Original Research Article

Integrative weed management tactics for rice (*Oryza sativa* L.) under direct-seeding in Kymore Plateau and Satpura Hills

ABSTRACT

Aims: Weed infestation is the major problem in wide adoption of direct-seeding technology by rice farmers. Integration of herbicides with different manual and mechanical methods only can be a permanent solution of weed problem in direct-seeded rice.

Study design: Randomized block design was taken with three replications for this field experiment.

Place and duration of study: The experiment was carried out during *kharif*, 2019 at the Experimental Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh.

Methodology: The treatments were comprised of eight post-emergence weed management treatments including hand weeding twice at 20 and 40 DAS, respectively and weedy check treatment. All the treatments were allocated randomly in each replication.

Results: Spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS was best in decreasing the infestation of grassy weeds such as *Eleusine indica and Echinochloa colona* and a sedge weed, *Cyperus rotundus* during the crop growing period except hand weeding. But broadleaved weeds such as *Alternanthera sessilis* and *Ludwigia parviflora* were controlled more effectively with metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS than the 1st treatment. Highest grain yield (3155.67 kg ha^{-1}), gross monetary return (Rs 57736 ha^{-1}), net monetary return (Rs 1140 ha^{-1}) and benefit-cost ratio (1.91) were registered[1] under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + use of conoweeder at 40 DAS among the chemical and integrative weed control options.

Conclusion: The spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS followed by use of conoweeder at 40 DAS could be the best sustainable option to control the weed infestation in direct-seeded rice.

Keywords: Direct-seeding; integrated weed management; rice.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a leader of cereal crops of our world [1] and greater than 50% of the human race have need of this crop for their day-to-day nutrition [2]. Transplanting is a major method of rice cultivation in India and direct-seeding is an existing substitute of transplanting [3]. Scarcity of labour is a driving force for seeding of rice directly [4]. Labour requirement for establishment of rice minimized by greater than 75% by applying direct-seeding technology in comparison to transplanting technique [5]. Direct-seeded rice complete its life cycle 7-11 days in advance than the rice grown under transplanted situation and makes possible sowing of succeeding crop on time [6]. But weeds are the prime biological constraint and a considerable threat in direct-seeded rice based cropping systems towards its production and adoption by the farmers [7]. Uncontrolled weed density can reduce the productivity of rice by 96% in dry direct-seeded condition and 61% in wet direct-seeded condition [8]. Continuous use of an herbicide or herbicides with same mode of action will lead to the form herbicide resistant weeds and shift in weed flora either rapidly or slowly. Herbicide factors are behind the resistance development in weeds, those include residual activity for long time period, single target site of action, specific mode of action and very effective control rate for a large number of weed species. One of the recent methods to control the weed flora shifting and to stop the formation or delay the formation of resistance against herbicide application in weeds is the application of herbicide mixtures. There is an essentiality for combining the various weed management tactics to get an efficient and sustainable weed control of rice in direct-seeded situation. Thus, herbicides are being integrated with different manual and mechanical methods for keeping the weeds under control in direct-seeded rice.

Write the aim of the research.

2. MATERIALS AND METHODS

The field experiment was conducted at the Experimental Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh in rainy season of 2019. Total amount of rainfall received was 1575.4 mm in 51 rainy days during the cropping period. During the crop season, lowest and highest air temperature observed was 17.7 and 34.9^{0}C, respectively. Initially, the top soil layer of the experimentation site (0-15 cm soil layer) was sandy clay loam textured and neutral in pH (7.15) with low available N (246.7 kg ha^{-1}) and extractable P_2O_5 (33.4 kg ha^{-1}) and medium exchangeable K_2O (275.2 kg ha^{-1}) status. Line sowing was done manually at 20 cm apart in rows and continuously in a row following the seed rate of 60 kg ha^{-1}. A quick maturing (110-115 days) rice cultivar '*MTU 1010*' had been taken in this experiment which is recommended for cultivation in Jabalpur, Madhya Pradesh. The recommended rates of major nutrients were 120 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O. Half rate of N, complete rate of P_2O_5 and K_2O was applied just before sowing, top-dressing of one fourth of full N rate was done during active tillering (30-45 DAS) and remaining one-fourth of full N rate was applied as split dose at panicle initiation stage (60 DAS). The design followed in this experimentation was randomized block design (RBD) with three replications. Eight post-emergence weed management treatments comprised of Bispyribac Sodium

10% SC at 25 g ha^{-1}, Bispyribac Sodium 10% SC at 25 g ha^{-1} + conoweeder, Metsulfuron Methyl 20% WP at 4 g ha^{-1}, Metsulfuron Methyl 20% WP at 4 g ha^{-1} + conoweeder, Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10% WP at 4 g ha^{-1}, Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10% WP at 4 g ha^{-1} + conoweeder, hand weeding two times at 20 and 40 days after sowing (DAS) and weedy check, respectively were allocated randomly in all the replications. All the herbicides were sprayed at 20 DAS followed by the use of conoweeder at 40 DAS as per the treatment. One irrigation was given before operating conoweeder in the field.

