

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 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 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 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 @ 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

32 by greater than 75% by applying direct-seeding technology in comparison to transplanting technique [5].
33 Direct-seeded rice complete its life cycle 7-11 days in advance than the rice grown under transplanted
34 situation and makes possible sowing of succeeding crop on time [6]. But weeds are the prime biological
35 constraint and a considerable threat in direct-seeded rice based cropping systems towards its production
36 and adoption by the farmers [7]. Uncontrolled weed density can reduce the productivity of rice by 96% in
37 dry direct-seeded condition and 61% in wet direct-seeded condition [8]. This experiment had been taken
38 to study the associated weed flora in direct-seeded rice under Kymore Plateau and Satpura Hills region.

39 Continuous use of an herbicide or herbicides with same mode of action will lead to the form
40 herbicide resistant weeds and shift in weed flora either rapidly or slowly. Herbicide factors behind the
41 resistance development in weeds are residual activity for long time period, single target site of action,
42 specific mode of action and very effective control rate for a large number of weed species. One of the
43 recent methods to control the weed flora shifting and to stop the formation or delay the formation of
44 resistance against herbicide application in weeds is the application of herbicide mixtures. There is an
45 essentiality for combining the various weed management tactics to get an efficient and sustainable weed
46 control of rice in direct-seeded situation. Thus, herbicides are being integrated with different manual and
47 mechanical methods for keeping the weeds under control in direct-seeded rice. This experiment also
48 aims to find out the most suitable integrative weed management tactics in Kymore Plateau and Satpura
49 Hills region.

50 2. MATERIALS AND METHODS

51 The field experiment was conducted at the Experimental Farm of Jawaharlal Nehru Krishi Vishwa
52 Vidyalaya, Jabalpur, Madhya Pradesh in rainy season of 2019. Total amount of rainfall received was
53 1575.4 mm in 51 rainy days during the cropping period. During the crop season, lowest and highest air
54 temperature observed was 17.7°C and 34.9°C, respectively. Initially, the top soil layer of the
55 experimentation site (0-15 cm soil layer) was sandy clay loam textured and neutral in pH (7.15) with low
56 available N (246.7 kg ha⁻¹) and extractable P₂O₅ (33.4 kg ha⁻¹) and medium exchangeable K₂O (275.2 kg
57 ha⁻¹) status. Line sowing was done manually at 20 cm apart in rows and continuously in a row following
58 the seed rate of 60 kg ha⁻¹. A quick maturing (110-115 days) rice cultivar 'MTU 1010' had been taken in
59 this experiment which is recommended for cultivation in Jabalpur, Madhya Pradesh. The recommended
60 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
61 rate of P₂O₅ and K₂O was applied just before sowing, top-dressing of one fourth of full N rate was done
62 during active tillering (30-45 DAS) and remaining one-fourth of full N rate was applied as split dose at
63 panicle initiation stage (60 DAS). The design followed in this experimentation was randomized block
64 design (RBD) with three replications. Eight post-emergence weed management treatments comprised of
65 Bispyribac Sodium 10% SC at 25 g ha⁻¹, Bispyribac Sodium 10% SC at 25 g ha⁻¹ + conoweeder,
66 Metsulfuron Methyl 20% WP at 4 g ha⁻¹, Metsulfuron Methyl 20% WP at 4 g ha⁻¹ + conoweeder,
67 Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10% WP at 4 g ha⁻¹, Metsulfuron Methyl 10% WP +
68 Chlorimuron Ethyl 10% WP at 4 g ha⁻¹ + conoweeder, hand weeding two times at 20 and 40 days after

69 sowing (DAS) and weedy check, respectively were allocated randomly in all the replications. All the
 70 herbicides were sprayed at 20 DAS followed by the use of conoweeder at 40 DAS as per the treatment.
 71 One irrigation was given before operating conoweeder in the field.

