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Chemical Weed Management in Transplanted Rice (*Oryza sativa* L.) under Rice – Mustard Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. Author RS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JG and PP managed the analyses of the study. Authors SM and MP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted at instructional farm Uttar Banga Krishi Viswavidyalaya during *kharif* season, 2017 to find out a suitable chemical weed management practice in transplanted rice. The experiment was laid out in randomized block design having 12 treatments replicated thrice. The treatments were $\mathbf{T_1}$: Weedy check, $\mathbf{T_2}$: Weed free, $\mathbf{T_3}$: Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 14 DAT, $\mathbf{T_4}$: Bispyribac sodium 10% SC @ 30 g *a.i* ha^{-1} at 14 DAT, $\mathbf{T_5}$: Butachlor 1.5 kg *a.i* ha^{-1} at 3 DAT, $\mathbf{T_6}$: Pendimethalin 1.0 kg *a.i.* ha^{-1} at 3 DAT, $\mathbf{T_7}$: Pretilachlor 0.60 kg *a.i* ha^{-1} at 3 DAT + 2,4-D sodium salt 0.50 kg *a.i* ha^{-1} at 30 DAT, $\mathbf{T_8}$: Butachlor 1.5 kg *a.i* ha^{-1} at 3 DAT + 2,4-D sodium salt 0.50 kg *a.i* ha^{-1} at 30 DAT, $\mathbf{T_9}$: Metsulfuron methyl 20% WP @ 8 g *a.i* ha^{-1} at 14 DAT, $\mathbf{T_{10}}$:

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Pretilachlor 0.60 kg *a.i* ha^{-1} at 3 DAT + Almix @ 20 g *a.i.* ha^{-1} at 21 DAT, **T_{11}**: Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 21 DAT and **T_{12}**: Almix @ 20 g *a.i* ha^{-1} at 21 DAT. The rice variety used in the experiment was MTU 1075. It was observed that different herbicides treatments influenced weed control efficiency, weed index and yield components in transplanted rice. The highest number of filled grains (113.12 panicle^{-1}), 1000 grain weight (22.90 g), grain yield (5.07 t ha^{-1}) and straw yield (7.15 t ha^{-1}) of rice was recorded with weed free (T_2) treatment being at par with T_{11}, T_4, T_3 and T_{10}. In mustard, plots under weed free *i.e.* T_2 treatment in rice performed the best in terms of every yield attribute *viz*. number of siliqua (77.00 plant^{-1}), number of seeds (20.41siliqua^{-1}), 1000 seed weight (3.14 g) as well as seed yield (1067.46 kg ha^{-1}) and stover yield (2157.40 kg ha^{-1}) being statistically at par with the plots under treatment T_{11} & plots under treatment T_4. It can be concluded that the treatment comprising combination of pre-emergence & post-emergence herbicide like T_{11} *i.e.* Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT or application of higher dose of efficient & highly effective post-emergent herbicide molecule like T_4 *i.e*. Bispyribac sodium 10% SC @ 30 g *a.i* ha^{-1} at 14 DAT can be opted for sufficient control of weeds in transplanted *kharif* paddy in *terai* zone of West Bengal to maximize the economic return.

Keywords: Transplanted rice; herbicides; mustard; WCE; WI; yield components; yield.

1. INTRODUCTION

Rice, as a staple food, will remain the mainstay of the sustenance of Asia's population for years to come. Rice production in Asia alone represents more than 90% of global production (144 million hectares area; 612 million tonnes production) and consumption with China and India dominating with over half of the total area harvested [1]. In Asia, it is the main diet of 3.5 billion people and the burgeoning population in this dynamic region is still expected to need 70% additional rice by 2025 [2]. According to the reports, India has exported 10.23 million tonnes of rice in the year 2015 as compared to Thailand's 9.8 million tonnes. In terms of imports, China remains the number one importer of rice. Asian rice production has been increased many folds because of advancement in research, formulations of agro-ecological based production and protection technologies and efficient production input delivery systems.

