



Integrative Weed Management Tactics for Rice (*Oryza sativa* L.) under Direct-Seeding in Kymore Plateau and Satpura Hills

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Authors' contributions

This work was carried out in collaboration among all authors. Authors ST and AT collected the data. Authors RS and IN performed the statistical analysis of data. Author TM wrote the first draft of the manuscript. Author VBU idea conceptualization and designed the analysis. All authors read and approved the final manuscript.

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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.

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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 days after sowing (DAS) 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 earlier 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 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 is 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]. This experiment had been taken to study the associated weed flora and its management in direct-seeded rice under Kymore Plateau and Satpura Hills region.

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 behind the resistance development in weeds are 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. This experiment also aims to find out the most suitable integrative weed management tactic in Kymore Plateau and Satpura Hills region.

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°C and 34.9°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), low extractable P₂O₅ (33.4 kg ha⁻¹) and medium exchangeable K₂O (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 P₂O₅ and 40 kg ha⁻¹ K₂O. Half rate of N, complete rate of P₂O₅ and K₂O 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].

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

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. The observations related to weed population and weed biomass followed the poisson distribution. Since for such a distribution the variance is exactly equal to the mean, to stabilize the variance, square root transformation of the data was done [12].

3. RESULTS AND DISCUSSION

3.1 Dominant Weed Species in Direct-Seeded Rice

Species wise data on weeds at 30 DAS, 60 DAS, 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%). [13] noticed that *A. sessilis* was a pre-dominant species of dicot or broadleaved weeds found in direct-seeded rice in Jabalpur, Madhya Pradesh, 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 [14] and [15] corroborated the present findings.

3.2 Weed Population in Direct-Seeded Rice

The population of *E. colona* was differed significantly at 30 DAS, 60 DAS, 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 and 6.91 m⁻², respectively under weedy check plots at all the dates. Minimum weed density being 4.51, 3.34, 2.40 and 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 and 2.49 m⁻², respectively among all

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

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

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 [16]. However, hand weeding at 20 DAS and 40 DAS was noticed as most superior in reducing the population of *E. colona* being 1.99, 1.53, 1.21 and 1.07 m², respectively at 30, 60, 90 DAS and harvest as compared to all other options which was similar to the earlier report of [17].

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 reducing the population being 5.08, 4.74, 3.62 and 2.72 m², 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 being 6.18, 5.64 4.49 and 3.67 m², respectively at 30, 60, 90 DAS and harvesting stage 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 [16]. The minimum population of this weed being 2.01, 1.78, 1.37 and 1.21 m², respectively was observed at all the dates with hand weeding at 20 DAS and 40 DAS, respectively which was similar to the earlier report of [17] (Table 2).

Various weed management options gradually diminished the population of *C. rotundus* from 30 DAS to harvestable maturity. Maximum weed population of being 7.99, 7.58, 6.96 and 6.36 m², 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 and 1.46 m², 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 and 2.02 m², respectively at all the dates 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 [16]. The least weed density on all dates being 1.28, 1.17, 1.07 and 1.03 m², respectively was observed under hand weeding two times at 20 DAS and 40 DAS.

The population of *A. sessilis* was varied significantly by various treatment of weed control at all the dates (Table 5). Population of this weed m² was maximum being 8.35, 6.89, 6.31 and 6.07 m², respectively under weedy plots. Population of this weed was noticed as minimum being 3.70, 3.85, 2.92 and 2.11 m², 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 and 2.78 m², respectively among all the integrative and herbicidal weed control treatments. Earlier report of [16] corroborated these results. Two times hand weeding operation at 20 DAS and 40 DAS, respectively was always noted down as best in minimizing weed population being 2.25, 1.20, 1.11 and 1.09 m², respectively on all dates which was similar to the earlier report of [17].

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 and 5.98 m², respectively at 30 DAS, 60 DAS, 90 DAS and harvesting stage. Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10% WP at 4 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS showed significant reduction in its population

being 3.69, 3.39, 2.97 and 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 among all the treatments being 4.34, 3.85, 3.29 and 2.86 m⁻², respectively at 30, 60, 90 DAS and harvest. Earlier report of [16] 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 this weed population being 1.37, 1.17, 1.00 and 1.00 m⁻², respectively during the crop growing period which was similar to the earlier report of [17] (Table 5).