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

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

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

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

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

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

75 Gross monetary return, net monetary return and benefit-cost ratio (B:C) were measured with the help of
 76 market price of paddy grain (₹18.15 kg⁻¹ in 2018) and paddy straw (₹2.00 kg⁻¹ in 2018). All the data were
 77 analyzed in analysis of variance model with SPSS software. The treatment mean variations were tested
 78 at 5% level of significance. The observations related to weed population and weed biomass followed the
 79 poisson distribution. Since for such a distribution the variance is exactly equal to the mean, to stabilize the
 80 variance, square root transformation of the data was done [12].

81 3. RESULTS AND DISCUSSION

82 3.1 Dominant weed species in direct-seeded rice

83 Species wise data on weeds at 30 DAS, 60 DAS, 90 DAS and harvest under weedy check
 84 treatment exhibited that there was predominance of grassy weeds i.e., *Echinochloa colona* and *Eleusine*
 85 *indica*, sedge weed i.e., *Cyperus rotundus* and broadleaved weeds i.e., *Ludwigia parviflora* and
 86 *Alternanthera sessilis* in the experimental field. Among all these weeds, *E. colona* was more rampant
 87 (25.24%) at all the dates of observations followed by *E. indica* (22.22%). Grassy weeds were found to be
 88 more prominent with higher relative density than the broadleaved weeds i.e., *A. sessilis* (17.05%) and *L.*
 89 *parviflora* (16.97%). [13] noticed that *A. sessilis* was a pre-dominant species of dicot or broadleaved
 90 weeds found in direct-seeded rice in Jabalpur, Madhya Pradesh. Among the sedges, abundance of *C.*
 91 *rotundus* (18.52%) was noted down in the experimental plot (Table 1). The weed species reported earlier
 92 in rice under direct-seeded situation by [14] and [15] corroborated the present findings.

93 **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

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95 3.2 Weed population in direct-seeded rice

96 The population of *E. colona* was differed significantly at 30 DAS, 60 DAS, 90 DAS and harvesting
97 stage because of various integrative and chemical weed control treatments (Table 2). The population of
98 *E. colona* was maximum being 9.71, 9.58, 7.22 and 6.91 m⁻², respectively under weedy check plots at all
99 the dates. Minimum weed density being 4.51, 3.34, 2.40 and 1.93 m⁻², respectively of *E. colona* was
100 found under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40
101 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha⁻¹ at 20 DAS +
102 conoweeder at 40 DAS being 6.37, 3.84, 2.97 and 2.49 m⁻², respectively among all integrated and
103 chemical weed management practices. Integration of herbicides along with the use of conoweeder was
104 found to be more superior in reducing the weed population than application of herbicides alone. Similar
105 results were mentioned previously by [16]. However, hand weeding at 20 DAS and 40 DAS was noticed
106 as most superior in reducing the population of weeds being 1.99, 1.53, 1.21 and 1.07 m⁻², respectively of
107 *E. colona* as compared to all other treatments which was similar to the earlier report of [17].

108 Spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS
109 informed its better role than other treatments in reducing the population being 5.08, 4.74, 3.62 and 2.72
110 m⁻², respectively of *E. indica* at all stages of observation followed by metsulfuron methyl 10% WP +
111 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
112 3.67 m⁻², respectively among all integrated and herbicidal weed management practices. Integration of
113 herbicide use along with conoweeder application was found to be more superior in reducing the weed
114 population than application of herbicides alone. Similar results were also described previously by [16].
115 The minimum population of weeds being 2.01, 1.78, 1.37 and 1.21 m⁻², respectively was observed with
116 hand weeding at 20 DAS and 40 DAS, respectively which was similar to the earlier report of [17] (Table
117 2).

118 Various weed management options gradually diminished the population of *C. rotundus* from 30
119 DAS to harvestable maturity. Maximum population of weeds being 7.99, 7.58, 6.96 and 6.36 m⁻²,
120 respectively was reported under weedy check (Table 4). Bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20
121 DAS + conoweeder at 40 DAS showed maximum reduction in population being 2.91, 2.40, 1.68 and 1.46
122 m⁻², respectively of this weed at all the dates of observation followed by metsulfuron methyl 10% WP +
123 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
124 2.02 m⁻², respectively among the various weed management practices. Herbicides and conoweeder

125 together was found to be more superior in reducing the weed population than application of herbicides
126 alone. Similar findings were also reported previously by [16]. The least density being 1.28, 1.17, 1.07 and
127 1.03 m^{-2} , respectively was observed under hand weeding two times at 20 DAS and 40 DAS.

