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Integrated use of the stale seedbed technique with preemergence herbicides to control weedy rice in wet seeded rice

Research Article

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Abstract

This study was undertaken to investigate the integration effects of pretilachlor, oxadiazon, and dimethenamid with or without glyphosate in a stale seedbed method to control weedy rice in wet-seeded rice. The study, conducted in 2018 and 2019, comprised two seedbed treatments in main plots, with and without glyphosate (850 g ae ha^{-1}), and four subplot treatments: pretilachlor, oxadiazon, dimethenamid, and unsprayed check. Fifteen days after glyphosate spray, each subplot was treated with preemergence herbicides at 500 g ai ha^{-1} under standing water conditions (2 to 3 in.), and the water level was maintained for 7 d. Pregerminated rice seeds (var. MR297) were hand-broadcasted in the moist soil at 120 kg ha^{-1} seeding rate. In 2019, the density and dry weight of weedy rice were 30% and 118% higher Gthan those observed in 2018, respectively. A stale seedbed with glyphosate reduced weedy rice dry weight by 12% as compared to what was observed in a stale seedbed without glyphosate. Addition of oxadiazon and pretilachlor to the stale seedbed drastically reduced weedy rice dry weight by 70% to 88% and 53% to 60% in both years. Dimethenamid contributed to a significant reduction of weedy rice dry weight of 19% in 2019 only but failed to provide a positive economic return. Integration of pretilachlor and oxadiazon in a stale seedbed with glyphosate gave profitable returns of $84.00 to 311.4 ha^{-1} and $175.70 to 483.8 ha^{-1}, respectively. Without the presence of glyphosate, pretilachlor and oxadiazon contributed a positive return of $318.90 and $469.40, respectively, in 2018, but the economic returns were negative in 2019. These results suggest that integration of pretilachlor or oxadiazon in a stale seedbed with glyphosate is more crucial when weedy rice infestation is high, but glyphosate can be excluded from the management regime when the weedy rice populations are low.

Introduction

Rice plays a pivotal role in global food security, as it is the staple food for more than half of the global population (FAO 2022). Rice is the primary source of income for small-scale farmers, and several countries, such as India, Thailand, Vietnam, and Pakistan. are highly dependent on rice as a source of government revenue (Ha et al. 2017; Laiprakobsup 2019). Traditionally, rice is grown by transplanting seedlings into puddled soil. However, escalating labor costs and limited access to irrigation water are demanding a shift from transplanting to wet direct seeding (wet seeding) of rice. In wet seeding, pre-germinated seeds are broadcast onto wet puddled soil. This system is more water efficient when compared to the transplanting system (Tabbal et al. 2002). However, the biggest drawback of wet seeding is weeds. This is because weeds germinate and emerge at the same time as the rice, and the absence of standing water in the initial stage of crop establishment allows weeds to be more competitive under wet-seeding systems (Kumar and Ladha 2011).

Wet-seeding rice growers are able to control most of the weed species that grow in the early crop establishment stage by applying preemergence herbicides, except for weedy rice. There is no selective herbicide (except herbicide-resistant rice technology) available to control weedy rice without affecting cultivated rice because weedy rice has similar morphological and physiological traits to those of cultivated rice (Chauhan 2012). Thus weedy rice has emerged as one of the most troublesome weeds occurring in rice-growing areas worldwide (Ziska et al. 2015). It has been reported that weedy rice can cause severe yield loss ranging from 15% to 100% (Kumar and

Ladha 2011). In addition to yield loss, weedy rice reduces rice grain quality and grower net income (Ottis et al. 2005). The introduction of imidazolinone (IMI)-resistant rice (also known as Clearfield® [BASF, Ludwigshafen, Germany] rice technology) in recent years has offered weedy rice management with a selective chemical control option. Clearfield® rice technology is based on an induced mutant resistant to IMI herbicides that inhibits enzyme acetohydroxyacid synthase (Singh et al. 2017). This innovative solution delivers significant value and benefits to the rice farmers through effective weedy rice control (Fish et al. 2015), reduced cost of production (Azmi et al. 2012), increased yield potential (Sudianto et al. 2013), and improved crop quality (Duong et al. 2007).