The relative density of weeds was measured by using the following formula of [9].

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of same species}}{\text{Number of individuals of all species}} \times 100$$

The weed control efficiency (WCE) was calculated by using the following formula of [10].

$$\text{WCE (\%)} = \frac{\text{Dry wt. of weed from weedy check plot} - \text{Dry wt. of weed from treated plot}}{\text{Dry wt. of weed from weedy check plot}} \times 100$$

Weed index (WI) of all the treatments was calculated as per the following formula of [11].

$$\text{WI (\%)} = \frac{\text{Grain yield in weed free plot - Grain yield in treated plot}}{\text{Grain yield in weed free plot}} \times 100$$

Gross monetary return, net monetary return and benefit-cost ratio (B:C) were measured with the help of market price of paddy grain (₹18.15 kg^{-1} in 2018) and paddy straw (₹2.00 kg^{-1} in 2018). All the data were analyzed in analysis of variance model with SPSS software. The treatment mean variations were tested at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Dominant weed species in direct-seeded rice

Species wise data on weeds at 30, 60, 90 DAS and harvest under weedy check treatment exhibited that there was predominance of grassy weeds *i.e.*, *Echinochloa colona and Eleusine indica, sedge weed i.e., Cyperus rotundus* and broadleaved weeds *i.e.*, *Ludwigia parviflora and Alternanthera sessilis* in the experimental field. Among all these weeds, *E. colona* was more rampant (25.24%) at all the dates of observations followed by *E. indica* (22.22%). Grassy weeds were found to be more prominent with higher relative density than the broadleaved weeds *i.e.*, *A. sessilis* (17.05%) *and L. parviflora* (16.97%). [12] noticed that *A. sessilis* was a pre-dominant species of dicot or broadleaved weeds found in direct-seeded rice in Jabalpur, Madhya Predesh. Among the sedges, abundance of *C. rotundus* (18.52%) was noted down in the experimental plot (Table 1). The weed species reported earlier in rice under direct-seeded situation by [13] and [14] corroborated the present findings.

Table 1: Relative density of various weed species in direct-seeded situation of rice

Types of weeds	Relative density (%)
1. Grassy weeds	
a) *Echinochloa colona*	25.24
b) *Eleusine indica*	22.22
2. Sedge weed	
a) *Cyperus rotundus*	18.52
3. Broadleaved weeds	
a) *Alternanthera sessilis*	17.05
b) *Ludwigia parviflora*	16.97
Total	100.00

3.2 Weed population in direct-seeded rice

The population of *E. colona* was differed significantly at 30, 60, 90 DAS and harvesting stage because of various integrative and chemical weed control treatments (Table 2). The population of *E. colona* was maximum, being 9.71, 9.58, 7.22, 6.91 m^{-2} , respectively under weedy check plots at all the dates. Minimum weed density, being 4.51, 3.34, 2.40, 1.93 m^{-2}, respectively of *E. colona* was found under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS , being 6.37, 3.84, 2.97, 2.49 m^{-2}, respectively among all integrated and chemical weed management practices. Integration of herbicides along with the use of conoweeder was found to be more superior in reducing the weed population than application of herbicides alone. Similar results were mentioned previously by [15]. However, hand weeding at 20 and 40 DAS was noticed as most superior in reducing the population of weeds, being 1.99, 1.53, 1.21, 1.07 m^{-2}, respectively of *E. colona* as compared to all other treatments.

Spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS informed its better role than other treatments in decreasing the population, being 5.08, 4.74, 3.62, 2.72 m^{-2}, respectively of *.E.indica* at all stages of observation followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS (6.18, 5.64 4.49 and 3.67 m^{-2}) among all integrated and herbicidal weed management practices. Integration of herbicide use along with conoweeder application was found to be more superior in reducing the weed population than application of herbicides alone. Similar results were also described previously by [15]. The minimum population of weeds, being2.01, 1.78, 1.37, 1.21 m^{-2}, respectively was observed with hand weeding at 20 DAS and 40 DAS, respectively (Table 2).

Various weed management options gradually diminished the population of *C. rotundus* from 30 DAS to harvestable maturity. Maximum population of weeds, being 7.99, 7.58, 6.96, 6.36 m^{-2}, respectively was reported under weedy check (Table 4). Bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS showed maximum reduction in population, being 2.91, 2.40,1.68,1.46 m^{-2}, respectively of this weed at all the dates of observation followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being 3.53, 2.80, 2.19,

2.02 m^{-2}, respectively among the various weed management practices. Herbicides and conoweeder together was found to be more superior in reducing the weed population than application of herbicides alone. Similar findings were also reported previously by [15]. The least density, being 1.28, 1.17, 1.07, 1.03 m^{-2}, respectively was observed under hand weeding two times at 20 and 40 DAS.

