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Performance of Different Herbicides in a Dry-Seeded Rice System in Sri Lanka

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Dry-seeded rice systems are an emerging production technology in many Asian countries. A field study was conducted in 2011 and 2012 at the farm of the Rice Research and Development Institute, Batalagoda, Sri Lanka, to evaluate the performance of different herbicides in a dry-seeded rice system. Weed control treatments were nontreated (weedy), pretilachlor plus pyribenzoxim, cyhalofop-butyl, thiobencarb plus propanil, propanil, and bispyribac-sodium plus metamifop. All these POST herbicides were applied at 8 d after sowing, followed by an MCPA spray at 20 d after sowing. The dominant weeds in the study were barnyardgrass, Chinese sprangletop, and knotgrass. All herbicide treatments provided similar weed control, which ranged from 82 to 99%. Weeds in the nontreated plots reduced rice grain yield by 58 to 79% compared with the herbicide-treated plots. All herbicide-treated plots, except cyhalofop-butyl-treated ones, produced similar grain yield, which ranged from 3.7 to 4.2 t ha^{-1} in 2011 and from 6.0 to 7.0 t ha^{-1} in 2012. The results of our study suggest that different herbicides provided similar weed control and therefore different herbicides can be rotated in different seasons to reduce selection pressure on weeds.
Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.) Beauv.; Chinese sprangletop, *Leptochloa chinensis* (L.) Nees; knotgrass, *Paspalum distichum* L.; rice, *Oryza sativa* L.
Key words: Asia, herbicide efficacy, weed biomass, weed density.

Los sistemas de siembra en seco de arroz son una tecnología que está surgiendo en muchos países asiáticos. En 2011 y 2012, se realizó un experimento de campo en la finca del Instituto de Investigación y Desarrollo del Arroz, Batalagoda, Sri Lanka, para evaluar el desempeño de diferentes herbicidas en un sistema de arroz de siembra en seco. Los tratamientos de control de malezas fueron sin-tratamiento (enmalezado), pretilachlor más pyribenzoxim, cyhalofop-butyl, thiobencarb más propanil, propanil, y bispyribac-sodium más metamifop. Todos estos herbicidas POST fueron aplicados a 8 días después de la siembra, seguidos de una aspersión con MCPA a 20 días después de la siembra. Las malezas dominantes en el estudio fueron *Echinochloa crus-galli*, *Leptochloa chinensis*, y *Paspalum distichum*. Todos los tratamientos de herbicidas brindaron un control de malezas similar, el cual varió entre 82 y 99%. Las malezas en las parcelas sin tratamiento redujeron el rendimiento de grano del arroz en 58 a 79%, al compararse con las parcelas tratadas con herbicidas. Todas las parcelas tratadas con herbicidas, excepto aquellas tratadas con cyhalofop-butyl, produjeron un rendimiento de grano similar, el cual varió entre 3.7 a 4.2 t ha^{-1} en 2011 y entre 6.0 y 7.0 t ha^{-1} en 2012. Los resultados de nuestro estudio sugieren que los diferentes herbicidas brindaron un control de malezas similar, y por lo tanto, diferentes herbicidas pueden ser rotados en diferentes temporadas de producción para reducir la presión de selección sobre las malezas.

Rice is a staple food for Sri Lankans and provides livelihood to more than 1.3 million farmers (Abeysekera et al. 2010). In Sri Lanka, approximately 95% of the total rice is established as seeded rice, dry- and wet-seeded; most is wet-seeded and only 2 to 3% is dry-seeded (Weerakoon et al. 2011). In wet-seeded rice, the soil is cultivated under flooded conditions, called *puddling*, and then pregerminated rice seeds are broadcast on puddled soil. Puddling, however, consumes a considerable amount of water (Chauhan 2012; Chauhan et al. 2012). In Sri Lanka, the agricultural sector uses 85 to 90% of the total water withdrawals and rice cultivation uses 94% of the total irrigation withdrawals (Manthrithilake and Molden 2010). In the future, a significant area in South Asia, including Sri Lanka, will face water scarcity and farmers will have limited water for rice production, especially for performing puddling and providing flood irrigation (Jayatillake 2003; Mahajan et al. 2012; Tuong and Bouman 2003).