However, there is a downside to this technology, which is the prevalence and spread of IMI-resistant weedy rice through IMI-resistant gene transfer from Clearfield® rice to weedy rice (Burgos et al. 2008; Merotto et al. 2016). Many countries that adopt Clearfield® rice have reported IMI-resistant weedy rice (Sudianto et al. 2013; Dilipkumar et al. 2018). This has prompted rice growers to find alternative solutions and additional tools for weedy rice management. Because weedy rice and cultivated rice are conspecific, weedy rice should be controlled before rice planting. A stale seedbed is one of the techniques to control weedy rice prior to rice sowing. It works by stimulating the emergence of weedy rice seedlings, which are then destroyed mechanically or chemically (Chauhan 2013). As well, applying preemergence herbicides immediately after tillage under standing water conditions has been documented to control weedy rice effectively (Chauhan 2013; Olajumoke et al. 2016). Both these techniques incrementally deplete the soil seedbank of weedy rice. In an intensive wet-seeding rice system, there is a need to evaluate the possibility of using both techniques together to control weedy rice.

Several previous studies have provided helpful insights on preemergence herbicides, such as pretilachlor (Olajumoke et al. 2016), oxadiazon (Eleftherohorinos and Dhima 2002), and dimethenamid (Ferrero and Vidotto 1999), which are effective against weedy rice before its emergence. In addition, postemergence, glyphosate is the most commonly employed nonselective herbicide in rice fields using the stale seedbed technique (Singh et al. 2018). However, information on the potential of preemergence herbicides to improve weedy rice control under a stale seedbed is sparse for wet-seeded rice systems. Therefore a field study was conducted to evaluate the integration effects of pretilachlor, oxadiazon, and dimethenamid with or without glyphosate in stale seedbed method to control weedy rice.

Materials and Methods

Experimental Site

A field study was conducted under irrigated conditions in 2018 and 2019 at the research field of the MARDI Seberang Perai, Pulau Pinang, Malaysia (5°32′35.8″N 100°27′51.6″E). The soil texture is sandy clay loam (51% sand, 12% silt, and 37% clay) with a pH of 5.8 and organic matter content of 0.8%. To avoid herbicide residue effects, the field experiment in 2019 was moved to an adjacent area with similar soil physicochemical properties (47% sand, 14% silt, and 39% clay with 5.6 pH and 0.8% organic matter content). Climate data were obtained from the MARDI Seberang Perai meteorological station located 0.5 km from the experimental site. The monthly temperatures and amount of rainfall recorded at the experimental site during the experimental periods are presented in Figure 1.

