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Herbicides and herbicide combinations for management of *Leptochloa chinensis* in wet-seeded rice

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ABSTRACT

An experiment was conducted to evaluate the efficiency of various herbicides for the management of chinese sprangletop (*Leptochloa chinensis*) at Integrated Farming System Research Station, Karamana, Thiruvananthapuram of Kerala Agricultural University, India during *Kharif* (rainy season) 2018 and 2019. Grass weeds were the most dominant weed species followed by broad-leaf weeds and sedges during both the crop seasons. The present study revealed that fenoxaprop-p-ethyl at 60 g/ha was the most effective herbicide against *L. chinensis* followed by cyhalofop-butyl at 80 g/ha. Dry matter production of *L. chinensis* was lower in sole application of fenoxaprop-p-ethyl at 60 g/ha and cyhalofop-butyl at 80 g/ha compared to their tank mix combination with bispyribac-sodium at 25 g/ha during both the years. Ready-mix combination of penoxsulam + cyhalofop-butyl (6% OD) at 150 g/ha was very effective in managing the complex spectrum of weeds however, it was not effective in managing *L. chinensis* compared to other herbicidal treatments. Application of bispyribac-sodium alone at 25 g/ha was not effective in controlling *L. chinensis* resulted in lower weed control efficiency of 37 and 48% during 2018 and 2019, respectively. Tank mix application of bispyribac-sodium with fenoxaprop-p-ethyl (at 25 + 60 g/ha) or cyhalofop-butyl (at 25 + 80 g/ha) recorded the least total dry matter production of weeds. All the tested herbicides and the herbicide combinations increased the grain yield compared to unweeded control during both the years.

INTRODUCTION

Chinese sprangletop or Red sprangletop scientifically known as *Leptochloa chinensis* (L.) Nees., is one of the most problematic grass weeds in rice. It is a strongly tufted, annual or short-lived perennial C_4 grass with glabrous leaves and fibrous roots. Its flowering culms are erect or ascending from a branching base and the inflorescence forms an open panicle of 15-60 cm long with numerous, slender flexuous branches (CABI 2019).

L. chinensis was earlier confined as a weed specific to the alkaline soils of Kerala and considered as an indicator plant for alkaline conditions. Of late, it has become problematic due to the shift in weed flora in the paddy fields (Jacob 2017) and heavy infestation of this weed has been reported from major rice tracts of Kerala. The weed has been spreading fast due to its prolific seed production capacity. Its ability to withstand waterlogged conditions as well as drained and moist conditions makes it a problem weed in rice (Galinato *et al*. 1999). It competes with rice from the middle of the vegetative stage to the grain filling stage and one-third loss in the yield has been reported from the plots which had 40 red sprangletop plants/m^2 (Jacob 2014).

Chemical weed control is probably the only feasible alternative in wet seeded rice. However, continuous use of a single herbicide is not effective in eliminating the weed menace in context of emerging weed shifts. Continuous use of bispyribac-sodium since 1998 onwards to control barnyard grass has resulted in a shift of dominance by *L. chinensis* in wetland rice fields of Sri Lanka (Marambe 2002). In addition, reliance on a single herbicide may result in the evolution of herbicide resistance. Continuous use of same herbicide or herbicides with a similar mode of action will lead to the development of herbicide resistance (Duary 2008). To widen the spectrum of weed control and to avoid build-up of herbicide resistance, the use of compatible mixtures of novel herbicides by tank mixing is a viable economic option. As *L. chinensis* has become a major weed in the majority of rice growing tracts of Kerala such as Kole, Kuttanad and Palakkad, formulating an effective and economic management strategy is highly essential before its population reaches alarming proportions.