Transplanted rice suffers from more number of weed species as it is grown under favorable moisture and other input environment. The competition between rice and weeds is in high order [3]. The loss of yield due to uncontrolled weed growth in transplanted rice ranges from 16 to 86 per cent [4]. It was reported that to increase the efficiency of the applied inputs weed management is one important operation in transplanted rice. Weeds are more competitive in their early growth stages than at later stages and hence the crop growth is affected and finally the grain yield decreases [5]. The critical period of crop weed competition in transplanted rice is 30 to 60 days after transplanting [6].

In order to achieve maximum return from the supplied inputs weed management at critical stages of crop weed competition is important. It is well known that weed management through manual hand weeding is most efficient and safe but high physical energy and cost involvement make it difficult for its timely implication in large areas. Most of the farmers in our country are not aware about yield loss due to weeds, so they don't give importance to timely weed management resulting in considerable yield loss to their crops. In addition, shortage of labour supply during the peak period and high wages force the farmers to neglect weed management practices. Thus, manual removal of weeds in rice is difficult, highly labour intensive and time consuming. Recently, due to this problem, chemical weed management is getting pace in weed management practices.

The use of herbicides offers scope for economical control of weeds right from the beginning, giving rice crop an advantage of good start and competitive superiority. Pre-emergence herbicides such as Butachlor, Pretilachlor and Anilofos are being frequently used for the effective management of weeds in transplanted rice [7] and continuous application of these voluminous herbicides year after year may lead to shift in weed flora from grassy to non-grassy weeds and sedges and development of herbicide resistance in weeds. Some of the promising low dose high efficacy pre-emergence and post-emergence herbicides are available for control of wide spectrum of weed flora in lowland rice. The sequential application of pre-emergence and post-emergence herbicides, especially with those of low dose high efficiency herbicides in relation to weed dynamics has not been investigated adequately in transplanted rice [8]. The present study was undertaken to test the relative efficacy of pre and post-emergence herbicides on weed flora in transplanted rice. The present study was therefore, undertaken to find out an effective method of weed management with promising pre-emergence and post-emergence herbicides in *kharif* rice in rice-mustard cropping system.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted during *kharif* season of 2017 at Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal. The experiment site was situated at 26°19'86" N latitude, 89°23'53" E longitude and at an altitude of 43 m above the mean sea level. This area lies under the *Terai* agro-ecological zone of West Bengal.

2.2 Soil and Its Characteristics

The experimental soil was sandy loam in texture, slightly acidic in reaction, low in organic carbon, available nitrogen and medium in available phosphorus and available potassium (Table 1).

2.3 Agro-Climatic Condition of *Terai* Zone

The climatic condition of *terai* zone is sub-tropical in nature with eminent characteristics of high rainfall, high humidity and prolong winter season. In this zone, there are two distinctive seasons in a year - a much extended winter or dry *rabi* season and a long rainy season. The winter season starts from middle of October with fall in night temperature and is extended up to March with the same range of low night temperature, very light rainfall, cool temperature, high humidity and dry clean sunny days. Wet or rainy season characterized by hot and humid weather, heavy rain fall brought about by south-west monsoon with cloudy overcast days and fewer hours of bright sunshine. The crop growing season of this zone are broadly classified as *Pre-kharif* (dry and warm) starting from March to May, *Kharif* (wet and warm) starting from June to October and *Rabi* (dry and cool) during November to February. The rainy season starts from 2nd fortnight of May and sometime it appears during 1st week of June. Rainy season continues up to last week of September having intermittent drizzling and occasional heavy rainfall. In addition to this a light shower occurs during the first fortnight of April followed by a dry spell up to the onset of monsoon. The average rainfall of this zone varies between 2100 to 3300 mm. The maximum rainfall, *i.e.*, about 80% of the total, is received from south-west monsoon during the rainy months from June to September (Table 2).

2.4 Experimental Design with Treatment Details

The experiment was laid out in a Randomized Block Design (RBD) with 12 treatments and replicated thrice giving a total of 36 unit plots each measuring 6.0 m × 3.5 m (21 sq. meter).