3.3 Weed Biomass in Direct-Seeded Rice

Weed biomass of *E. colona* was found to be maximum being 11.44, 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 and 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 + application 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 being 7.28, 4.63, 4.07 and 3.19 g m⁻², respectively among all the weed management options. Similar results were noted down earlier by [18] and [19]. However, hand weeded plots where weeds were removed two times at 20 DAS and 40 DAS had minimum biomass of *E. colona* being 1.45, 1.30, 1.13 and 1.06 g m⁻², respectively during the different dates which was similar to the earlier report of [17] (Table 3).

The biomass of *E. 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 and 6.14 g m⁻², respectively than all other treatments (Table 3). Lowest weed biomass being 5.78, 3.92, 3.60 and 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 and 4.40 g m⁻², respectively. Similar results were mentioned earlier by [18] and [19]. Hand weeding operation at 20 DAS and 40 DAS, respectively obtained minimum biomass of this weed being 1.71, 1.37, 1.34 and 1.04 g m⁻², respectively at all the dates which was similar to the previous report of [17].

Various weed control options significantly diminished the biomass of *C. rotundus* at different period of crop growth over weedy treatment. Biomass of this weed was maximum being 9.27, 9.06, 8.51 and 5.67 g m⁻², respectively in weedy plots where weed control measures were not taken (Table 4). Decrement in biomass of this weed was more pronounced being 3.39, 2.11, 1.96 and 1.74 g m⁻², respectively under 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 3.99, 2.79, 2.63 and 2.55 g m⁻², respectively at all the dates. Integration of herbicide application along with conoweeder was found to be more superior in reducing the weed biomass than application of herbicides alone. Similar results were mentioned previously by [18] and [19]. Least weed biomass of this sedge being 1.71, 1.37, 1.34 and 1.04 g m⁻², respectively was always obtained with hand weeding operation two times at 20 and 40 DAS, respectively which was similar to the previous report of [17].

Maximum biomass of *A. sessilis* at 30, 60, 90 DAS and harvest being 8.42, 8.20, 8.11 and 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 at all the dates 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 [18] and [19]. Least weed population being 2.37, 1.86 1.66 and 1.64 g m⁻², respectively was obtained with hand weeding 2 times at 20 and 40 DAS, respectively which was similar to the previous report of [17].

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 *L. parviflora* was always observed in weedy treatment being 12.28, 8.24, 7.67 and 5.41 g m⁻², respectively. Maximum reduction being 4.98, 3.83, 2.98 and 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 the 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 and 3.11 g m⁻², respectively among all integrative and herbicidal weed control practices. Similar findings were observed earlier by [18] and [19]. Lowest weed biomass being 1.24, 1.17, 1.13 and 1.07 g m⁻², respectively was always noticed in hand weeding two times at 20 DAS and 40 DAS, respectively which was similar to the previous report of [17].

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 [20] and [21]. 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).

The weed index was calculated least (0.00%) under hand weeding two times at 20 DAS and 40 DAS which was similar to the previous report of [22]. This result was followed by bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + use of 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 + use of conoweeder at 40 DAS treatment (27.57%). The weed index was found maximum (58.95%) under weedy check treatment (Fig. 2).