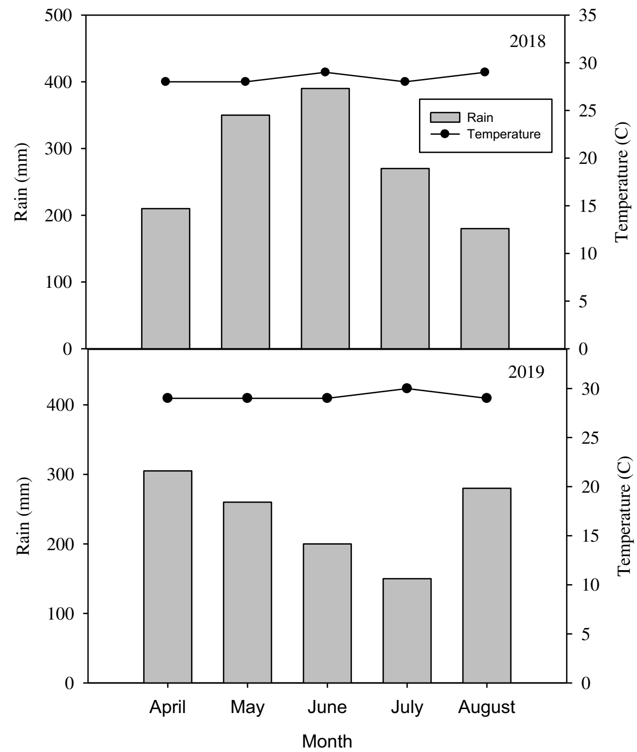

Figure 1. Average air temperature and rainfall data recorded at the experimental site in 2018 and 2019 at the research field of the MARDI Seberang Perai, Pulau Pinang, Malaysia (5°32′35.8″N, 100°27′51.6″E).

Experimental Design and Agronomic Management

The field experiment was conducted in a split-plot design with four replicates. Two seedbed treatments were compared in the main plots, (1) with and (2) without glyphosate (Monsanto, Pasir Gudang, Johor, Malaysia), and four preemergence herbicide treatments were compared in subplots: (1) pretilachlor (Syngenta Crop Protection, Shah Alam, Selangor, Malaysia), (2) oxadiazon (Hextar Chemicals, Pelabuhan Klang, Selangor, Malaysia), (3) dimethenamid (BASF, Shah Alam, Selangor, Malaysia), and (4) unsprayed check. The glyphosate was sprayed at 850 g ae ha^{-1}, and the preemergence herbicides were sprayed at 500 g ai ha^{-1}, respectively. The application rates were based on the product label. The size of each subplot was 25 m^2. The standard procedure of stale seedbed preparation in wet-seeded rice systems was carried out as described by Senthilkumar et al. (2019). This involves stimulation of the weed emergence, followed by chemical or mechanical destruction through deep tillage under dry soil conditions and shallow tillage under flooded soil conditions and, finally, land leveling with a wooden plank at 1 to 2 d before rice sowing.

Main plot treatments of glyphosate were applied 10 d after rice harvest. Dry tillage followed by wet tillage was conducted at 7 to 14 d after glyphosate applications. Each subplot was separated by a distance of 1 m with an earth levee (28 to 33 cm wide) to avoid herbicide contamination from one plot to another. One day after the wet tillage, preemergence herbicide treatments were sprayed in each subplot under standing water conditions. The water depth in each subplot was maintained at 5 to 7.5 cm for 7 d. The soil–water level and intervening time were selected based on a recent glasshouse study that showed optimum application timing of pretilachlor, oxadiazon, and dimethenamid with excellent efficacy at 7 d after spraying under standing water conditions (unpublished data).

All herbicides were sprayed using a CO_2-pressurized backpack sprayer fitted with a flat-fan nozzle, and the sprayer was calibrated at 145 kPa to deliver spray solution at 350 L ha^{-1} and 200 L ha^{-1} for glyphosate and preemergence herbicide, respectively. Seven days after spraying the preemergence herbicides, land leveling was performed in each subplot using a wooden plank. Pre-germinated rice seeds (var. MR297) were hand-broadcasted in the moist soil at 120 kg ha^{-1} seeding rate. In line with the local recommendation for wet-seeding rice systems, 120 kg ha^{-1} of urea was applied in equal split doses at 15, 30, and 60 d after sowing (DAS). Full doses of triple super phosphate (57 kg ha^{-1}) and potassium chloride (42 kg ha^{-1}) were applied at 15 DAS. The field was irrigated at 10 DAS, and water depth was maintained up to 5 to 7.5 cm until 2 wk before harvest.