128 The population of *A. sessilis* was varied significantly by various treatment of weed control at all
129 the dates (Table 5). Number of weeds m^{-2} was maximum being 8.35, 6.89, 6.31 and 6.07 m^{-2} , respectively
130 under weedy plots. Population of this weed was noticed as minimum being 3.70, 3.85, 2.92 and 2.11 m^{-2} ,
131 respectively with applying metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha^{-1} at 20
132 DAS + conoweeder at 40 DAS on all the dates of observation followed by bispyribac sodium 10% SC at
133 $25 \text{ g a.i. ha}^{-1}$ at 20 DAS + conoweeder at 40 DAS treatment being 5.08, 4.37, 3.39 and 2.78 m^{-2} ,
134 respectively among all the integrative and herbicidal weed control treatments. Earlier report of [16]
135 corroborated these results. Two times hand weeding operation at 20 DAS and 40 DAS, respectively was
136 always noted down as best in minimizing weed population being 2.25, 1.20, 1.11 and 1.09 m^{-2} ,
137 respectively which was similar to the earlier report of [17].

138 The population of *L. parviflora* was significantly higher than all other treatments at different
139 stages in weedy check plots being 8.47, 6.72, 6.34 and 5.98 m^{-2} , respectively. Metsulfuron Methyl 10%
140 WP + Chlorimuron Ethyl 10% WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS showed significant
141 reduction in weed population being 3.69, 3.39, 2.97 and 2.27 m^{-2} , respectively during the period of
142 observation followed by bispyribac sodium 10% SC at $25 \text{ g a.i. ha}^{-1}$ at 20 DAS + conoweeder at 40 DAS
143 being 4.34, 3.85, 3.29 and 2.86 m^{-2} , respectively among all the treatments. Earlier report of [16] was in
144 line with these results obtained. Two times hand weeding operation at 20 DAS and 40 DAS, respectively
145 was noticed as most superior in controlling weed population being 1.37, 1.17, 1.00 and 1.00 m^{-2} ,
146 respectively during the crop growing period which was similar to the earlier report of [17] (Table 5).

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149 3.3 Weed biomass in direct-seeded rice

150 Weed biomass of *E. colona* was found to be maximum being 11.44, 9.87, 9.40 and 9.29 g m^{-2} ,
151 respectively in weedy check treatment at all the stages of observation. Biomass of this grassy weed
152 decreased gradually from vegetative phase to harvest on all the dates of observation under all the
153 treatments. Among the chemical and integrative weed control options, minimum dry matter of *E. colona*
154 being 5.32, 3.46, 3.07 and 2.41 g m^{-2} , respectively was noted down under the spraying of bispyribac
155 sodium 10% SC at $25 \text{ g a.i. ha}^{-1}$ at 20 DAS + conoweeder at 40 DAS followed by metsulfuron methyl 10%
156 WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha^{-1} at 20 DAS + conoweeder at 40 DAS treatment being
157 7.28, 4.63, 4.07 and 3.19 g m^{-2} , respectively among all the weed management options. Similar results
158 were noted down earlier by [18] and [19]. However, hand weeded plots where weeds were removed two
159 times at 20 DAS and 40 DAS had minimum weed biomass being 1.45, 1.30, 1.13 and 1.06 g m^{-2} ,
160 respectively during the crop growing period which was similar to the previous report of [17] (Table 3).