The population of *A. sessilis* was varied significantly by various treatment of weed control at all the dates (Table 5). Number of weeds m^{-2} was maximum, being 8.35, 6.89, 6.31 and 6.07 m^{-2}, respectively under weedy plots. Population of this weed was noticed as minimum, being 3.70, 3.85, 2.92, 2.11 m^{-2}, respectively with applying metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS on all the dates of observation followed by bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment, being 5.08, 4.37, 3.39, 2.78 m^{-2}, respectively among all the integrative and herbicidal weed control treatments. Earlier report of [15] corroborated these results. Two times hand weeding operation at 20 and 40 DAS, respectively was always noted down as best in minimizing weed population, being 2.25, 1.20, 1.11, 1.09 m^{-2}).

The population of *L. parviflora* was significantly higher than all other treatments at different stages in weedy check plots, being 8.47, 6.72, 6.34, 5.98 m^{-2}, respectively. Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10% WP 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS showed significant reduction in weed population, being 3.69, 3.39, 2.97, 2.27 m^{-2}, respectively during the period of observation followed by bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being 4.34, 3.85, 3.29, 2.86 m^{-2}, respectively among all the treatments. Earlier report of [15] was in line with these results obtained. Two times hand weeding operation at 20 DAS and 40 DAS, respectively was noticed as most superior in controlling weed population, being 1.37, 1.17, 1.00, 1.00 m^{-2}, respectively during the crop growing period (Table 5).

3.3 Weed biomass in direct-seeded rice

Weed biomass of *E. colona* was found to be maximum, being11.44, 9.87, 9.40 and 9.29 g m^{-2}, respectively in weedy check treatment at all the stages of observation. Biomass of this grassy weed decreased gradually from vegetative phase to harvest on all the dates of observation under all the treatments. Among the chemical and integrative weed control options, minimum dry matter of *E. colona* , being 5.32, 3.46, 3.07, 2.41 g m^{-2}, respectively was noted down under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment, being 7.28, 4.63, 4.07, 3.19 g m^{-2}, respectively among all the weed management options. Similar results were noted down earlier by [16] and [17]. However, hand weeded plots where weeds were removed two times at 20 and 40 DAS had minimum weed biomass, being 1.45, 1.30, 1.13 and 1.06 g m^{-2}, respectively during the crop growing period (Table 3).

The biomass of *Eleusine indica* at 30, 60, 90 DAS and harvesting stage under various weed control options showed that significantly higher biomass of this weed at all the stages of observation in

weedy treatment, being 10.32, 10.23, 9.44, 6.14 g m^{-2}, respectively than all other treatments (Table 3). Lowest weed biomass, being 5.78, 3.92, 3.60, 3.58 g m^{-2}, respectively was recorded under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment, which was significantly lower than all other chemical and integrative weed control options. This treatment was followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being 6.89, 5.76, 4.89, 4.40 g m^{-2}, respectively treatment. Similar results were mentioned earlier by [16] and [17]. Hand weeding operation at 20 and 40 DAS, respectively obtained minimum biomass of this weed, being1.71, 1.37, 1.34 and 1.04 g m^{-2}, respectively on all the dates.

Various weed control options significantly diminished the biomass of *Cyperus rotundus* at different period of crop growth over weedy treatment. Biomass of this weed was maximum (9.27, 9.06, 8.51 and 5.67 g m^{-2}, respectively in weedy plots where control measures were not taken at 30, 60, 90 DAS and harvest, respectively (Table 4). Decrement in weed biomass was more pronounced, being 3.39, 2.11, 1.96, 1.74 g m^{-2}, respectively under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being3.99, 2.79, 2.63, 2.55 g m^{-2}, respectively. Integration of herbicide use along with conoweeder application was found to be more superior in reducing the weed biomass than application of herbicides alone. Similar results were mentiomned previously by [16] and [17]. Least weed biomass , being 1.71, 1.37, 1.34, 1.04 g m^{-2},, respectively of this sedge was obtained with hand weeding operation two times at 20 and 40 DAS, respectively.

Maximum biomass of *Alternanthera sessilis* at 30, 60, 90 DAS and harvest, being 8.42, 8.20 and 8.11, 5.01 g m^{-2}, respectively was observed under weedy plots (Table 6). Most prominent decrement , being 4.06, 3.59, 2.76, 2.63 g m^{-2}, respectively in the biomass of this weed was found under metsulfuron methyl 10% WP + chlorimuron Ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS on all the dates of observation followed by bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being 5.33, 4.38, 3.68, 3.53 g m^{-2}, respectively among all integrated and herbicidal weed management options. Integration of herbicide use along with conoweeder application was found to be more superior in reducing the weed biomass than application of herbicides alone. Similar results were observed earlier by [16] and [17]. Minimum weed density, being 2.37, 1.86 1.66, 1.64 g m^{-2}, respectively was obtained with hand weeding two times at 20 DAS and 40 DAS, respectively.