MATERIALS AND METHODS

Field experiments to evaluate the performance of herbicides and herbicide combinations for the management of *L. chinensis* were carried out during the *Kharif* (rainy) seasons of 2018 and 2019 at the Integrated Farming System Research Station, Karamana, Thiruvananthapuram of Kerala Agricultural University, India. The field was situated geographically at 8^0 47' N latitude and 76^0 96' E longitude. The soil in the experimental field was sandy clay loam (62% sand, 10% silt, and 28% clay) with a pH of 4.84, 225.8 kg available N, 32 kg available P, and 450.9 kg available K per hectare during 2018. The experiment was conducted in another field of the station during 2019 with a pH of 5.86, 175.6 kg available N, 29 kg available P, and 377.66 kg available K per hectare. Rice variety '*Uma*' (*MO 16*) (115 - 120 days duration) seeds at 100 kg/ha (200 g/plot) were broadcasted in the individual plots of 20 m^2 (5 x 4 m) size. The treatments included cyhalofop-butyl at 80 g/ha, penoxsulam + cyhalofop-butyl (6% OD) – ready-mix formulation at 150 g/ha, cyhalofop-butyl + carfentrazone-ethyl at 80 + 200 g/ha, bispyribac-sodium at 25 g/ha, bispyribac-sodium + cyhalofop-butyl at 25 + 80 g/ha, bispyribac-sodium + fenoxaprop-p-ethyl at 25 + 60 g/ha, fenoxaprop-p-ethyl at 60 g/ha, stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl at 800 + 150 *fb* 80 + 200 g/ha, hand weeding twice at 20 and 45 days after sowing and an untreated control. The treatments were replicated thrice with randomized block design and the plot size adopted was 20 m^2 (5 x 4 m). All the herbicides were applied as post-emergence at 18 DAS, when weeds reached 3-4 leaf stages. The spray volume used in the study was 500 L/ha and herbicides were sprayed with a hand operated knapsack sprayer fitted with a flat-fan nozzle. In stale seedbed treatment, the fields were drained and allowed the weed seeds to germinate for 15 days followed by chemical weeding with glyphosate at 800 g/ha + oxyfluorfen at 150 g/ha at 18 days after land preparation (DALP), followed by flooding after two days until sowing of the crop. Pre-germinated rice seeds were sown after draining the field and cyhalofop-butyl + carfentrazone-ethyl at 80 + 200 g/ha was applied later at the 3-4 leaf stage of weed.

The crop was fertilized with a recommended dose of FYM (5 t/ha) and incorporated at the time of the last ploughing. Fertilizers were applied at 90:45:45 kg/ha N:P:K (KAU 2016). Observations on weed density and weed dry weight for total weeds and *L. chinensis* were recorded separately using a quadrate of size 50 x 50 cm (0.25 m^2) randomly at two sites in each plot at 15, 30, 45 days after treatment application (DATA). Data on weed count and biomass, which showed wide variation, were subjected to square root transformation. While the ANOVA indicated significant treatment effects, means were separated at $p<0.05$ and adjusted with Fisher's protected least significant difference (LSD) test. Weed control efficiency (WCE) was computed separately for *L. chinensis* and total weeds by using weed dry weight. Yield attributing characters like panicles/m^2, grains/panicle, percentage of filled grains and 1000 grain weight were recorded at harvest by placing the quadrate (0.25 x 0.25 m) in each plot. The data generated from the experiments were subjected to analysis of variance of RBD using the statistical package WASP (Web-Based Agricultural Statistics Software Package).

RESULTS AND DISCUSSION

Weed flora and density

Grass weeds were the most dominant weed species followed by broad-leaf weeds and sedges during both the crop seasons. The grass weeds comprised of *Leptochloa chinensis, Echinochloa colona*, and *Isachne miliacea.* The major broad-leaf weeds were *Sphenocleaa zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis, Alternnathera philoxeroides* and *Lindernia parviflora*. The sedges present were *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea.*