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Dry seeding is one way of reducing the water requirement during field preparation (Mahajan et al. 2011, 2012). In dry-seeded rice systems, cultivation and seeding are also performed under dry conditions. In Sri Lanka, the area under dry seeding is very small because of the nonavailability of seed drills. As labor is becoming more costly, there are indications that mechanized dry seeding may increase in the future in Sri Lanka (Chauhan 2012; Weerakoon et al. 2011). In dry-seeded systems, however, weeds are one of the most important biological constraints (Chauhan 2012; Chauhan and Opeña 2012; Chauhan et al. 2012). In Sri Lanka, rice yield losses due to weeds have been reported to be 20 to 40% (Amarsinghe et al. 1998; Herath Banda et al. 1998). A yield reduction of up to 80% was reported when weed infestation was high (Amarsinghe et al. 1998). In a recent survey in Sri Lanka, around 80% of the farmers reported weeds as the major production constraint in rice (Abeysekera et al. 2010).

Herbicides are widely used to control weeds in rice in Sri Lanka. Some of the recommended herbicides for rice weed control in the country are propanil, bispyribac-sodium, cyhalofop-butyl, MCPA, ethoxysulfuron, fenoxaprop, and 2,4-D (Abeysekera et al. 2010). However, almost all the available information on herbicide performance is for the wet-seeded rice production system. As dry-seeded rice area may

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Table 1. Effect of weed control treatments on barnyardgrass, Chinese sprangletop, and knotgrass density at 42 d after sowing in 2011 and 2012. Weed-density data were subjected to square-root transformation before analysis. Original weed density values are shown in parentheses.[a]

	Weed density					
	Barnyardgrass		Chinese sprangletop		Knotgrass	
Weed control treatments	2011	2012	2011	2012	2011	2012
	No. m^{-2}					
Weedy (nontreated)	6.9 (48.9)	3.4 (16.7)	12.6 (181.0)	14.2 (211.0)	7.1 (58.0)	1.2 (1.3)
Pretilachlor + pyribenzoxim fb MCPA	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	1.2 (1.0)	5.0 (36.0)	0.7 (0.0)
Cyhalofop-butyl fb MCPA	2.0 (6.4)	0.7 (0.0)	3.9 (28.0)	3.2 (14.0)	6.3 (89.0)	4.1 (27.0)
Thiobencarb + propanil fb MCPA	0.7 (0.0)	2.0 (6.4)	0.7 (0.0)	0.7 (0.0)	5.4 (35.0)	2.3 (6.4)
Propanil fb MCPA	2.0 (6.4)	1.4 (2.6)	1.2 (1.0)	5.2 (27.0)	2.8 (15.0)	2.0 (6.4)
Bispyribac-sodium + metamifop fb MCPA	1.2 (1.3)	0.7 (0.0)	2.1 (8.0)	3.9 (24.0)	4.2 (19.0)	3.1 (12.9)
$LSD_{0.05}$[a]	2.2	NS	6.1	4.8	NS	NS

[a] Abbreviations: fb, followed by; $LSD_{0.05}$, least significant difference at 5% level of significance; NS, nonsignificant.

increase in the future in Sri Lanka, there is a need to evaluate different herbicides under dry-seeded conditions. Therefore, a field study was conducted in Sri Lanka to evaluate the performance of different herbicides in a dry-seeded rice system.