L. parviflora showed its biomass at 30, 60, 90 DAS and harvest under various weed management treatments and significantly varied among all the treatments (Table 6). Maximum biomass production of *Ludwigia parviflora* was observed, being12.28, 8.24, 7.67 and 5.41 g m^{-2}, , respectively in weedy treatment. Maximum reduction, being 4.98, 3.83, 2.98, 2.68 g m^{-2}, , respectively in the weed biomass was observed under metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS at all stages of observation followed by bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS, being 6.69, 4.25, 3.78, 3.11 g m^{-2}, respectively among all

integrative and herbicidal weed control practices. Similar findings were observed earlier by [16] and [17]. Lowest weed biomass, being1.24, 1.17,1.13 and 1.07 g m^{-2}, respectively was noticed in hand weeding two times at 20 DAS and 40 DAS, respectively.

T. No.	Treatments	Dose (g a.i. ha^{-1})	Population of grassy weeds (No. m^{-2})							
			Echinochloa colona after (DAS)				*Eleusine indica* after (DAS)			
			30	60	90	Harvest	30	60	90	Harvest
T_1	Bispyribac Sodium 10% SC at 20 DAS	25	7.15 (50.62)	4.18 (16.99)	3.63 (12.65)	3.03 (8.66)	6.39 (40.29)	5.98 (35.31)	5.02 (24.66)	4.06 (15.96)
T_2	T_1 + Conoweeder at 40 DAS	25	4.51 (19.86)	3.34 (10.65)	2.40 (5.27)	1.93 (3.23)	5.08 (25.32)	4.74 (21.97)	3.62 (12.61)	2.72 (6.91)
T_3	Metsulfuron Methyl 20% WP at 20 DAS	4	7.20 (51.33)	4.37 (18.57)	3.89 (14.65)	3.24 (9.98)	6.62 (43.29)	6.28 (38.97)	5.49 (29.66)	4.22 (17.29)
T_4	T_3 + Conoweeder at 40 DAS	4	7.11 (49.99)	3.93 (14.97)	3.29 (10.29)	2.73 (6.98)	6.23 (38.29)	5.87 (33.98)	4.81 (22.66)	3.89 (14.64)
T_5	Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS	4	7.13 (50.33)	4.26 (17.65)	3.76 (13.65)	3.13 (9.33)	6.44 (40.95)	6.07 (36.31)	5.31 (27.65)	4.15 (16.73)
T_6	T_5 + Conoweeder at 40 DAS	4	6.37 (40.12)	3.84 (14.28)	2.97 (8.33)	2.49 (5.69)	6.18 (37.64)	5.64 (31.33)	4.49 (19.65)	3.67 (12.99)
T_7	Hand weeding at 20 DAS and 40 DAS	-	1.99 (3.47)	1.53 (1.84)	1.21 (0.97)	1.07 (0.65)	2.01 (3.54)	1.78 (2.66)	1.37 (1.39)	1.21 (0.96)
T_8	Weedy check	-	9.71 (93.73)	9.58 (91.33)	7.22 (51.65)	6.91 (47.18)	8.65 (74.30)	8.10 (65.13)	7.86 (61.25)	7.06 (49.28)
	S.Em. (±)		0.42	0.16	0.15	0.18	0.12	0.17	0.15	0.19
	C.D. (*P*=.05)		1.29	0.49	0.44	0.55	0.35	0.52	0.45	0.58

Table 2: Impact of weed management treatments on population of grassy weeds in direct-seeded rice

Figures in the parentheses are original values. Data subjected to $(\sqrt{x+0.5})$ square root transformation.

Table 3: Impact of weed management treatments on biomass of grassy weeds in direct-seeded rice

T. No.	Treatments	Dose (g a.i. ha^{-1})	Biomass of grassy weeds (g m^{-2})							
			Echinochloa colona after (DAS)				*Eleusine indica* after (DAS)			
			30	60	90	Harvest	30	60	90	Harvest
T_1	Bispyribac Sodium 10% SC at 20 DAS	25	7.37 (53.89)	5.07 (25.17)	4.69 (21.50)	4.01 (15.59)	7.31 (52.96)	6.51 (41.93)	5.41 (28.73)	4.54 (20.15)
T_2	T_1 + Conoweeder at 40 DAS	25	5.32 (27.81)	3.46 (11.49)	3.07 (8.95)	2.41 (5.31)	5.78 (32.96)	3.92 (14.85)	3.60 (12.43)	3.58 (12.32)
T_3	Metsulfuron	4	7.58	5.12	5.04	4.30	7.68	7.14	5.62	4.71