161 The biomass of *E. indica* at 30, 60, 90 DAS and harvesting stage under various weed control
162 options showed that significantly higher biomass of this weed at all the stages of observation in weedy
163 treatment being 10.32, 10.23, 9.44 and 6.14 g m⁻², respectively than all other treatments (Table 3).
164 Lowest weed biomass being 5.78, 3.92, 3.60 and 3.58 g m⁻², respectively was recorded under the
165 spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS treatment
166 which was significantly lower than all other chemical and integrative weed control options. This treatment
167 was followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha⁻¹ at 20 DAS +
168 conoweeder at 40 DAS being 6.89, 5.76, 4.89 and 4.40 g m⁻², respectively. Similar results were
169 mentioned earlier by [18] and [19]. Hand weeding operation at 20 DAS and 40 DAS, respectively
170 obtained minimum biomass of this weed being 1.71, 1.37, 1.34 and 1.04 g m⁻², respectively on all the
171 dates which was similar to the previous report of [17].

172 Various weed control options significantly diminished the biomass of *C. rotundus* at different
173 period of crop growth over weedy treatment. Biomass of this weed was maximum being 9.27, 9.06, 8.51
174 and 5.67 g m⁻², respectively in weedy plots where control measures were not taken at 30, 60, 90 DAS
175 and harvest, respectively (Table 4). Decrement in weed biomass was more pronounced being 3.39, 2.11,
176 1.96 and 1.74 g m⁻², respectively under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20
177 DAS + conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at
178 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.
179 Integration of herbicide use along with conoweeder application was found to be more superior in reducing
180 the weed biomass than application of herbicides alone. Similar results were mentioned previously by [18]
181 and [19]. Least weed biomass being 1.71, 1.37, 1.34 and 1.04 g m⁻², respectively of this sedge was
182 obtained with hand weeding operation two times at 20 DAS and 40 DAS, respectively which was similar
183 to the previous report of [17].

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185 Maximum biomass of *A. sessilis* at 30, 60, 90 DAS and harvest being 8.42, 8.20, 8.11 and 5.01 g
186 m⁻², respectively was observed under weedy plots (Table 6). Most prominent decrement being 4.06, 3.59,
187 2.76, 2.63 g m⁻², respectively in the biomass of this weed was found under metsulfuron methyl 10% WP +
188 chlorimuron Ethyl 10 % WP at 4 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS on all the dates of
189 observation followed by bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS
190 being 5.33, 4.38, 3.68, 3.53 g m⁻², respectively among all integrated and herbicidal weed management
191 options. Integration of herbicide use along with conoweeder application was found to be more superior in
192 reducing the weed biomass than application of herbicides alone. Similar results were observed earlier by
193 [18] and [19]. Minimum weed density being 2.37, 1.86 1.66 and 1.64 g m⁻², respectively was obtained
194 with hand weeding two times at 20 DAS and 40 DAS, respectively which was similar to the previous
195 report of [17].

196 *L. parviflora* showed its biomass at 30, 60, 90 DAS and harvest under various weed management

197 treatments and significantly varied among all the treatments (Table 6). Maximum biomass production of
198 *L. parviflora* was observed being 12.28, 8.24, 7.67 and 5.41 g m⁻², respectively in weedy treatment.
199 Maximum reduction being 4.98, 3.83, 2.98 and 2.68 g m⁻², respectively in the weed biomass was
200 observed under metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha⁻¹ at 20 DAS +
201 conoweeder at 40 DAS at all the stages of observation followed by bispyribac sodium 10% SC at 25 g a.i.
202 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
203 integrative and herbicidal weed control practices. Similar findings were observed earlier by [18] and [19].
204 Lowest weed biomass being 1.24, 1.17, 1.13 and 1.07 g m⁻², respectively was noticed in hand weeding
205 two times at 20 DAS and 40 DAS, respectively which was similar to the previous report of [17].

206 Table 2: Impact of weed management treatments on population of grassy weeds in direct-seeded
207 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=05)		1.29	0.49	0.44	0.55	0.35	0.52	0.45	0.58

208 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 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=05)		0.34	0.38	0.44	0.42	0.59	0.49	0.58	0.48

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

213 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

214 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

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	4.38	3.68	3.53	6.69	4.25	3.78	3.11