Data Collection

Herbicide efficacy was determined by evaluating weedy rice density and dry weight at the rice harvest stage. Two quadrates (50 × 50 cm) were placed randomly in the center of each plot (3 × 3 m). Emerged weedy rice plants were counted, and aboveground tissues of weed rice plants were harvested and oven-dried at 70 C for 5 d. To evaluate herbicide phytotoxicity in rice, rice plant density and dry weight were determined using the quadrate method, as described earlier. Rice plant height was recorded from ten plants randomly selected in each plot. Rice grain yield was determined by harvesting an area of 12 m^2 in the center of each plot. The grain yield was converted to tons per hectare at 14% moisture content.

Economic Analysis

Economic analysis of each treatment was performed by deducting the net variable cost from the gross return (Rashid et al. 2012). All costs were converted to USD ($1 equal to MYR4.12). The general variable input costs (ha^{-1}) for all treatments are as follows (R. Hairazi, personal communication, September 25, 2019): certified rice seed ($97), machinery rate ($250), pesticides ($173), fertilizers ($240), and labor cost ($220). Additional costs per treatment were the costs of glyphosate ($17), pretilachlor ($44), oxadiazon ($66), dimethenamid ($52), and spraying ($12). The local market price for rice grain yield was $379 t ha^{-1}.

Statistical Analyses

All data were checked for normality and homogeneity of variance before being subjected to analysis of variance (ANOVA) using SAS version 9.4 (SAS Institute Inc., Cary, NC). All data were subjected to ANOVA as a split-plot design using the GLIMMIX procedure in SAS. The main effects of glyphosate treatment, preemergence herbicide treatment and year, and all interactions were treated as fixed effects, and block nested within year was treated as a random effect. The means were then separated using Tukey's test at a 5% level of significance.

Results and Discussion

Weedy Rice Density

Because no year-by-glyphosate, treatment-by-preemergence herbicide, year-by-preemergence herbicide, and year-by-glyphosate treatment interactions were observed, data were pooled over main effects. In 2019, the density of weedy rice was greater than that observed in 2018 (Figure 2 A). This indicates that the weed