	Methyl 20% WP at 20 DAS		(56.91)	(25.67)	(24.91)	(17.97)	(58.45)	(50.43)	(31.12)	(21.65)
T_4	**T_3 + Conoweeder at 40 DAS**	**4**	7.30 (52.80)	5.05 (25.00)	4.51 (19.80)	3.61 (12.56)	7.17 (50.97)	6.25 (38.53)	5.18 (26.35)	4.43 (19.15)
T_5	**Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS**	**4**	7.43 (54.68)	5.07 (25.17)	4.87 (23.21)	4.16 (16.79)	7.41 (54.46)	6.89 (47.01)	5.35 (28.16)	4.58 (20.47)
T_6	**T_5 + Conoweeder at 40 DAS**	**4**	7.28 (52.53)	4.63 (20.97)	4.07 (16.11)	3.19 (9.67)	6.89 (46.99)	5.76 (32.63)	4.89 (23.38)	4.40 (18.82)
T_7	**Hand weeding at 20 DAS and 40 DAS**	**-**	1.45 (1.59)	1.30 (1.19)	1.13 (0.77)	1.06 (0.62)	2.41 (5.31)	2.00 (3.48)	1.81 (2.77)	1.44 (1.57)
T_8	**Weedy check**	**-**	11.44 (130.43)	9.87 (96.87)	9.40 (87.81)	9.29 (85.76)	10.32 (105.97)	10.23 (104.12)	9.44 (88.70)	6.14 (37.15)
	S.Em. (±)		0.58	0.14	0.15	0.14	0.15	0.22	0.26	0.10
	C.D. (*P*=.05)		1.77	0.43	0.45	0.44	0.44	0.66	0.79	0.31

Figures in the parentheses are original values. Data subjected to $(\sqrt{x+0.5})$ square root transformation.

Table 4: Impact of weed management treatments on population and biomass of sedge weed in direct-seeded rice

T. No.	Treatments	Dose (g a.i. ha^{-1})	Population of sedge weed (no. m^{-2})				Biomass of sedge weed (g m^{-2})			
			Cyperus rotundus after (DAS)				*Cyperus rotundus* after (DAS)			
			30	60	90	Harvest	30	60	90	Harvest
T_1	**Bispyribac Sodium 10% SC at 20 DAS**	**25**	3.76 (13.66)	3.19 (9.66)	2.48 (5.66)	2.20 (4.32)	4.06 (15.94)	3.18 (9.62)	2.88 (7.78)	2.71 (6.83)
T_2	**T_1 + Conoweeder at 40 DAS**	**25**	2.91 (7.98)	2.40 (5.27)	1.68 (2.31)	1.46 (1.64)	3.39 (10.99)	2.11 (3.93)	1.96 (3.32)	1.74 (2.51)
T_3	**Metsulfuron Methyl 20% WP at 20 DAS**	**4**	4.02 (15.66)	3.49 (11.65)	2.80 (7.33)	2.48 (5.63)	4.24 (17.47)	3.60 (12.45)	3.26 (10.14)	2.89 (7.83)
T_4	**T_3 + Conoweeder at 40 DAS**	**4**	3.67 (12.99)	3.03 (8.66)	2.27 (4.66)	2.11 (3.96)	4.00 (15.50)	2.90 (7.91)	2.76 (7.13)	2.64 (6.49)
T_5	**Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS**	**4**	3.94 (15.00)	3.34 (10.66)	2.68 (6.66)	2.34 (4.97)	4.06 (15.99)	3.44 (11.32)	3.07 (8.94)	2.83 (7.50)
T_6	**T_5 + Conoweeder at 40 DAS**	**4**	3.53 (11.96)	2.80 (7.33)	2.19 (4.28)	2.02 (3.56)	3.99 (15.41)	2.79 (7.28)	2.63 (6.40)	2.55 (5.98)
T_7	**Hand weeding at 20 DAS and 40 DAS**	**-**	1.28 (1.14)	1.17 (0.88)	1.07 (0.65)	1.03 (0.57)	1.71 (2.41)	1.37 (1.39)	1.34 (1.30)	1.04 (0.58)
T_8	**Weedy check**	**-**	7.99 (63.33)	7.58 (57.00)	6.96 (47.98)	6.36 (40.00)	9.27 (85.50)	9.06 (81.56)	8.51 (71.99)	5.67 (31.67)
	S.Em. (±)		0.11	0.13	0.14	0.14	0.20	0.16	0.19	0.16
	C.D. (*P*=.05)		0.34	0.38	0.44	0.42	0.59	0.49	0.58	0.48

Figures in the parentheses are original values. Data subjected to $(\sqrt{x+0.5})$ square root transformation.

Table 5: Impact of weed management treatments on population of broadleaved weeds in direct-seeded rice

Figures in the parentheses are original values. Data subjected to $(\sqrt{x+0.5})$ square root transformation.