At 45 DATA, grass weeds constituted 89% during 2018 and 75% during 2019 (**Table 1**). Out of this, *L. chinensis* constituted 81% during 2018 and 56% during 2019 (**Table 2**). Density of *L. chinensis* was zero in fenoxaprop-p-ethyl at 60 g/ha sprayed plots at 15 DATA during both the years and provided very good control at 30 and 45 DATA during both the years (**Table 3**). This result was closely confirmed with the findings of Jacob (2014), who reported fenoxaprop-p-ethyl as the most effective herbicide against *L. chinensis* and resulted in 100% control at 30 and 60 DAS. Application of bispyribac-sodium at 25 g/ha alone was not effective in controlling *L. chinensis.* Abeysekera and Wickrama (2004), Jacob (2014) and Atheena (2016) also observed the inefficiency of bispyribac-sodium in controlling *L. chinensis*. On the other hand, it's combination with fenoxaprop-p-ethyl (at 25 + 60 g/ha) and cyhalofop-butyl (at 25 + 80 g/ha) resulted in a conspicuous reduction in *L. chinensis* population during all stages of observation. Wang *et al*. (2000) and Mahajan and Chauhan (2015) reported improved control of *L.*

chinensis with the tank mix of fenoxaprop-p-ethyl and bispyribac-sodium.

Stale seedbed *fb* glyphosate + oxyfluorfen (at 800 + 150 g/ha) *fb* cyhalofop-butyl + carfentrazone-ethyl (at 80 + 200 g/ha) was effective in controlling the germination and establishment of *L. chinensis* in the early stages of the crop, as indicated by the *L. chinensis* density at 15 and 30 DATA. A higher germination (95%) percentage immediately after maturity indicated the absence of dormancy in *L. chinensis* and reiterated the implication of stale seedbed strategies before crop establishment to deplete the soil seed bank (Chauhan and Johnson 2008). Application of cyhalofop-butyl at 80 g/ha alone and the tank mix combination of cyhalofop-butyl with carfentrazone-ethyl at 80 + 200 g/ha or bispyribac-sodium at 80 + 25 g/ha were effective in controlling *L. chinensis* and brought about considerable reduction (93-97%) in the count of *L. chinensis* in the early stages of the crop during both the years. Jacob (2014) reported cyhalofop-butyl as the next best herbicide to fenoxaprop-p-ethyl in controlling grasses including *L. chinensis*.

Considerable reduction (24-50%) in *L. chinensis* population was observed with the application of fenoxaprop-p-ethyl at 60 g/ha alone compared to its combined application with bispyribac-sodium at 25 g/ ha during both the years. It was also observed that the tank mix combinations of cyhalofop-butyl with penoxsulam or carfentrazone-ethyl or bispyribac-sodium recorded highest *L. chinensis* count compared to the application of cyhalofop-butyl alone. Application of fenoxaprop-p-ethyl at 60 g/ha or cyhalofop-butyl at 80 g/ha alone resulted in 35-50% and 11-40% reduction in *L. chinensis* population, respectively compared to its tank mix combinations. This might be due to the antagonistic responses of the herbicides used for the combinations against the weed. Studies conducted by Bhullar *et al*. (2016) also observed antagonistic effect of bispyribac-sodium and fenoxaprop-p-ethyl mixture for the control of *L. chinensis* during 2012. However, the tank mix combination of fenoxaprop-p-ethyl + bispyribac-sodium (at 60 + 25 g/ha) was effective in managing the total weed population. Application of fenoxaprop-p-ethyl at 60 g/ha or cyhalofop-butyl at 80 g/ha was not able to control the complex spectrum of weed (**Table 2**) as indicated by the increased total population of weeds contributed by broad-leaf weeds and sedges in the plots treated with these herbicides alone (**Table 1**). Ready-mix combination of penoxsulam with cyhalofop-butyl at 150 g/ha was less effective in controlling the *L. chinensis* population in the field during both the years, compared to the application of fenoxaprop-p-ethyl at 60 g/ha alone.

