 0.05.

Without pretilachlor, increases in flooding depth from 2 to 6 cm progressively reduced seedling growth of junglerice (Figure 1b). The combination of pretilachlor at the lowest rate (0.075 kg $ha^{-1}$) and flooding to 4 cm completely inhibited growth of junglerice. In this treatment, the first leaf of junglerice seedlings failed to emerge from the coleoptiles, typical of leaf roll or leaf seal symptoms in grasses treated with chloroacetamides, such as pretilachlor (Monaco *et al.* 2002). Leaves that emerged were rolled from the tips and the plants were stunted and chlorotic (visual observations). The highest rate of pretilachlor (0.3 kg $ha^{-1}$) completely suppressed the shoot growth of junglerice when trays were subsequently flooded to 2-cm depth.

Without pretilachlor, flooding did not prevent the seedling emergence of smallflower umbrella sedge and there was 40 to 50% seedling emergence at 2- to 6-cm depth of flooding (Figure 2a). Pretilachlor application, however, suppressed seedling emergence of smallflower umbrella sedge and even at the lowest rate (0.075 kg $ha^{-1}$), no seedlings emerged. Without pretilachlor application, 2-cm flooding depth reduced shoot growth by more than 50% compared with seedling growth in saturated soil (Figure 2b).

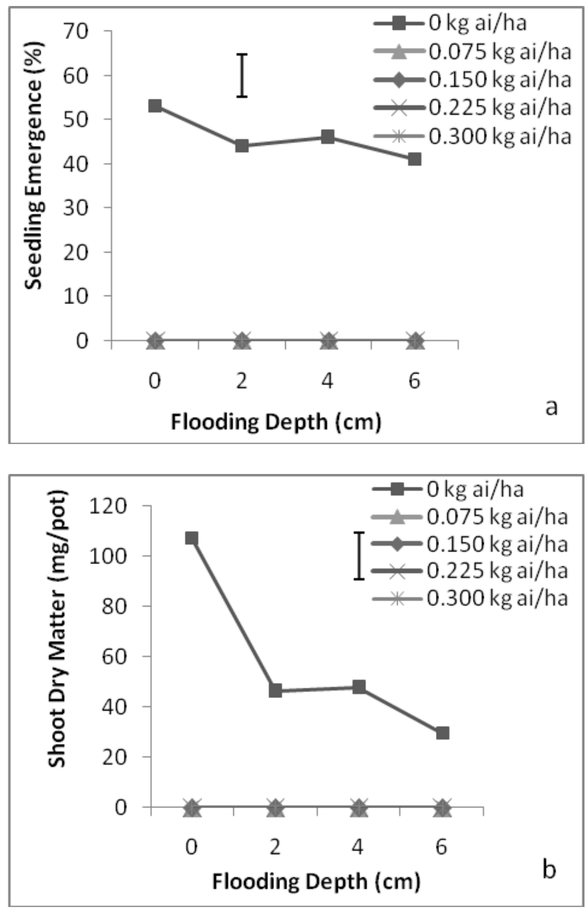


**Figure 2.** Seedling emergence (a) and shoot dry matter (b) of smallflower umbrella sedge treated with different rates of pretilachlor and subjected to alternate flooding (0 to 6 cm water) and draining and grown for 20 d. Vertical bars indicate LSD at P = 0.05.

Without the application of pretilachlor, flooding to 2 cm or 4 cm incrementally decreased the seedling emergence of ludwigia (Figure 3a). Compared with the untreated treatment, pretilachlor application reduced the seedling emergence of ludwigia by more than 80% in saturated soil (0 cm flooding) and seedling emergence decreased further with an increase in flooding from 2 to 6 cm. No seedlings emerged when flooding of 4- to 6-cm depth was given after the application of pretilachlor at the highest rate (i.e., 0.3 kg $ha^{-1}$). Flooding had a more pronounced effect on shoot growth than on seedling emergence (Figure 3b). When ludwigia seedlings emerged, either flooding or pretilachlor almost completely suppressed seedling growth, even at the lowest flooding depth or herbicide rate. Seedlings, either flooded or treated with pretilachlor, were stunted with dark green leaves and a poorly developed root system (visual observations). Seedlings treated with pretilachlor did not develop beyond the cotyledon leaf stage.

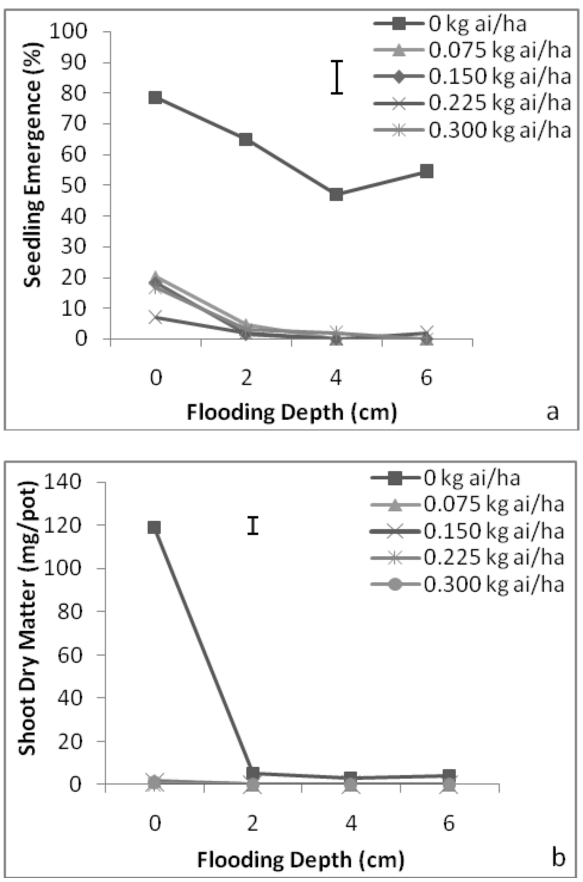


**Figure 3.** Seedling emergence (a) and shoot dry matter (b) of ludwigia treated with different rates of pretilachlor and subjected to alternate flooding (0 to 6 cm water) and draining and grown for 20 d. Vertical bars indicate LSD at P = 0.05.