T. No.	Treatments	Dose (g a.i. ha^{-1})	Population of broadleaved weeds (No. m^{-2})							
			Alternanthera sessilis after (DAS)				*Ludwigia parviflora* after (DAS)			
			30	60	90	Harvest	30	60	90	Harvest
T_1	Bispyribac Sodium 10% SC at 20 DAS	25	5.37 (28.31)	4.60 (20.63)	3.81 (14.00)	3.49 (11.65)	4.60 (20.65)	4.22 (17.33)	3.72 (13.33)	3.19 (9.65)
T_2	T_1 + Conoweeder at 40 DAS	25	5.08 (25.33)	4.37 (18.59)	3.39 (10.99)	2.78 (7.23)	4.34 (18.31)	3.85 (14.33)	3.29 (10.33)	2.86 (7.66)
T_3	Metsulfuron Methyl 20% WP at 20 DAS	4	5.70 (31.98)	4.85 (22.99)	4.10 (16.33)	3.81 (13.99)	4.91 (23.65)	4.41 (18.99)	3.76 (13.65)	3.49 (11.65)
T_4	T_3 + Conoweeder at 40 DAS	4	5.24 (26.99)	4.44 (19.25)	3.63 (12.66)	3.12 (9.26)	4.45 (19.32)	4.02 (15.66)	3.53 (11.99)	3.02 (8.64)
T_5	Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS	4	5.46 (29.31)	4.64 (20.99)	3.98 (15.33)	3.63 (12.66)	4.78 (22.32)	4.34 (18.33)	3.76 (13.65)	3.29 (10.30)
T_6	T_5 + Conoweeder at 40 DAS	4	3.70 (13.23)	3.85 (14.33)	2.92 (8.00)	2.11 (3.96)	3.69 (13.12)	3.39 (10.99)	2.97 (8.33)	2.27 (4.66)
T_7	Hand weeding at 20 DAS and 40 DAS	-	2.25 (4.55)	1.20 (0.93)	1.11 (0.73)	1.09 (0.68)	1.37 (1.37)	1.17 (0.88)	1.00 (0.50)	1.00 (0.50)
T_8	Weedy check	-	8.35 (69.29)	6.89 (46.93)	6.31 (39.26)	6.07 (36.29)	8.47 (71.21)	6.72 (44.69)	6.34 (39.65)	5.98 (35.29)
	S.Em. (±)		0.23	0.16	0.13	0.19	0.21	0.14	0.10	0.16
	C.D. (*P*=.05)		0.69	0.48	0.41	0.57	0.63	0.41	0.29	0.48

Table 6: Impact of weed management treatments on biomass of broadleaved weeds in direct-seeded rice

T. No.	Treatments	Dose (g a.i. ha^{-1})	Biomass of broadleaved weeds (g m^{-2})							
			Alternanthera sessilis after (DAS)				*Ludwigia parviflora* after (DAS)			
			30	60	90	Harvest	30	60	90	Harvest
T_1	Bispyribac Sodium 10% SC at 20 DAS	25	5.61 (30.95)	4.93 (23.80)	4.63 (20.97)	3.83 (14.15)	7.75 (59.52)	4.81 (22.66)	4.23 (17.36)	3.29 (10.32)
T_2	T_1 + Conoweeder at 40 DAS	25	5.33 (27.88)	4.38 (18.67)	3.68 (13.01)	3.53 (11.95)	6.69 (44.25)	4.25 (17.56)	3.78 (13.79)	3.11 (9.16)
T_3	Metsulfuron Methyl 20% WP at 20 DAS	4	5.92 (34.49)	5.32 (27.76)	5.07 (25.18)	4.06 (15.99)	8.22 (67.02)	4.87 (23.21)	4.63 (20.97)	3.51 (11.83)
T_4	T_3 + Conoweeder at 40 DAS	4	5.42 (28.87)	4.69 (21.53)	4.14 (16.66)	3.74 (13.50)	6.97 (48.01)	4.57 (20.38)	4.01 (15.56)	3.19 (9.66)
T_5	Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS	4	5.66 (31.49)	5.15 (26.06)	4.83 (22.79)	3.89 (14.65)	7.96 (62.83)	4.87 (23.21)	4.36 (18.54)	3.41 (11.16)
T_6	T_5 + Conoweeder at 40 DAS	4	4.06 (15.96)	3.59 (12.38)	2.76 (7.13)	2.63 (6.42)	4.98 (24.27)	3.83 (14.16)	2.98 (8.38)	2.68 (6.70)
T_7	Hand weeding at 20 DAS and 40 DAS	-	2.37 (5.12)	1.86 (2.97)	1.66 (2.27)	1.64 (2.19)	1.24 (1.04)	1.17 (0.88)	1.13 (0.77)	1.07 (0.65)
T_8	Weedy check	-	8.42 (70.40)	8.20 (66.75)	8.11 (65.32)	5.01 (24.64)	12.28 (150.23)	8.24 (67.40)	7.67 (58.30)	5.41 (28.76)
	S.Em. (±)		0.30	0.25	0.23	0.13	0.55	0.13	0.22	0.13
	C.D. (*P*=.05)		0.90	0.75	0.69	0.40	1.68	0.38	0.66	0.40

Figures in the parentheses are original values. Data subjected to $(\sqrt{x+0.5})$ square root transformation.

3.4 Weed control efficiency and weed index in direct-seeded rice

Among the herbicidal and integrative weed control options, best weed control efficiency (80.17%) was obtained under the spraying of Bispyribac sodium 10% SC **at** 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment This result was in accordance with the earlier findings of [18] and [19]. The treatment, metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP **at** 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS was also achieved 2nd highest weed control efficiency (77.12%) among the chemical and integrated weed management treatments. Hand weeding twice at 20 DAS and 40 DAS, respectively was noted down as superior (97.29%) among all the weed management options (Fig. 1).