Weed dry weight and weed control efficiency

Treatments had a significant effect on dry matter production of *L. chinensis* at 15, 30 and 45 DATA during 2018 and 2019 (**Table 3**). Weed dry

Table 1. Effect of treatments on *L. chinensis* density and total weed density

Treatment	*L. chinensis* density (no./m^2)						Total weed density (no./m^2)			
	15 DATA		30 DATA		45 DATA		15 DATA		45 DATA	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Cyhalofop-butyl (80 g/ha)	1.1 (1.3)	1.7 (2.6)	2.2 (5.3)	2.1 (4.0)	3.0 (9.3)	2.1 (5.3)	10.8 (121.3)	10.4 (109.3)	11.8 (140.0)	13.1 (180.0)
Penoxsulam + cyhalofop-butyl (150 g/ha)	2.1 (5.3)	2.4 (5.3)	3.0 (9.3)	2.8 (8.0)	4.1 (17.3)	3.7 (13.3)	3.3 (14.6)	4.5 (20.0)	7.3 (54.6)	7.1 (52.0)
Cyhalofop-butyl + carfentrazone-ethyl (80+200 g/ha)	0.7 (0)	1.3 (1.3)	2.0 (4.0)	2.1 (4.0)	3.4 (12.0)	2.3 (5.3)	5.8 (34.6)	5.8 (33.3)	8.8 (90.6)	8.0 (68.0)
Bispyribac-sodium (25 g/ha)	6.5 (44.0)	6.0 (36.0)	8.9 (80.0)	7.6 (58.6)	9.0 (81.3)	8.0 (64.0)	7.1 (53.3)	6.6 (44.0)	9.9 (98.6)	9.4 (90.6)
Bispyribac-sodium + cyhalofop-butyl (25+80 g/ha)	1.6 (2.6)	1.7 (2.6)	2.5 (6.6)	2.6 (6.6)	3.0 (9.3)	2.9 (8.0)	5.3 (28.0)	3.3 (10.6)	10.7 (118.6)	5.5 (30.6)
Bispyribac-sodium + fenoxaprop-p-ethyl (25+60 g/ha)	0.7 (0)	0.7 (0)	2.0 (4.0)	1.6 (2.6)	2.5 (6.6)	2.4 (5.3)	1.1 (1.3)	1.7 (2.6)	4.5 (21.3)	3.2 (10.6)
Fenoxaprop-p-ethyl (60 g/ha)	0.7 (0)	0.7 (0)	1.6 (2.6)	1.1 (1.3)	2.0 (4.0)	2.1 (4.0)	8.3 (76.0)	11.6 (136.0)	8.3 (73.3)	12.0 (148.0)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	0.7 (0)	0.7 (0)	2.0 (4.0)	2.1 (4.0)	3.0 (9.3)	2.3 (5.3)	0.7 (0.0)	0.7 (0.0)	12.9 (168.0)	8.4 (72.0)
Hand weeding	0.7 (0)	0.7 (0)	1.1 (1.3)	1.7 (2.6)	3.0 (9.3)	2.9 (8.0)	2.5 (6.6)	2.9 (8.0)	6.5 (44.0)	3.9 (16.0)
Unweeded control	8.0 (64.0)	8.8 (78.6)	10.1 (104.0)	10.9 (119.0)	10.9 (120.0)	9.3 (88.0)	17.0 (292.0)	14.3 (206.6)	12.8 (165.3)	14.2 (208.0)
LSD (p=0.05)	14.99	5.05	2.77	3.82	2.76	8.83	3.03	0.56	3.12	2.90

DATA – Days after treatment application; *fb,* Followed by; BLW – Broad-leaf weeds; LSD: Least significant difference at the 5% level of significance; The figures in the parentheses are original values weight of *L. chinensis* was the highest in unweeded control during both the years at 15, 30 and 45 DATA and was statistically at par with bispyribac-sodium at 25 g/ha during both the years and resulted in the lowest weed control efficiency. The inefficiency of bispyribac-sodium at 25 g/ha in controlling *L. chinensis* population resulted in high dry matter production of *L. chinensis* in bispyribac-sodium treated plots and hence resulted in lower weed control efficiency.