Table 1. Physico-chemical properties of soil of experimental field

Particle size distribution	Value	Method employed
Sand	62.14%	International Pipette method(Piper, 1950)
Silt	20.59%	
Clay	17.30%	
pH	6.15	pH meter (Jackson, 1973).
Organic carbon (%)	1.07	Rapid Titration Method (Walkley and Black, 1934)
Available nitrogen (kg ha^{-1})	126.35	Modified Macro Kjeldahl method (Jackson, 1967).
Available Phosphorus (kg ha^{-1})	29.67	Bray and Kurtz methods (Bray and Kurtz, 1945)
Available potassium (kg ha^{-1})	101.69	Flame Photometer method (Baruah and Barthakur, 1997)

Table 2. Meteorological monthly mean data pertaining to the period of experiments from June, 2017 to November 2017

Month	Temperature (ºC)		Relative Humidity (%)		Rainfall (mm)	Bright Sunshine (Hour)	Evaporation
	Max.	Min.	Max.	Min.			
June	32.80	24.66	91.97	75.60	167.5	3.78	3.61
July	32.12	25.49	90.97	78.23	133.3	3.60	3.76
August	32.22	25.64	96.97	80.58	316.0	3.15	2.80
September	32.88	25.10	95.97	76.47	177.5	3.81	2.92
October	30.84	22.31	96.35	74.39	72.4	3.96	2.84
November	29.51	15.69	94.83	55.40	00.0	6.52	2.19

Source: Project on GKMS, AMFU, UBKV, Pundibari, Coochbehar

Chart 1. Treatment details

Treatment	Details
T_1	Weedy check/Control
T_2	Weed free
T_3	Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 14 DAT
T_4	Bispyribac sodium 10% SC @ 30 g *a.i* ha^{-1} at 14 DAT
T_5	Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT
T_6	Pendimethalin 1.0 kg *a.i.* ha^{-1} at 3 DAT
T_7	Pretilachlor 0.60 kg *a.i.* ha^{-1} at 3 DAT + 2,4-D sodium salt 0.50 kg *a.i* ha^{-1} at 30 DAT
T_8	Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + 2,4-D sodium salt 0.50 kg *a.i* ha^{-1} at 30 DAT
T_9	Metsulfuron methyl 20% WP @ 8 g *a.i* ha^{-1} at 14 DAT
T_{10}	Pretilachlor 0.60 kg *a.i.* ha^{-1} at 3 DAT + Almix @ 20 g *a.i* ha^{-1} at 21 DAT
T_{11}	Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 21 DAT
T_{12}	Almix @ 20 g *a.i* ha^{-1} at 21 DAT

2.5 Agricultural Operations Followed during the Experiment

The experimental field was prepared by a tractor drawn cultivator followed by tractor drawn rotavator to obtain good tilth. Paddy seed @ 30 kg ha^{-1} was broadcasted in the well prepared nursery bed and 25 days old seedlings were transplant in the main field. The recommended dose of fertilizers *viz.* 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} were applied in the from Urea, Single super phosphate (SSP) and Muriate of potash (MOP) respectively. One third (1/3) quantity of nitrogen (N) and full amount of phosphorus (P_2O_5) and potassium (K_2O) were applied in the experimental plot as basal on the day of transplanting. Rest two third (2/3) quantity of N was applied in two splits as top dressing *i.e.* one third (1/3) of nitrogen was top dressed at 21 DAT and rest one third (1/3) of nitrogen was top dressed at 42 DAT. The crop was harvested when most of panicles turned golden yellow. Harvesting was done manually by using sickle. After harvesting of rice, small furrows were opened in each unaltered plot with the help of tyne in between the rows of rice stubbles and seeds of mustard were dropped manually in the furrows. Then the furrows were covered with soil with the help of foot. All other agronomic and plant protection measures were adopted as per the recommended packages.