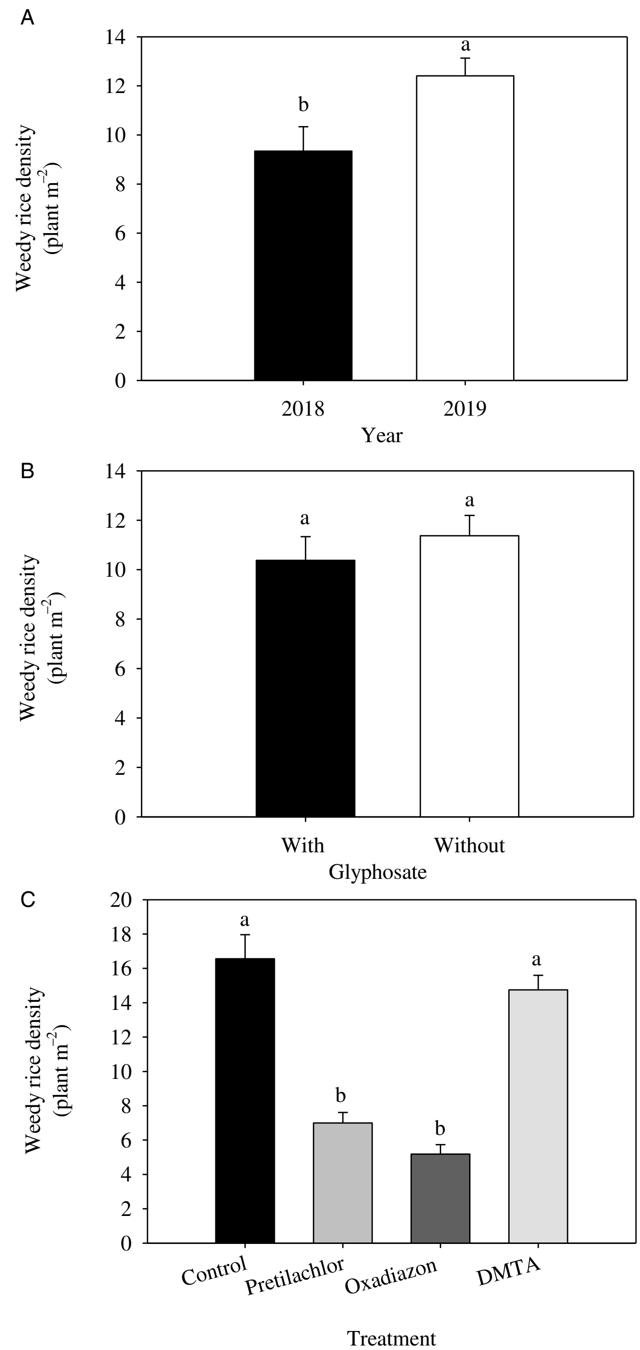

Figure 2. Main effects of year (A), glyphosate treatment (B), and preemergence herbicides (C) on the density of weedy rice. Means followed by a different lowercase letter have a significant difference at the 5% significance level.

pressure in the adjacent field was higher than in the first field. Glyphosate in the stale seedbed did not reduce weedy rice density as compared to treatments without glyphosate (Figure 2 B).

Flooding has been the most effective and widespread cultural practice for weedy rice control in rice production (Nadir et al. 2017). The present study shows that flooding plus preemergence herbicide provides greater control of weedy rice as compared to flooding alone. Oxadiazon and pretilachlor decreased the density of weedy rice by 70% and 58%, respectively (Figure 2 C). Oxadiazon has been reported to control weedy rice effectively when applied 15 d before rice sowing (Estorninos et al. 2005).

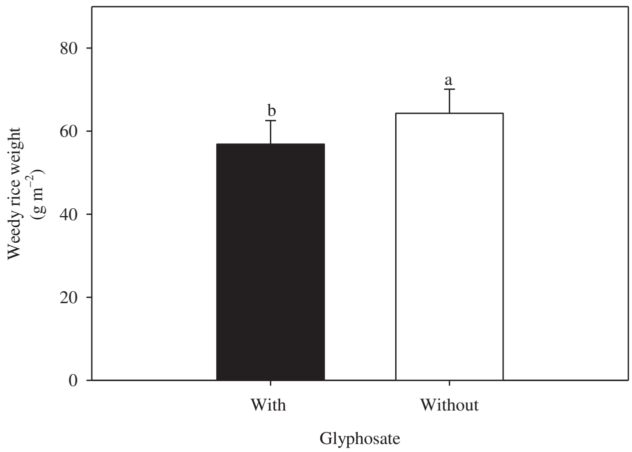

Figure 3. Main effect of glyphosate treatment on the dry weight of weedy rice. Means followed by a different lowercase letter have a significant difference at the 5% significance level.

Lin et al. (2016) demonstrated that pre-sowing application of oxadiazon at 450 g ai ha^{-1} under dry soil conditions inhibited weedy rice emergence by 44%, while the efficacy level was increased almost 2-fold (86%) when the same oxadiazon rate was applied under standing water conditions.

Pretilachlor usage after rice sowing in wet-seeded rice is common in many countries (Rashid et al. 2012; Dilipkumar et al. 2017); however, only a few studies have demonstrated pretilachlor efficacy for weed control before rice sowing. In Thailand, dripping pretilachlor directly into the water during land leveling and before rice sowing was reported to control weedy rice effectively (Allard et al. 2005). Azmi et al. (2005) claimed 35% to 55% reduction in the weedy rice seedbank when pretilachlor was applied just before or after tillage under standing water conditions. Although dimethenamid belongs to the same chemical group as pretilachlor, it failed to reduce weedy rice density significantly in the present study. Nevertheless, a high rate of dimethenamid at 1.4 kg ai ha^{-1} has been reported to reduce weedy rice panicle 53% to 100% with no phytotoxicity on rice when applied 15 d before rice sowing (Eleftherohorinos and Dhima 2002). However, the long interval period between herbicide spray and rice sowing may not be suitable for smallholders, who are highly dependent on input from external resources, such as service providers for machinery and irrigation.