T ₃	Metsulfuron Methyl 20% WP at 20 DAS	4	(27.88)	(18.67)	(13.01)	(11.95)	(44.25)	(17.56)	(13.79)	(9.16)
			5.92	5.32	5.07	4.06	8.22	4.87	4.63	3.51
			(34.49)	(27.76)	(25.18)	(15.99)	(67.02)	(23.21)	(20.97)	(11.83)
T ₄	T ₃ + Conoweeder at 40 DAS	4	5.42	4.69	4.14	3.74	6.97	4.57	4.01	3.19
			(28.87)	(21.53)	(16.66)	(13.50)	(48.01)	(20.38)	(15.56)	(9.66)
T ₅	Metsulfuron Methyl 10% WP + Chlorimuron Ethyl 10 % WP at 20 DAS	4	5.66	5.15	4.83	3.89	7.96	4.87	4.36	3.41
			(31.49)	(26.06)	(22.79)	(14.65)	(62.83)	(23.21)	(18.54)	(11.16)
T ₆	T ₅ + Conoweeder at 40 DAS	4	4.06	3.59	2.76	2.63	4.98	3.83	2.98	2.68
			(15.96)	(12.38)	(7.13)	(6.42)	(24.27)	(14.16)	(8.38)	(6.70)
T ₇	Hand weeding at 20 DAS and 40 DAS	-	2.37	1.86	1.66	1.64	1.24	1.17	1.13	1.07
			(5.12)	(2.97)	(2.27)	(2.19)	(1.04)	(0.88)	(0.77)	(0.65)
T ₈	Weedy check	-	8.42	8.20	8.11	5.01	12.28	8.24	7.67	5.41
			(70.40)	(66.75)	(65.32)	(24.64)	(150.23)	(67.40)	(58.30)	(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

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

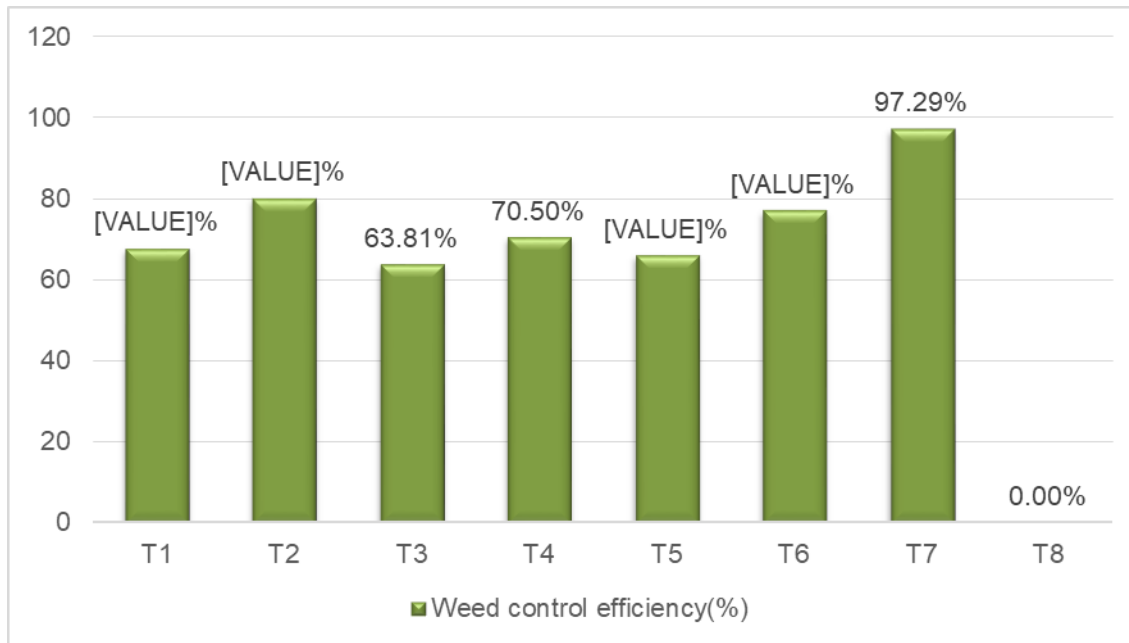
216 **Table 6: Impact of weed management treatments on biomass of broadleaved weeds in direct-**
217 **seeded rice**