Fenoxaprop-p-ethyl at 60 g/ha treated plots registered the lowest dry matter production of *L. chinensis* at all stages of observation during both the years, however, it was statistically comparable with all other treatments except unweeded control and bispyribac-sodium at 25 g/ha. The treatments fenoxaprop-p-ethyl at 60 g/ha, bispyribac-sodium + fenoxaprop-p-ethyl at 25 + 60 g/ha, stale seedbed *fb* glyphosate + oxyfluorfen + cyhalofop-butyl + carfentrazone-ethyl at 800 + 150 *fb* 80 + 200 g/ha were free of *L. chinensis* at the initial stages of crop growth during both the years.

Dry matter production of *L. chinensis* was higher in tank mix combination of bispyribac-sodium with fenoxaprop-p-ethyl (at 25 + 60 g/ha) or cyhalofop-butyl (at 25 + 80 g/ha) compared to the sole application of fenoxaprop-p-ethyl and cyhalofop-butyl at all stages of observations during both the years. The antagonistic response of the herbicides used in the combination resulted in the increased dry matter production of *L. chinensis.*

Ready-mix combination of penoxsulam + cyhalofop-butyl at 150 g/ha was very effective in managing the complex spectrum of weeds (**Table 4**) however, this treatment registered higher dry matter production (**Table 3**) and lower control efficiency of *L. chinensis* compared to other herbicidal treatments (**Table 5**). In the present location of the experiment, the soil texture was sandy clay loam which might be the reason for poor control of *L. chinensis*. This is consistent with the findings of Prakash *et al.* (2017) and Verma *et al.* (2017) where ready mix formulation of penoxsulam + cyhalofop-butyl recorded higher total weed dry weight in sandy loam soil. At 45 DATA,

Table 2. Effect of treatments on weed density at 45 DATA

Treatment	Weed density (no./m^2)					
	2018			2019		
	Grasses	BLW	Sedges	Grasses	BLW	Sedges
Cyhalofop-butyl (80 g/ha)	6.2(38.6)	8.2(68.0)	5.5(33.3)	4.4(20.0)	11.1(129.3)	5.1(30.6)
Penoxsulam + cyhalofop-butyl (150 g/ha)	5.4(29.3)	5.0(25.3)	0.7(0.0)	6.2(40.0)	3.5(12.0)	0.7(0.0)
Cyhalofop-butyl + carfentrazone-ethyl (80+200 g/ha)	6.2(42.6)	3.0(10.6)	5.1(37.3)	4.6(22.6)	6.1(42.6)	1.4(2.6)
Bispyribac-sodium (25 g/ha)	9.6(93.3)	2.2(5.3)	0.7(0.0)	9.4(90.6)	0.7(0.0)	0.7(0.0)
Bispyribac-sodium + cyhalofop-butyl (25+80 g/ha)	7.3(57.3)	6.3(40.0)	4.3(21.3)	4.8(24.0)	2.2(6.6)	0.7(0.0)
Bispyribac-sodium + fenoxaprop-p-ethyl (25+60 g/ha)	3.3(10.6)	3.1(10.6)	0.7(0.0)	3.2(10.6)	0.7(0.0)	0.7(0.0)
Fenoxaprop-p-ethyl (60 g/ha)	3.5(12.0)	6.8(53.3)	2.5(8.0)	3.8(14.6)	10.8(120.0)	3.5(13.3)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	3.9(20.0)	6.5(44.0)	10.2(104.0)	4.8(24.0)	6.2(40.0)	2.8(8.0)
Hand weeding	3.0(12.0)	5.6(32.0)	0.7(0.0)	3.0(9.3)	2.1(5.3)	1.1(1.3)
Unweeded control	12.1(148.0)	4.1(17.3)	0.7(0.0)	12.4(156.0)	6.7(52.0)	0.7(0.0)
LSD (p=0.05)	2.67	2.17	2.99	1.40	2.86	1.89

DATA – Days after treatment application; *fb,* Followed by; BLW – Broad-leaf weeds; LSD: Least significant difference at the 5% level of significance; The figures in the parentheses are original values