2.6 Biometric Observations

The observations for various growth attributes such as plant height, number of tillers per square meter, dry matter accumulation, leaf area index (LAI) at 30, 60 and 90 DAT were recorded from the earmarked area for destructive sampling. From those observations crop growth rate (CGR) and relative growth rate (RGR) at 30-60 and 60-90 DAT were worked out. Leaf area index (LAI) was calculated through area weight relationship method.

Yield attributes such as number of panicles m^{-2}, number of filled grains $panicle^{-1}$, test weight (1000 grain weight) in g., grain yield (t ha^{-1}), straw yield (t ha^{-1}) and harvest index (%) were recorded at the time of maturity. Weed flora composition (No. m^{-2}), Dry weight of weeds (g m^{-2}) was also recorded and accordingly Weed

Chart 2. Phytotoxicity observation

Score	Phytotoxicity (%)
0	No phytotoxicity
1	1-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9 & 10	Complete destruction

control efficiency (WCE %), Weed index (WI %) were worked out as per standard formula.

$$\textbf{Weed Control Effeciency (WCE)} = \frac{(\mathrm{WDM_C} - \mathrm{WDM_T})}{\mathrm{WDM_C}} \times 100$$

where,

WCE = Weed control efficiency.
WDM_C = Weed dry weight (unit m^{-2}) in control plot.
WDM_T = Weed dry weight (unit m^{-2}) in treated plot.

$$\textbf{Weed Index (WI)} = \frac{\mathrm{Y_{WF}} - \mathrm{Y_T}}{\mathrm{Y_{WF}}} \times 100$$

where,

WI = Weed index
Y_{WF} = Yield of the crop in weed free plot.
Y_T = Yield of the crop in treatment plot.

Finally, yield components of mustard *viz*. siliqua plant^{-1}, seeds siliqua^{-1}, 1000 grain weight in g., seed yield (kg ha^{-1}), stover yield (kg ha^{-1}) was measured.

2.7 Phytotoxicity Assessment

Phytotoxicity observations on leaf injury on tips/surface, wilting, necrosis, vein clearing, epinasty, hyponasty etc. were scored according to 0-10 (as below) scale at different treatments comprising herbicides on 7, 15 and 30 days after application from 10 plants and then average were taken.

2.8 Statistical Analysis

The data obtained as described earlier were subjected to statistical analysis by the Analysis of Variance method [9] and the significance of different sources of variations were tested by Error Mean Square by Fisher and Snedecor's 'F' test at probability level 0.05. For determination of critical difference at 5% level of significance, Fisher and Yate's table [10] was consulted.

2.9 Economic Analysis

The cost of cultivation, gross return, net return and return per rupee invested of different treatments were calculated and the cost of various inputs like seeds, fertilizers, herbicides and all other inputs including labour charges were estimated as per price of the items in the market. The value of products like grain and straw was also calculated on the basis of available price at the market.

3. RESULTS AND DISCUSSION

3.1 Weed Dry Weight, Weed Control Efficiency and Weed Index

It was evident that significant variations in weed dry weight were observed from the different chemical weed management practices. The lowest (0.00) weed dry weight was recorded with weed free treatment (T_2) and highest weed dry weight was recorded with weedy check (T_1) at all the stages of crop growth *i.e*. 30, 45 and 60 DAT.

Among the treatments T_3 to T_{12}, the lowest weed dry weight (1.00, 3.90 and 4.13 g m^{-2} at 30, 45 and 60 DAT respectively) was recorded with Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 21 DAT (T_{11}) being statistically at par with Bispyribac sodium 10% SC @ 30 g *a.i* ha^{-1} at 14 DAT (T_4), having the values of 1.23, 4.83 and 4.93 g m^{-2} at 30, 45 and 60 DAT respectively and Bispyribac sodium 10% SC @ 20 g *a.i* ha^{-1} at 14 DAT (T_3) having the values of 1.33, 5.23 and 5.83 g m^{-2} at all the crop growth periods *i.e.* 30, 45 and 60 DAT respectively. Weedy check (T_1) recorded the highest dry weight of weeds at all the stages of crop growth being significantly higher than the remaining treatments (Table 3).