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

219 3.4 Weed control efficiency and weed index in direct-seeded rice

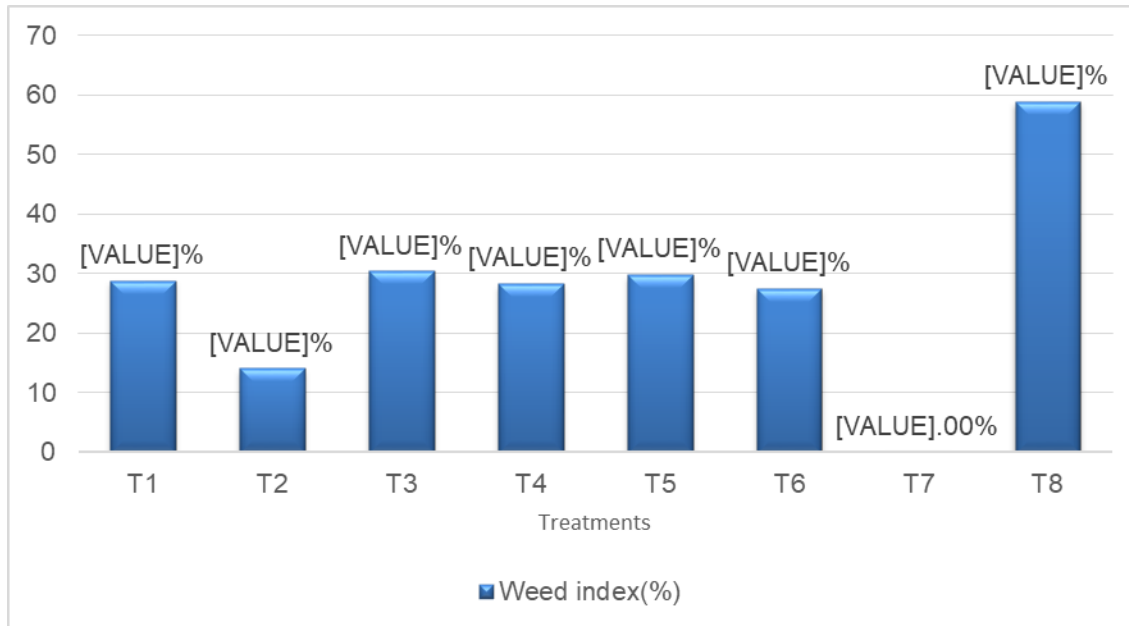
220 Among the herbicidal and integrative weed control options, best weed control efficiency (80.17%)
221 was obtained under the spraying of Bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder
222 at 40 DAS treatment This result was in accordance with the earlier findings of [20] and [21]. The

223 treatment, metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g a.i. ha⁻¹ at 20 DAS +
 224 conoweeder at 40 DAS was also achieved 2nd highest weed control efficiency (77.12%) among the
 225 chemical and integrated weed management treatments. Hand weeding twice at 20 DAS and 40 DAS,
 226 respectively was noted down as superior (97.29%) among all the weed management options (Fig. 1).



227
 228 **Fig. 1: Weed control efficiency (WCE)% as influenced by different weed control options in direct-**
 229 **seeded rice.**

230 The weed index was calculated least (0.00%) under hand weeding two times at 20 DAS and 40
 231 DAS which was similar to the previous report of [22]. This result was followed by bispyribac sodium 10%
 232 SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS (14.08%) treatment and metsulfuron methyl 10%
 233 WP + chlorimuron ethyl 10% WP at 4 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS treatment (27.57%).
 234 The weed index was found maximum (58.95%) under weedy check treatment (Fig. 2).