Weedy Rice Dry Weight

The stale seedbed with glyphosate treatment conferred a greater reduction in weedy rice dry weight when compared to that observed in a stale seedbed without glyphosate (Figure 3). There was a significant ($P < 0.001$) interaction between year and preemergence herbicides on weedy rice dry weight; hence the data were analyzed and presented separately for both years. Weedy rice dry weight was 103% higher in 2019 in comparison with 2018, because of the high weedy rice density in that year (Table 1). Oxadiazon was the most effective treatment compared to the other two preemergence herbicides tested in both years. Addition of oxadiazon to the stale seedbed drastically reduced weedy rice dry weight by 70% to 88%. Application of pretilachlor contributed to the reduction of weedy rice dry weight by 60% in 2018 and by 53% in 2019.

Table 1. Interaction effect of year and preemergence herbicide on weedy rice dry weight.[a]

Preemergence herbicide	2018	2019
	g ai ha^{-1}	
Control	63.6 a	128.8 a
Pretilachlor	25.3 b	60.9 c
Oxadiazon	7.8 c	38.5 d
Dimethenamid	55.9 a	104.1 b

[a]Means within a column followed by the same letter are not different according to the Tukey test at 5% significance.

Table 2. Integrated use of the stale seedbed with or without glyphosate and preemergence herbicides on dry weight, height, density, and yield of rice in 2018 and 2019.[a]

Source	Rice dry weight	Rice height	Rice density	Rice yield
	g m^{-2}	cm	hill m^{-2}	t ha^{-1}
Year				
2018	610.4 a	95.7 a	78.9 a	3.2 a
2019	352.6 b	93.1 b	62.2 b	2.5 b
Glyphosate				
With	505.8 a	94.7 a	72.5 a	2.9 a
Without	457.3 b	94.1 a	68.7 b	2.7 b
Treatment				
Control	342.1 d	92.4 b	57.7 c	2.2 b
Pretilachlor	555.1 b	96.3 a	77.3 a	3.2 a
Oxadiazon	624.3 a	95.8 a	83.1 a	3.6 a
Dimethenamid	404.7 c	93.2 b	64.3 b	2.5 b

[a]Means within a column followed by the same letter are not different according to the Tukey test at 5% significance.

Oxadiazon is characterized by a high persistence in the soil with a half-life ranging from 3 to 6 mo (MacBean 2012), while the half-life of pretilachlor in soil was reported to be 20 to 50 d (Worthing and Hance 1991). This could be the reason for higher efficacy of oxadiazon over the pretilachlor in controlling weedy rice, because oxadiazon is more available in the soil solution for absorption by the weedy rice compared to pretilachlor. On the other hand, the effect of dimethenamid on weedy rice dry weight was inconsistent across the years. In 2018, no significant reduction was observed in weedy rice dry weight, whereas in 2019, the weedy rice dry weight was reduced by 19%. However, this reduction in weedy rice dry weight may not be adequate to provide farmers with a profitable return.

Rice Yield Components and Grain Yield

There were no year-by-glyphosate, treatment-by-preemergence herbicide, year-by-preemergence herbicide, year-by-glyphosate treatment, and glyphosate treatment-by-preemergence herbicide interactions, therefore the data were combined, and the main effects are discussed. Greater values for rice plant height, rice density, rice dry weight, and grain yield were recorded in 2018 than in 2019 (Table 2). This was due to the lower weedy rice density and dry weight in 2018 (Figures 2 A and 3), thereby leading to lower rice–weedy rice competition. Hence high rice yield parameters and associated grain yield improvement were observed in 2018. Similar findings have been reported by Karn et al. (2020), where rice plant height and tiller number were reduced by 13% and 49%, respectively, under the competitive condition with weedy rice. A stale seedbed with glyphosate increased rice dry weight by 11%, density by 6%, and grain yield by 7% compared to the rates