Pretilachlor was effective on all three weed species, which concurs with previous reports (Quadranti and Ebner 1983) and illustrates the established value of this herbicide in irrigated rice systems. It appears that the herbicide may also have a valuable role in rice grown under saturated or intermittently flooded conditions. In our study, it appears that pretilachlor alone can be used to suppress weed growth but flooding alone was not effective. Of the three species, pretilachlor was most effective against smallflower umbrella sedge, completely reducing its seedling emergence and shoot growth even under saturated soil and at the lowest application rate of 0.075 kg $ha^{-1}$. Although pretilachlor alone did not completely suppress the emergence of junglerice and ludwigia, their control improved when the herbicide was combined with intermittent flooding. Flooding to 2 cm or more improved the efficacy of pretilachlor on junglerice, such that reducing the rate by 25 to 50% of the recommended rate provided control similar to the control obtained from the recommended rate of pretilachlor without flooding. This may result in substantial savings for farmers where intermittent flooding is possible. Greater susceptibility of weed seedlings to pretilachlor in flooded soils could be due to two reasons: 1) flooding slows seedling growth and thus causes seedlings to become more susceptible to herbicide injury (Moody 1992); and/or 2) flooding increases desorption of herbicide molecules and thus they are more available in soil solution for absorption by the weed roots (Devine *et al.* 1993). Pretilachlor is known to be absorbed by roots only (WSSA 2002).

Smallflower umbrella sedge was tolerant of flooding, with no reduction in seedling emergence when this weed was subjected to flooding from 2- to 6-cm water depth. Since smallflower umbrella sedge is considered an aquatic weed, shallow flooding (6 cm or less) cannot be used to suppress its emergence. Moody (1990) reported that at least 15 to 20 cm of water was necessary to effectively control smallflower umbrella sedge. Similarly, Chauhan and Johnson (2009a) observed that continuous and deep flooding reduced the seedling emergence of smallflower umbrella sedge but, as in our study, not intermittent shallow flooding. In our study, junglerice and ludwigia were less tolerant of flooding than smallflower umbrella sedge, and they had a 40 to 60% reduction in seedling emergence with flooding at 2- to 6-cm water depth. Ludwigia is considered an aquatic weed but in other studies it was shown that, unlike smallflower umbrella sedge, emergence was reduced by shallow and intermittent flooding, particularly when flooding occurred immediately after seeding (Chauhan and Johnson 2009b). Although often considered a dryland weed, junglerice can emerge even under flooded conditions (Ismail and Hossain 1995). Alternate flooding and draining to a depth of 2 cm or more could prevent the buildup of junglerice density. Our results are similar to those of Smith and Fox (1973), who reported that the emergence of barnyardgrass [*Echinochloa crus-galli* (P.) Beauv.], a close relative of junglerice, decreased by 90% with flooding to 1.3 cm.

Flooding depths in the rice fields of Asia may vary due to different rainfall patterns that can result in water levels ranging from drought to floods in the course of a single season (De Datta 1981), limited farmer resources resulting in poor land leveling (Maclean *et al.* 2002), and the turbidity of the irrigation water (Mortimer *et al.* 2005). Our results showed that the application of pretilachlor at reduced or normal-use rates followed by alternate flooding and draining can suppress the seedling emergence and shoot growth of junglerice, smallflower umbrella sedge, and ludwigia at variable water levels ranging from 0 to 6 cm, a situation that is typical on most rainfed rice farms with poor land leveling and uncontrolled water supply due to uneven rainfall distribution and poor irrigation facilities.

Anticipated trends of climate change will affect rainfall patterns and will decrease water resources. Many rice farmers, now and in the near future, will experience limited water availability, which may restrict their capacity to use continuous flooding as a weed control mechanism (Tuong *et al.* 2005). Farmers are increasingly likely to grow rice under non-flooded conditions in the future due to irrigation water shortage. Likewise, direct seeding is likely to increase as labor availability becomes increasingly lower and therefore weed management approaches for areas that were previously transplanted will have to be explored and herbicides are likely to be included in the majority of options. Concerns related to the development of resistance to herbicides in weeds, however, have been well established (Chauhan 2012; Chauhan *et al.* 2012a, b; Rao and Nagamani 2010; Rao *et al.* 2007). Integrated weed management measures provide a series of opportunities to mitigate the emergence of major resistance problems. Thus, novel integrated approaches to the use of herbicides, including reduced rates of herbicides combined with intermittent flooding, show promise as a potential improved weed management strategy. Future studies should investigate the efficacy of other herbicides, combined with intermittent flooding, against rice weeds. Further, there is a need to study the efficacy of such herbicides when combined with intermittent flooding of either turbid or clear water to represent the conditions in many farmers' fields.

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