235

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

237 **3.5 Grain and Straw yield of direct-seeded rice**

238 Grain yield of direct-seeded rice was significantly influenced because of various weed
 239 management options. The grain yield was found lowest (1507.67 kg ha⁻¹) under weedy treatment where
 240 weeds were allowed to grow throughout the cropping season (Table 7). The grain productivity was
 241 significantly greater (3672.67 kg ha⁻¹) in hand weeding at 20 DAS and 40 DAS, respectively than all other
 242 options. Among the integrative and chemical weed management options, maximum grain yield (3155.67
 243 kg ha⁻¹) was registered under the spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + use
 244 of conoweeder at 40 DAS followed by metsulfuron methyl 10% WP + chlorimuron ethyl 10% WP at 4 g
 245 a.i. ha⁻¹ at 20 DAS + use of conoweeder at 40 DAS treatment (2660.00 kg ha⁻¹). Minimum weed
 246 infestation was the main reason behind the improved grain productivity in these treatments which made
 247 the nutrients, spacing, water and sunlight more available resulting in more growth and development of
 248 rice. These results were in accordance with the previous report of [23] and [24].

249 Data pertaining to straw yield of direct-seeded rice showed significant variation due to the weed
 250 control measures taken (Table 7). The straw yield was found lowest (2786.64 kg ha⁻¹) under weedy
 251 treatment where weed management measures were not followed throughout the cropping season. The
 252 option, hand weeding twice at 20 DAS and 40 DAS registered significantly superior straw yield (6410.83
 253 kg ha⁻¹) than rest of the treatments followed by bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS +
 254 conoweeder application at 40 DAS (5600.90 kg ha⁻¹) and metsulfuron methyl 10% WP + chlorimuron
 255 ethyl 10% WP at 4 g a.i. ha⁻¹ at 20 DAS + conoweeder application at 40 DAS (4728.44 kg ha⁻¹). These
 256 results are in accordance with the previous findings of [23] and [24].

257 **3.6 Economics of direct-seeded rice cultivation**

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

262 Gross monetary return (GMR) was noted down lowest (Rs 32937 ha⁻¹) under weedy check
 263 (Table 7). The treatment obtaining two hand weeding showed the higher GMR (Rs 79481 ha⁻¹) followed
 264 by the spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS (Rs
 265 68477 ha⁻¹) and metsulfuron methyl 10% WP + chlorimuron ethyl 10 % WP at 4 g a.i. ha⁻¹ at 20 DAS +
 266 conoweeder at 40 DAS treatment (Rs 57736 ha⁻¹), respectively.

267 In Table 7, the net monetary return (NMR) was recorded least (Rs 1140 ha⁻¹) when crop was kept
 268 weedy. The NMR was found highest (Rs 35184 ha⁻¹) in hand weeding two times at 20 DAS and 40 DAS,
 269 respectively. Similar results were mentioned previously by [25] and [26] in transplanted rice. This was
 270 specifically due to attainment of highest grain and straw productivity under hand weeding treatment. This
 271 treatment was followed by the spraying of bispyribac sodium 10% SC at 25 g a.i. ha⁻¹ at 20 DAS +
 272 conoweeder at 40 DAS treatment (Rs 32568 ha⁻¹).

273 Benefit-cost ratio (BCR) was recorded maximum (1.91) under the spraying of bispyribac sodium
 274 10% SC at 25 g a.i. ha⁻¹ at 20 DAS + conoweeder at 40 DAS treatment because of proportionate
 275 enhancement in economic return because of lower cost involving management of weeds under this
 276 treatment than others. Similar results were mentioned previously in transplanted rice by [25] and [26].
 277 This treatment was followed by hand weeding two times at 20 DAS and 40 DAS treatment (1.79) (Table
 278 7).

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

280

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	-	-	-	-

281

282 4. CONCLUSION

283 From these findings, it can be concluded that the spraying of bispyribac sodium 10% SC at 25 g
284 a.i. ha⁻¹ at 20 DAS followed by managing the weeds in later period of rice growth through conoweeder at
285 40 DAS could be the best suitable alternative to hand weeding or chemical weed control alone to achieve
286 highest grain yield and economic return in direct-seeded condition.

287 **COMPETING INTERESTS:** Authors have declared that no competing interests exist.

288 **AUTHORS' CONTRIBUTIONS:** This work was carried out in collaboration among all authors. Author ST and
289 author AT collected the data. Author RS and author IN performed the statistical analysis of data. Author TM wrote
290 the first draft of the manuscript. Author VU idea conceptualization and designed the analysis. All authors read and
291 approved the final manuscript.

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