Materials and Methods

A field study was conducted during the *Maha* season of 2011 and *Yala* season of 2012 at the Rice Research and Development Institute, Batalagoda, Sri Lanka. The soil at the experimental site was a red–yellow podsolic. The field was plowed once, harrowed twice, and then leveled with a wooden board. As seed drills were not available at sowing time, rice seeds were sown by hand in shallow furrows and covered with soil. Rice seeds (cv. Bg 357) were sown at a rate of 100 kg ha^{-1} in rows 18 cm apart on September 22, 2011, and March 16, 2012. Phosphorus (50 kg P_2O_5 ha^{-1}) and potassium (22 kg K_2O ha^{-1}) were incorporated in the soil before crop sowing. Nitrogen (120 kg ha^{-1}) was applied in three equal splits: 10, 28, and 50 d after sowing (DAS). The experiments were surface irrigated immediately after sowing and then as required by the crop. There was no standing water for more than 1 d.

The herbicide treatments were pretilachlor (0.375 kg ai ha^{-1}) plus pyribenzoxim (0.025 kg ai ha^{-1}), cyhalofop-butyl (0.2 kg ai ha^{-1}), thiobencarb (2.0 kg ai ha^{-1}) plus propanil (1.0 kg ai ha^{-1}), propanil (2.7 kg ai ha^{-1}), and bispyribac-sodium (0.025 kg ai ha^{-1}) plus metamifop (0.063 kg ai ha^{-1}). All these herbicide treatments were applied at 8 DAS, followed by a POST application of MCPA (1.0 kg ai ha^{-1}) at 20 DAS. Herbicides were sprayed with a knapsack sprayer that delivered 320 L ha^{-1} of spray solution through hollow-cone nozzles. No weed control of any means was done in the weedy (nontreated) plots. In both seasons, the experimental plot size was 15 m^2.

The efficacy of different herbicides on weeds was evaluated at 42 DAS by randomly placing two 0.36 by 0.36–m quadrats in each plot. In these quadrats, the density and biomass of barnyardgrass, Chinese sprangletop, knotgrass, and total weeds were evaluated. Weeds were uprooted, washed with water, and then oven-dried at 70 C for 72 h. At maturity, the crop was harvested from an area of 9 m^2 and grain yield was converted to t ha^{-1} at 14% moisture content.

The experiment in each season was arranged in a randomized complete block design with three replications. All data were analyzed with ANOVA to evaluate differences between treatments, and the means were separated by LSD at the 5% level of significance (GenStat 8.0 2005). The density of individual weed species was subjected to square-root transformation [$\sqrt{(x+0.5)}$] before analysis. No transformations were required for total weed density, weed biomass, and other data.

Results and Discussion

The experimental plots contained many weed species: barnyardgrass, Chinese sprangletop, knotgrass, smallflower umbrella sedge (*Cyperus difformis* L.), rice flatsedge (*Cyperus iria* L.), globe fringerush [*Fimbristylis miliacea* (L.) Vahl], longfruited primrose-willow [*Ludwigia octovalvis* (Jacq.) Raven], and doveweed (*Murdannia nudiflora* L.). However, the results are presented only for the top three dominant species. In 2011, all herbicides reduced the density of barnyardgrass compared with the nontreated plots (Table 1). In 2012, however, barnyardgrass density was not affected by the herbicide treatments. Compared with the nontreated plots, all herbicides reduced the density of Chinese sprangletop in both years, but had no effect on the density of knotgrass. Total weed density, however, was greatly influenced by the herbicide treatments (Table 2). In both years, all herbicide treatments reduced weed density compared with the nontreated control. Pretilachlor plus pyribenzoxim followed by MCPA application, for example, reduced total weed density by 94 to 98%, and cyhalofop-butyl followed by MCPA reduced total weed density by 56 to 87% (Table 2).