Table 3. Effect of treatments on dry weight of *L. chinensis*

Treatment	Dry weight of *L. chinensis* (kg/ha)					
	15 DATA		30 DATA		45 DATA	
	2018	2019	2018	2019	2018	2019
Cyhalofop-butyl (80 g/ha)	1.2(1.6)	1.3(1.9)	4.1(17.4)	3.8(13.9)	6.7(44.7)	6.8(43.9)
Penoxsulam + cyhalofop-butyl (150 g/ha)	2.2(6.6)	1.5(2.4)	4.9(24.3)	5.4(33.1)	9.4(88.4)	8.9(80.1)
Cyhalofop-butyl + carfentrazone-ethyl (80+200 g/ha)	0.7(0.0)	1.2(1.4)	4.4(26.0)	3.2(13.8)	6.6(61.2)	6.8(47.3)
Bispyribac-sodium (25 g/ha)	7.7(62.1)	5.8(47.2)	14.8(219.3)	12.4(170.7)	22.7(519.0)	21.0(446.2)
Bispyribac-sodium + cyhalofop-butyl (25+80 g/ha)	1.6(2.5)	1.6(2.4)	4.9(24.7)	4.3(18.5)	6.5(42.7)	6.9(48.8)
Bispyribac-sodium + fenoxaprop-p-ethyl (25+60 g/ha)	0.7(0.0)	0.7(0.0)	3.2(13.9)	2.5(7.9)	4.8(31.4)	5.9(36.4)
Fenoxaprop-p-ethyl (60 g/ha)	0.7(0.0)	0.7(0.0)	2.8(16.2)	1.7(4.4)	4.9(23.9)	5.4(30.1)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	0.7(0.0)	0.7(0.0)	3.2(14.0)	2.9(10.7)	5.5(42.2)	6.4(42.6)
Hand weeding	0.7(0.0)	0.7(0.0)	1.9(6.3)	2.2(9.2)	5.5(41.8)	6.2(39.4)
Unweeded control	8.5(74.0)	10.6(121.3)	15.5(240.7)	17.9(374.5)	28.7(826.1)	29.2(855.0)
LSD (p=0.05)	1.80	2.98	2.83	6.2	4.78	1.61

DATA – Days after treatment application; *fb,* Followed by; BLW – Broad-leaf weeds; LSD: Least significant difference at the 5% level of significance; The figures in the parentheses are original values the dry matter production of *L. chinensis* in unweeded control has increased to three-fold (826.13 kg/ha) compared to 30 DATA. Hand weeded treatment recorded statistically similar dry matter and control efficiency of *L. chinensis* with all the tested herbicides and herbicide combinations except with bispyribac-sodium at 25 g/ha. However, hand weeded treatment recorded 41.8 and 39.4 kg/ha of *L. chinensis* dry matter at 45 DATA might be due to the similar morphology of this weed with rice crop in the seedling stages resulting in the escape of some weeds from hand weeding.

Yield and yield attributes

Tank mix combination of bispyribac-sodium with fenoxaprop-p-ethyl (at 25 + 60 g/ha) or cyhalofop-butyl (at 25 + 80 g/ha) and ready mix combination of penoxsulam + cyhalofop-butyl at 150 g/ha produced a similar number of tillers/m^2, number of grains/panicle and percentage of filled grains compared to hand weeded treatment (weed free check) during the years 2018 and 2019 (**Table 6**). All the tested herbicides and the herbicide combinations applied for the management of weeds increased the grain yield compared to unweeded control during both the years and yield ranged from 2.13 to 4.93 t/ha during 2018 and from 2.01 to 5.47 t/ha during 2019. The better yield performance of herbicide application might be the result of increased resource utilization by the crop due to decreased dry matter accumulation by the weed under these treatments.