Among the rest weed management practices, Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT *i.e.* (T_{11}) recorded the highest weed control efficiency (80.69, 81.49 and 82.63% at 30, 45 and 60 DAT respectively) being statistically at par with (76.25, 77.08 and 79.26% at 30, 45 and 60 DAT respectively) Bispyribac sodium 10% SC @ 30 g *a.i.* ha^{-1} at 14 DAT *i.e.* (T_4) and (74.32, 75.18 and 75.47% at 30, 45 and 60 DAT respectively) Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 14 DAT *i.e.* (T_3). The lowest weed control efficiency (34.56, 35.12 and 35.21% at 30, 45 and 60 DAT respectively) was recorded with T_9 *i.e.* Metsulfuron methyl 20% WP @ 8 g *a.i.* ha^{-1} at 14 DAT (Table 4).

It was found that the application of Bispyribac sodium 10% SC @ 25 g *a.i.* ha^{-1} gave significantly lowest weed density (16.8 & 16.5), lowest weed dry weight (2.4 & 2.1) g m^{-2}, lowest weed competition index (6.84 & 7.15) and highest weed control efficiency (83 & 86% respectively) [11].

Table. 3. Effect of herbicide treatments on weed dry weight (g m^{-2}) of transplanted *kharif* Rice

Treatment	Weed dry weight (g m^{-2})		
	30 DAT	**45 DAT**	**60 DAT**
T_1	5.18	21.07	23.77
T_2	0.00	0.00	0.00
T_3	1.33	5.23	5.83
T_4	1.23	4.83	4.93
T_5	3.20	12.33	13.71
T_6	3.25	12.94	14.52
T_7	2.80	10.53	12.09
T_8	2.94	11.25	12.95
T_9	3.39	13.67	15.40
T_{10}	2.78	10.01	10.98
T_{11}	1.00	3.90	4.13
T_{12}	3.15	11.87	13.07
S.Em ±	0.24	0.84	1.07
C.D. (0.05)	0.70	2.48	3.17

At 30, 45 and 60 DAT, maximum weed control efficiency (WCE), (100%) was recorded with weed free treatment (T_2) and the minimum (0%) was recorded with weedy check (T_1)

Table 4. Effect of herbicide treatments on weed control efficiency (WCE %) and weed index (WI %) of transplanted *kharif* Rice

Treatment	Weed control efficiency (%)			Weed index(%)
	30 DAT	**45 DAT**	**60 DAT**	**At harvest**
T_1	0.00	0.00	0.00	59.17
T_2	100.00	100.00	100.00	0.00
T_3	74.32	75.18	75.47	9.07
T_4	76.25	77.08	79.26	6.90
T_5	38.22	41.48	42.32	27.61
T_6	37.26	38.59	38.91	32.54
T_7	45.95	50.02	49.14	14.40
T_8	43.24	46.61	45.52	17.95
T_9	34.56	35.12	35.21	34.71
T_{10}	46.33	52.49	53.81	11.24
T_{11}	80.69	81.49	82.63	2.56
T_{12}	39.19	43.66	45.01	23.27
S.Em ±	4.42	3.66	4.16	2.13
C.D. (0.05)	13.05	10.81	12.29	6.31

Weed index (WI) indicated percentage of crop yield reduction by weeds. The maximum weed index value (59.17%) was recorded in the treatment weedy check (T_1) and minimum weed index value (0.00%) was observed in the treatment weed free (T_2)

Among the weed management practices excepting T_1 & T_2, the lowest weed index (2.56 %) was noticed with Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT *i.e*. (T_{11}) being statistically at par with T_4 *i.e*. Bispyribac sodium 10% SC @ 30 g *a.i.* ha^{-1} at 14 DAT (6.90%). Excepting control treatment, the highest yield reduction (34.71%) was recorded with Metsulfuron methyl 20% WP @ 8 g *a.i.* ha^{-1} at 14 DAT (T_9) followed by Pendimethalin 1.0 kg *a.i.* ha^{-1} at 3 DAT (32.54%) *i.e*.T_6 (Table 4).