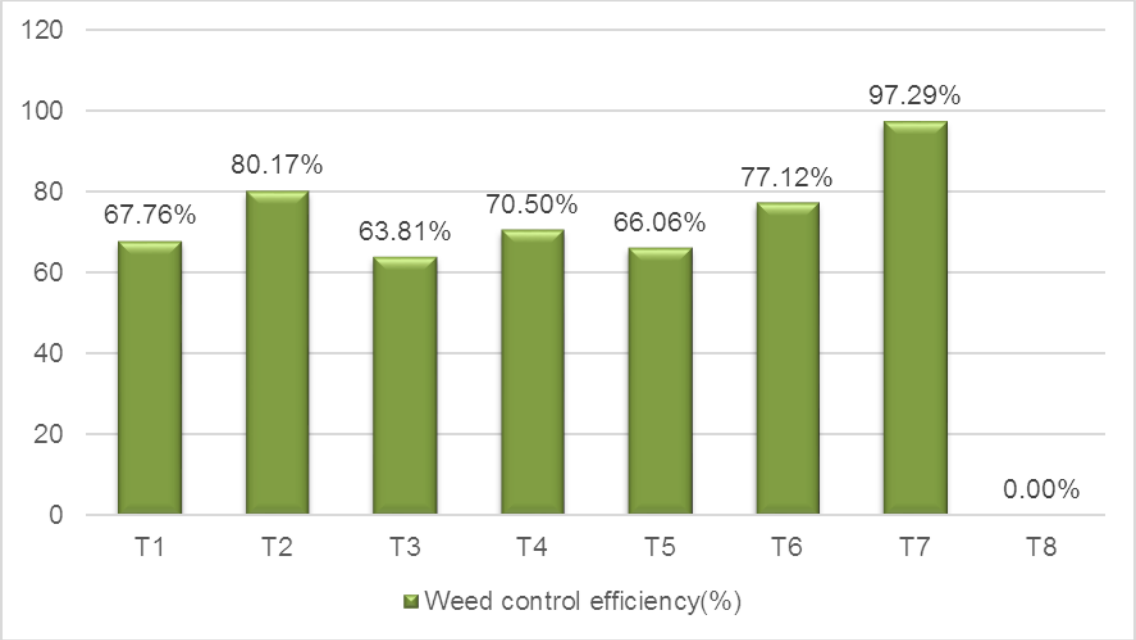

Fig. 1: Weed control efficiency (WCE)% as influenced by different weed control options in direct-seeded rice.

The weed index was calculated least (0.00%) under hand weeding two times at 20 DAS and 40 DAS followed by bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS (14.08%) treatment and metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment (27.57%). The weed index was found maximum (58.95%) under weedy check treatment (Fig. 2).

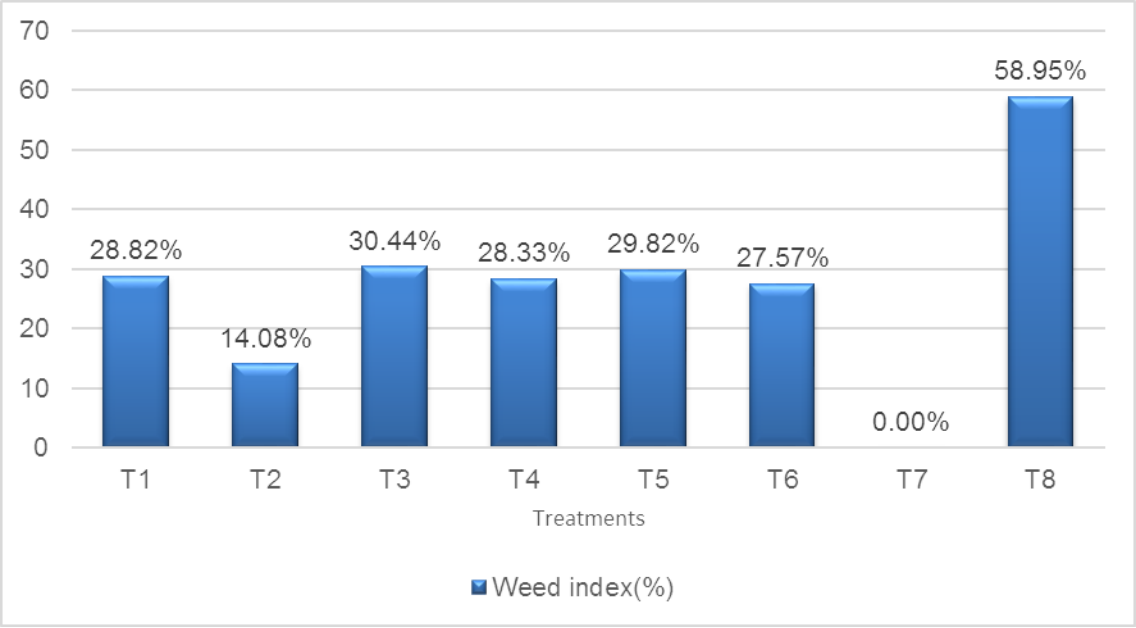

Fig. 2: Weed index (WI)% as influenced by different weed control options in direct-seeded rice.