Season-long weed competition in unweeded control caused 56.77% reduction in the yield during the first season and 63.13% compared to the treatments with the highest grain yield (bispyribac-sodium + fenoxaprop-p-ethyl at 25 + 80 g/ha during 2018 and penoxsulam + cyhalofop-butyl at 150 g/ha during 2019).

In both the years, tank mix combination of bispyribac-sodium with fenoxaprop-p-ethyl at 25 + 60 g/ha (4.76 and 5.30 t/ha) and cyhalofop-butyl at 25 + 80 g/ha (4.37 and 5.14 t/ha) and ready-mix combination of penoxsulam + cyhalofop-butyl at 150 g/ha treated plots recorded statistically similar grain yield (4.55 and 5.36 t/ha) to the plots kept weed free throughout the season (4.93 and 5.47 t/ha).

Table 4. Effect of treatments on total weed dry weight

Treatment	Weed dry weight (kg/ha)					
	15 DATA		30 DATA		45 DATA	
	2018	2019	2018	2019	2018	2019
Cyhalofop-butyl (80 g/ha)	9.2(86.0)	7.7(60.4)	25.0(626.6)	24.5(604.8)	39.0(1524.3)	35.0(1241.7)
Penoxsulam + cyhalofop-butyl (150 g/ha)	4.9(23.9)	2.7(7.1)	8.4(73.0)	7.5(56.5)	16.7(287.2)	15.7(249.9)
Cyhalofop-butyl + carfentrazone-ethyl (80+200 g/ha)	8.5(72.8)	6.7(45.5)	20.6(425.5)	17.4(306.5	30.0(905.0)	27.1(740.3)
Bispyribac-sodium (25 g/ha)	8.5(73.8)	7.2(55.9)	17.8(320.7)	14.6(219.4)	26.5(704.4)	23.9(584.2)
Bispyribac-sodium + cyhalofop-butyl (25+80 g/ha)	5.2(29.6)	2.8(7.7)	9.2(85.0)	9.5(91.6)	16.8(283.9)	14.9(224.0)
Bispyribac-sodium + fenoxaprop-p-ethyl (25+60 g/ha)	3.9(18.8)	2.1(4.6)	5.4(29.7)	6.2(39.4)	14.7(222.4)	11.3(127.9)
Fenoxaprop-p-ethyl (60 g/ha)	8.8(78.8)	7.4(55.9)	24.7(612.7)	21.0(448.6)	37.5(1411.7)	33.6(1137.0)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	0.7(0.0)	0.7(0.0)	16.1(261.1)	15.4(238.0)	27.0(730.5)	26.0(684.2)
Hand weeding	4.0(16.4)	2.4(5.5)	5.3(28.6)	5.1(26.6)	10.8(117.5)	10.8(118.6)
Unweeded control	18.0(333.6)	19.3(374.8)	43.1(1867.1)	44.2(1978.2)	43.0(1850.9)	38.5(1492.2)
LSD (p=0.05)	1.80	2.98	2.83	6.26	4.78	1.61

DATA – Days after treatment application; *fb,* Followed by; BLW – Broad-leaf weeds; LSD: Least significant difference at the 5% level of significance; The figures in the parentheses are original values

Table 5. Effect of treatments on *L. chinensis* control efficiency, total weed control efficiency at 45 DATA and weed index

Treatment	*L. chinensis* CE (%)		Total WCE (%)		Weed index	
	2018	2019	2018	2019	2018	2019
Cyhalofop-butyl (80 g/ha)	94.5	94.4	17.6	20.2	33.6	60.3
Penoxsulam + cyhalofop-butyl (150 g/ha)	89.2	90.6	84.4	83.2	7.6	7.2
Cyhalofop + carfentrazone-ethyl (80 + 200 g/ha)	92.5	94.4	51.1	50.3	25.3	23.1
Bispyribac-sodium (25 g/ha)	37.0	47.8	61.9	60.8	23.5	23.3
Bispyribac-sodium + cyhalofop-butyl (25 + 80 g/ha)	94.8	94.2	84.6	84.9	11.3	8.9
Bispyribac-sodium + fenoxaprop-p-ethyl (25 + 60 g/ha)	96.1	95.7	87.9	91.4	6.3	3.0
Fenoxaprop-p-ethyl (60 g/ha)	97.1	96.4	23.7	23.7	34.9	43.0
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	94.8	95.0	60.5	54.1	18.2	13.3
Hand weeding	94.93	95.3	93.6	92.0	0.00	0.00
Unweeded control	-	-	-	-	56.7	63.1