In both years, weed control treatments reduced the biomass of barnyardgrass and Chinese sprangletop (Table 3). In 2012, knotgrass biomass was not influenced by herbicide applications. Total weed biomass, however, declined markedly with herbicide applications (Table 2). The efficacy of all herbicides was similar. In 2011, compared with the weedy control, herbicide use reduced total weed biomass by 82 to 94%. These values in 2012 were 92 to 99%. In 2012, the sequential

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Table 2. Effect of weed control treatments on total weed density and total weed biomass at 42 d after sowing in 2011 and 2012.[a]

Weed control treatments	Total weed density		Total weed biomass	
	2011	2012	2011	2012
	No. m^{-2}		g m^{-2}	
Weedy (nontreated)	810	457	271	431
Pretilachlor + pyribenzoxim fb MCPA	51	10	26	6
Cyhalofop-butyl fb MCPA	355	59	50	17
Thiobencarb + propanil fb MCPA	159	13	16	15
Propanil fb MCPA	57	39	15	24
Bispyribac-sodium + metamifop fb MCPA	41	40	15	35
$LSD_{0.05}$	432	85	48	107

[a] Abbreviations: fb, followed by; $LSD_{0.05}$, least significant difference at 5% level of significance.

Table 3. Effect of weed control treatments on barnyardgrass, Chinese sprangletop, and knotgrass biomass at 42 d after sowing in 2011 and 2012.[a]

Weed control treatments	Weed biomass					
	Barnyardgrassa		Chinese sprangletop		Knotgrass	
	2011	2012	2011	2012	2011	2012
	g m^{-2}					
Weedy (nontreated)	11.1	26.2	133.7	224.0	65.2	1.7
Pretilachlor + pyribenzoxim fb MCPA	0.0	0.0	0.0	1.0	23.5	0.0
Cyhalofop-butyl fb MCPA	1.4	0.0	8.2	3.0	3.0	6.0
Thiobencarb + propanil fb MCPA	0.0	9.5	0.0	0.0	12.7	5.3
Propanil fb MCPA	4.3	2.9	0.4	20.0	3.5	0.9
Bispyribac-sodium + metamifop fb MCPA	0.4	0.0	1.6	32.0	7.5	3.3
$LSD_{0.05}$	7.7	10.0	42.8	108.0	30.9	NS

[a] Abbreviations: fb, followed by; $LSD_{0.05}$, least significant difference at 5% level of significance; NS, nonsignificant.

spray of pretilachlor plus pyribenzoxim followed by MCPA provided 99% weed control at 42 DAS (Table 2).

Herbicides effectively controlled the three dominant species and other weeds and all herbicides included in our study had a similar effect on weeds. Herbicides usually vary in their efficacy in dry-seeded rice. In a previous study in the Philippines, for example, pretilachlor had poor control of eclipta [*Eclipta prostrata* (L.) L.] and goosegrass [*Eleusine indica* (L.) Gaertn.] (Chauhan and Abugho 2013). In our study, however, pretilachlor plus pyribenzoxim followed by MCPA controlled up to 99% of all weeds. These differences between experiments in these countries could be due to the absence of eclipta and goosegrass and the addition of pyribenzoxim in our study. In a previous study in broadcast wet-seeded rice in Sri Lanka, the application of pretilachlor plus pyribenzoxim had excellent control of a broad range of weeds (Herath et al. 2007). In that study, however, this commercial mixture was not effective on knotgrass. These results are consistent with our study, in which knotgrass produced 24 g m^{-2} of biomass in the pretilachlor plus pyribenzoxim–treated plots. Although this biomass was lower than those in the weedy plots, it was still 36% of the knotgrass biomass without herbicide treatment.

Chinese sprangletop was the most dominant weed in the weedy plots. In Sri Lanka, the repeated use of some herbicides (e.g., bispyribac-sodium, penoxsulam, etc.) has increased the infestation of Chinese sprangletop (Marambe 2002; Pandit et al. 2007). The mixture of pretilachlor plus pyribenzoxim controlled Chinese sprangletop almost 100%. These results are consistent with the findings of a previous study in which pretilachlor plus pyribenzoxim applied at 6–10 DAS had excellent control of Chinese sprangletop (Pandit et al. 2007). Sri Lankan farmers predominantly apply propanil followed by MCPA, and our results suggest that the alternative use of other available herbicides can also provide effective weed control in dry-seeded rice systems.