Table 3. Net economic returns under different seedbed and preemergence herbicide treatments in wet-seeded rice in 2018 and 2019.[a]

	2018				2019			
	Check	Pre	Oxa	DMTA	Check	Pre	Oxa	DMTA
	USD ha^{-1}							
Stale seedbed with glyphosate	−21.1	311.4	483.8	−9.3	−258.0	84.0	175.7	−170.4
Stale seedbed without glyphosate	−51.4	318.9	469.4	−60.5	−307.3	−116.9	−15.8	−238.6

[a]Abbreviations: Pre, pretilachlor; Oxa, oxadiazon; DMTA, dimethenamid.

observed under non-glyphosate treatment (Table 2). Weedy rice dry weight was reduced using a stale seedbed followed by glyphosate (Figure 3), indicating their partial success in reducing competitive effects on rice. This result differs from that of Singh et al. (2018), who reported lower efficacy of the stale seedbed with glyphosate than with shallow tillage. The authors pointed out that some weed seedlings might have escaped because they emerged after glyphosate application. In the present study, use of deep tillage following glyphosate application controlled weedy rice that emerged after application.

Pretilachlor and oxadiazon increased the dry weight (62% to 82%), plant height (4%), density (34% to 44%), and grain yield (45% to 64%) of rice when compared to the rates observed in control plots (Table 2). However, addition of dimethenamid to the stale seedbed did not increase rice yield. These results indicate that integration of preemergence herbicides in a stale seedbed will confer additional benefits to rice grain yield, but the efficacy is dependent on the herbicide type. Pretilachlor and oxadiazon kill weedy rice effectively, hence providing a competitive advantage to the rice during its early stages of growth. Higher rice plant density and dry weight will ultimately lead to further weed suppression (Weiner et al. 2001).

Economic Return

The present study indicates that application of glyphosate and/or integration of preemergence herbicide to stale seedbeds reduces the weedy rice population and consequently increases rice yield. However, assessment of economic feasibility is vital to determine the cost-effectiveness of these techniques. Application of glyphosate to a stale seedbed reduced economic losses by approximately 59% in 2018 and 16% in 2019 when compared to stale seedbeds without glyphosate (Table 3). Nevertheless, the net income was negative in both years, indicating that a stale seedbed with glyphosate alone does not benefit farmers in terms of gaining profitable returns. Integration of pretilachlor and oxadiazon in a stale seedbed with glyphosate gave positive returns in 2018 ($311.40 and 483.80 ha^{-1}) and 2019 ($84.00 and 175.7 ha^{-1}), respectively. The decrease in net returns in 2019 was expected because weedy rice density and growth were higher in that year compared to the previous year (Figure 2 A and Table 1). Such a case has been reported in Arkansas, where the economic loss due to a high infestation of weedy rice was estimated to be $274 ha^{-1} (Burgos et al. 2008).

A positive return was obtained in 2018 when pretilachlor ($318.90) or oxadiazon ($469.40) was integrated into a stale seedbed without the presence of glyphosate. Surprisingly, a similar trend was not observed in 2019, when the economic returns were negative for both pretilachlor (−$116.90) and oxadiazon (−$15.80). These results suggest that integration of pretilachlor or oxadiazon into a stale seedbed with glyphosate is more crucial when the weedy rice infestation is high, but glyphosate can be excluded from the management regime when the weedy rice population is low. Dimethenamid did not provide control of weedy rice; therefore negative net returns were observed with and without the use of glyphosate.

The present study highlights the potential use of pretilachlor and oxadiazon in a stale seedbed to control weedy rice in wet-seeding rice. However, to evaluate the ability of this technique to reduce the seedbank of weedy rice in soil, a repeat experiment at the same site over consecutive seasons is warranted.

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