DATA: Days after treatment application; CE: Control efficiency; *fb:* Followed by

Table 6. Effect of treatments on yield attributes and grain yield

Treatment	No. of tillers/m^2		No. of panicles/m^2		No. of grains/panicle		Filled grains (%)		Grain yield (t/ha)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Cyhalofop-butyl (80 g/ha)	249.3	265.3	224.0	210.6	114.0	139.0	52.8	60.1	3.26	2.17
Penoxsulam + cyhalofop-butyl (150 g/ha)	316.0	328.0	304.0	290.6	133.6	162.6	68.2	77.8	4.55	5.36
Cyhalofop + carfentrazone-ethyl (80+200 g/ha)	285.3	302.6	254.6	240.0	111.6	161.0	58.3	64.2	3.68	4.20
Bispyribac-sodium (25 g/ha)	314.6	321.3	264.0	258.6	120.6	167.6	61.0	69.4	3.76	4.19
Bispyribac-sodium + cyhalofop-butyl (25+80 g/ha)	336.0	330.6	272.0	276.0	131.6	170.0	63.0	72.6	4.37	5.14
Bispyribac-sodium + fenoxaprop-p-ethyl (25+60 g/ha)	318.6	336.0	321.3	304.0	132.6	176.0	71.6	76.1	4.76	5.30
Fenoxaprop-p-ethyl (60 g/ha)	289.3	270.6	213.3	228.0	114.0	151.3	57.9	65.0	3.20	3.12
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (800 + 150 *fb* 80 + 200 g/ha)	302.6	322.6	274.6	258.6	116.3	145.0	66.4	67.6	4.02	4.74
Hand weeding	313.3	330.6	304.0	288.0	133.3	170.3	61.6	69.2	4.93	5.47
Unweeded control	202.6	197.3	100.0	104.0	96.3	106.0	44.2	53.4	2.13	2.01
LSD (p=0.05)	23.5	24.6	58.4	53.4	17.9	22.4	13.0	12.4	0.88	1.02

fb: Followed by; LSD: Least significant difference at the 5% level of significance

Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl (at 800 + 150 *fb* 80 + 200 g/ha) and bispyribac-sodium at 25 g/ha alone produced statistically similar grain yield during 2019. Among the tank mix application of herbicides, the lowest grain yield was obtained in plots treated with cyhalofop-butyl + carfentrazone-ethyl at 80 + 200 g/ha (3.68 and 4.20 t/ha). Cyhalofop-butyl at 80 g/ha (3.26 and 2.17 t/ha) and fenoxaprop-p-ethyl at 60 g/ha (3.20 and 3.12 t/ha) treated plots produced significantly inferior grain yield during both the years and was comparable with the weedy check (2.13 and 2.01 t/ha) during 2019. This might be due to the inefficiency of cyhalofop-butyl and fenoxaprop-p-ethyl to control broad-leaf weeds and sedges even though they are excellent in controlling grass weeds.

Conclusion

It was concluded that fenoxaprop-p-ethyl at 60 g/ha and cyhalofop-butyl at 80 g/ha at 15-18 DAS were the most effective herbicide against *L. chinensis*. In places where *L. chinensis* is not a problem, broad-spectrum herbicide bispyribac-sodium alone at 25 g/ha can be recommended. Fenoxaprop-p-ethyl and cyhalofop-butyl were ineffective in managing broad-leaf weeds and sedges resulting in high weed dry matter production. Hence, these herbicides need to be used in combinations with bispyribac-sodium for broad-spectrum weed control.

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