3.5 Grain and Straw yield of direct-seeded rice

Grain yield of direct-seeded rice was significantly influenced because of various weed management options. The grain yield was found lowest (1507.67 kg ha^{-1}) under weedy treatment where weeds were allowed to grow throughout the cropping season (Table 7). The grain productivity was significantly greater (3672.67 kg ha^{-1}) in hand weeding at 20 DAS and 40 DAS, respectively than all other options. Among the integrative and chemical weed management options, maximum grain yield (3155.67 kg ha^{-1}) was registered under the spraying of bispyribac sodium 10% SC **at** 25 g a.i. ha^{-1} at 20 DAS + use of conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP **at** 4 g a.i. ha^{-1} at 20 DAS + use of conoweeder at 40 DAS treatment (2660.00 kg ha^{-1}). Minimum weed infestation was the main reason behind the improved grain productivity in these treatments which made the nutrients, spacing, water and sunlight more available resulting in more growth and development of rice. These results were in accordance with the previous report of [20] and [21].

Data pertaining to straw yield of direct-seeded rice showed significant variation due to the weed control measures taken (Table 7). The straw yield was found lowest (2786.64 kg ha^{-1}) under weedy treatment where weed management measures were not followed throughout the cropping season. The option, hand weeding twice at 20 DAS and 40 DAS registered significantly superior straw yield (6410.83 kg ha^{-1}) than rest of the treatments followed by bispyribac sodium 10% SC **at** 25 g a.i. ha^{-1} at 20 DAS + conoweeder application at 40 DAS (5600.90 kg ha^{-1}) and metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP **at** 4 g a.i. ha^{-1} at 20 DAS + conoweeder application at 40 DAS (4728.44 kg ha^{-1}). These results are in accordance with the previous findings of [20] and [21].

3.6 Economics of direct-seeded rice cultivation

Weedy treatments possess the least cost of production (Rs 31797 ha^{-1}) and hand weeded plots registered highest cost of cultivation (Rs 44297 ha^{-1}). Among the integrative and chemical weed control options, cost of cultivation (Rs 35910 ha^{-1}) was registered maximum under the spraying of bispyribac sodium 10% SC @ **at** 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS (Table 7).

Gross monetary return (GMR) was noted down lowest (Rs 32937 ha^{-1}) under weedy check (Table 7). The treatment obtaining two hand weeding showed the higher GMR (Rs 79481 ha^{-1}) followed by the spraying of bispyribac sodium 10% SC **at** 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS (Rs 68477 ha^{-1}) and metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP **at** 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment (Rs 57736 ha^{-1}), respectively.

In Table 7, the net monetary return (NMR) was recorded least (Rs 1140 ha^{-1}) when crop was kept weedy. The NMR was found highest (Rs 35184 ha^{-1}) in hand weeding two times at 20 DAS and 40 DAS, respectively. Similar results were mentioned previously by [22] and [23]. This was specifically due to attainment of highest grain and straw productivity under hand weeding treatment. This treatment was followed by the spraying of bispyribac sodium 10% SC **at** 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment (Rs 32568 ha^{-1}).

Benefit-cost ratio (BCR) was recorded maximum (1.91) under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment because of proportionate enhancement in economic return because of lower cost involving management of weeds under this treatment than others. Similar results were mentioned previously by [22] and [23]. This treatment was followed by hand weeding two times at 20 DAS and 40 DAS treatment (1.79) (Table 7).

Table 7: Impact of weed management treatments on yields and economics of direct-seeded rice

T. No.	Treatments	Dose (g a.i. ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Cost of cultivation (Rs ha^{-1})	GMR (Rs ha^{-1})	NMR (Rs ha^{-1})	BCR
T_1	Bispyribac Sodium 10% SC	25	2614.33	4723.18	34160	56897	22737	1.67
T_2	T_1 + Conoweeder	25	3155.67	5600.90	35910	68477	32568	1.91
T_3	Metsulfuron Methyl 20% WP	4	2554.67	4719.80	32647	55807	23160	1.71
T_4	T_3 + Conoweeder	4	2632.33	4723.49	34397	57224	22827	1.66
T_5	Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP	4	2577.33	4721.40	32803	56221	23418	1.71
T_6	T_5 + Conoweeder	4	2660.00	4728.44	34553	57736	23183	1.67
T_7	Hand weeding at 20 DAS and 40 DAS	-	3672.67	6410.83	44297	79481	35184	1.79
T_8	Weedy check	-	1507.67	2786.64	31797	32937	1140	1.04
	S.Em. (±)		33.28	58.66	-	-	-	-
	C.D. (*P*=.05)		100.94	177.93	-	-	-	-

4. CONCLUSION

From these findings, it can be concluded that the spraying of bispyribac sodium 10% SC @ 25 g a.i. ha^{-1} at 20 DAS followed by managing the weeds in later period of rice growth through conoweeder at 40 DAS could be the best suitable alternative to hand weeding or chemical weed control alone to achieve highest grain yield and economic return in direct-seeded condition.

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