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

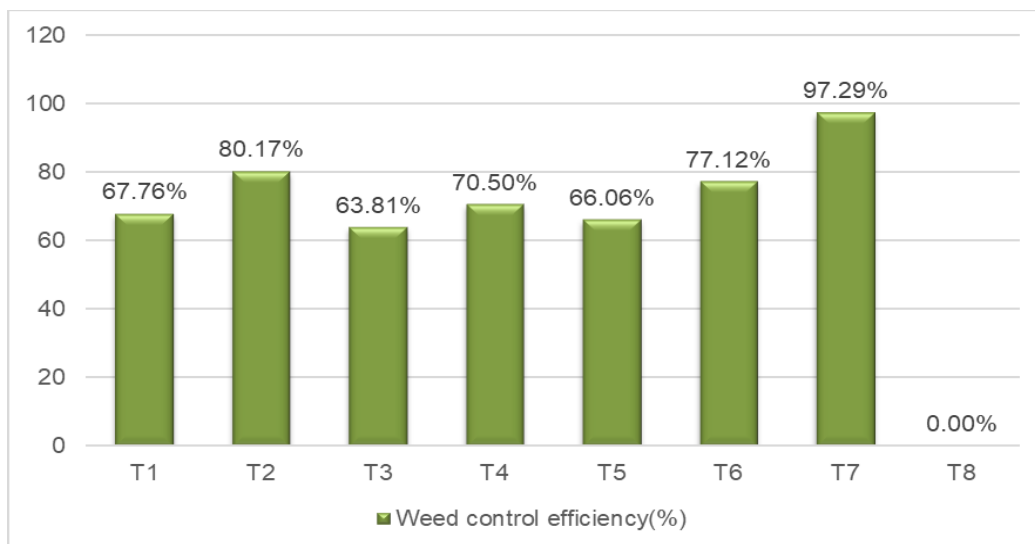


Fig. 1. Weed control efficiency (WCE)% as influenced by different weed control options in direct-seeded rice

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 [23] and [24].

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 were in accordance with the previous findings of [23] and [24].

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 had two hand weeding operations 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 + application of 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 + application of 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 [25] and [26] in transplanted rice. 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 in the management of weeds under this treatment than others. Similar results were mentioned previously in transplanted rice by [25] and [26]. This treatment was followed by hand weeding 2 times at 20 and 40 DAS treatment (1.79) (Table 7).

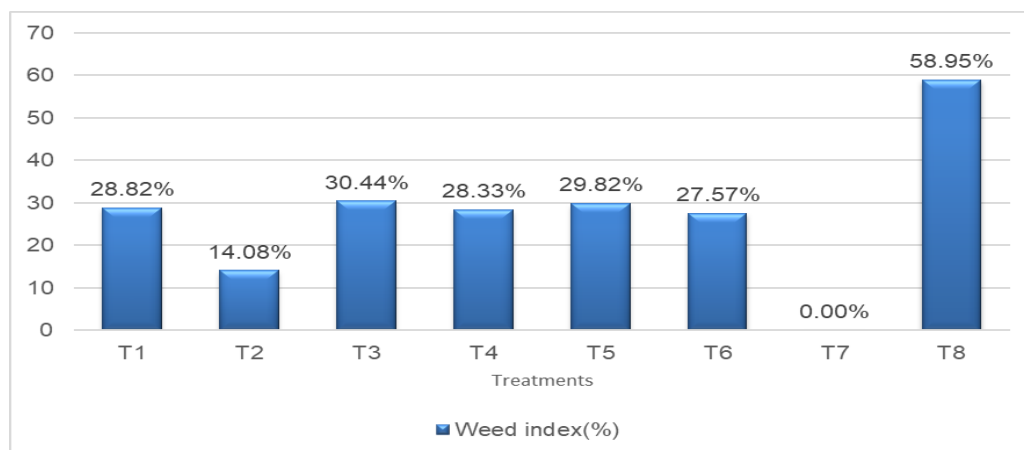


Fig. 2. Weed index (WI)% as influenced by different weed control options in direct-seeded rice

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

T. No.	Treatments	Dose (g a.i. ha ⁻¹)	Population of grassy weeds (No. m ⁻²)							
			<i>Echinochloa colona</i>				<i>Eleusine indica</i>			
			30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	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=0.05)		1.29	0.49	0.44	0.55	0.35	0.52	0.45	0.58

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)	Population of sedge weed (No. m ⁻²)				Biomass of sedge weed (g m ⁻²)			
			<i>Cyperus rotundus</i>				<i>Cyperus rotundus</i>			
			30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	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=0.05)		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 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)	Biomass of grassy weeds (g m ⁻²)							
			<i>Echinochloa colona</i>				<i>Eleusine indica</i>			
			30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	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 Methyl 20% WP at 20 DAS	4	7.58 (56.91)	5.12 (25.67)	5.04 (24.91)	4.30 (17.97)	7.68 (58.45)	7.14 (50.43)	5.62 (31.12)	4.71 (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=0.05)		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 5. Impact of weed management treatments on population of broadleaved weeds in direct-seeded rice

T. No.	Treatments	Dose (g a.i. ha ⁻¹)	Population of broadleaved weeds (No. m ⁻²)							
			<i>Alternanthera sessilis</i>				<i>Ludwigia parviflora</i>			
			30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	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=0.05)		0.69	0.48	0.41	0.57	0.63	0.41	0.29	0.48

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

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)							
			<i>Alternanthera sessilis</i>				<i>Ludwigia parviflora</i>			
			30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	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=0.05)		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

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 at 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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