Herbicide applications greatly improved rice grain yield. Weedy plots had only 1.3 t ha^{-1} of yield in 2011 and 1.5 t ha^{-1} in 2012 (Table 4). Compared with the herbicide-treated plots, weeds in the weedy plots reduced yield by 58 to 69% in 2011 and by 75 to 79% in 2012. In 2011, the highest grain yield (4.2 t ha^{-1}) was achieved in plots treated with

Table 4. Effect of weed control treatments on rice grain yield in 2011 and 2012.[a]

Weed control treatments	Grain yield	
	2011	2012
	t ha^{-1}	
Weedy (nontreated)	1.30	1.49
Pretilachlor + pyribenzoxim fb MCPA	4.05	7.04
Cyhalofop-butyl fb MCPA	3.09	6.48
Thiobencarb + propanil fb MCPA	3.68	6.36
Propanil fb MCPA	4.07	6.43
Bispyribac-sodium + metamifop fb MCPA	4.19	5.96
$LSD_{0.05}$	0.64	1.13

[a] Abbreviations: fb, followed by; $LSD_{0.05}$, least significant difference at 5% level of significance.

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bispyribac-sodium plus metamifop; however, yield in these plots was similar to the yield in plots treated with pretilachlor plus pyribenzoxim, thiobencarb plus propanil, and propanil alone. Plots treated with cyhalofop-butyl produced only 3.1 t ha^{-1} of rice grain yield. Cyhalofop-butyl–treated plots had 82% weed control; however, this treatment still produced 50 g m^{-2} of weed biomass. This was the highest weed biomass produced among herbicide-treated plots, which resulted in the lowest grain yield (3.1 t ha^{-1}) among plots with herbicides. All herbicide treatments produced comparable yields (6 to 7 t ha^{-1}) in 2012 (Table 4). Overall, compared with weedy plots, the application of herbicides improved rice yield by 2.4 to 3.2 times in 2011 and 4.0 to 4.7 times in 2012.

Weeds are considered the major biological constraints in dry-seeded rice systems, and our study supports previous reports (Chauhan 2012; Chauhan and Opeña 2012; Chauhan et al. 2012; Singh et al. 2007). In our study, compared with the herbicide-treated plots, weeds in the weedy plots reduced grain yield by 58 to 79%. These values, however, are higher than the losses observed in farmers' fields because farmers implement some kind of weed control. In Asia, farmers practice at least one weed control method (one hand-weeding or one application of herbicide). In the Philippines, herbicide use increased yield up to 35% compared with one hand-weeding in a dry-seeded rice system (Chauhan and Abugho 2013). Yield losses due to weeds depend on the density and type of weed flora. Among other factors, crop cultivar, planting time, timing of field operations, weather, etc., also alter the weed impact on yield. In some studies, yield losses due to weeds were reported to surpass 90% (Chauhan and Johnson 2011).

In summary, weeds cause high yield losses in dry-seeded rice if not controlled. Propanil and MCPA are most popular in Sri Lanka. Our study found that other herbicides can also effectively control weeds in dry-seeded rice systems. Therefore, different herbicides can be rotated in different seasons to help reduce the problem of resistance evolution against a particular herbicide. With the continuous use of a particular establishment method (for example, dry-seeded rice systems), weed species composition will also change and the efficacy of herbicides used in this study may be diminished. Therefore, there is a need to test different weed management strategies. In Sri Lanka, dry-seeded rice systems are very new and are currently practiced only in a small area. Before these systems become widely adopted, there is a need to develop integrated weed management programs for dry-seeded rice systems. Different components of these integrated weed management programs may involve the use of a stale seedbed practice, thorough land preparation, competitive cultivars, residue as mulch, and other options.

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