It was observed that weed control efficiency of 72.8% and 85.7% in the treatments Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} & Bispyribac sodium 10% SC @ 30 g *a.i.* ha^{-1} respectively in direct seeded rice [12].

3.2 Phytotoxicity Effect of Herbicides on Rice

It was observed from the experiment that no herbicide had any phytotoxic effect on crop plants at any stage of the crop.

The bispyribac sodium has no any phyto-toxicity on rice and no residual toxicity on succeeding crop of wheat [13].

3.3 Growth Attributes, Yield Components and Yield of Rice

At 30, 60 and 90 DAT, T_2 *i.e.* weed free treatment showed the highest plant height (cm) and number of tillers m^{-2} being statistically at par with all other treatments except T_1 *i.e*. weedy check. The leaf area index (LAI) and relative growth rate (RGR) revealed that there was no significant difference due to the effect of different chemical weed management practices but crop growth rate (CGR) was significantly differed due to various chemical weed management practices.

The highest number of panicles per m^{-2} (211.46) was recorded with the weed free treatment (T_2) being statistically at par with T_{11} *i.e*. Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT (208.36) and T_4 *i.e.* Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 14 DAT (205.32) but differed from all other treatments significantly. The lowest number of panicles m^{-2} (132.90) was recorded with T_1 *i.e*. weedy check (Table 5).

The highest number of filled grains $panicle^{-1}$ (113.12) was recorded with weed free (T_2) treatment being at par with T_{11} *i.e.* Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT (110.58), T_4 *i.e*. Bispyribac sodium 10% SC @ 30 g *a.i.* ha^{-1} at 14 DAT (107.83), T_3 *i.e.* Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 14 DAT (105.82) and T_{10} *i.e*. Pretilachlor 0.60 kg *a.i.* ha^{-1} at 3 DAT + Almix @ 20 g *a.i* ha^{-1} at 21 DAT (104.62). The lowest number of filled grains $panicle^{-1}$ (76.33) was recorded with the weedy check (T_1). The maximum test weight (22.90 g) was recorded with weed free (T_2) treatment being statistically at par with T_{11}, T_4, T_3, T_7, T_{10}, T_8 and T_{12}. Weedy check recorded the lowest test weight 20.94 g among all the treatments (Table 5).

Table 5. Effect of herbicide treatments on panicle m^{-2}, filled grains $panicle^{-1}$, grain yield (t ha^{-1}), straw yield (t ha^{-1}) and 1000 grains weight (g) of transplanted *kharif* Rice

Treatment	No. of Panicles (m^{-2})	Filled grains $panicle^{-1}$	Grain yield t ha^{-1}	Straw yield t ha^{-1}	1000 grain weight (g)
T_1	132.90	76.33	2.07	3.61	20.94
T_2	211.46	113.12	5.07	7.15	22.90
T_3	200.27	105.82	4.61	6.63	22.43
T_4	205.32	107.83	4.72	6.86	22.77
T_5	168.23	95.53	3.67	5.96	21.77
T_6	173.70	97.73	3.42	5.75	21.80
T_7	189.92	102.78	4.34	6.38	22.27
T_8	184.08	101.30	4.16	6.41	22.13
T_9	164.58	93.25	3.31	5.27	21.30
T_{10}	194.47	104.62	4.50	6.54	22.27
T_{11}	208.36	110.58	4.94	6.98	22.83
T_{12}	178.41	99.67	3.89	6.07	21.93
S. Em (±)	2.09	3.11	0.20	0.22	0.33
C.D. (0.05)	6.15	9.17	0.59	0.66	0.97

The highest grain yield (5.07 t ha^{-1}) and straw yield (7.15 t ha^{-1}) of rice was obtained with weed free (T_2) treatment being statistically at par with T_{11} *i.e*. Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i*. ha^{-1} at 21 DAT (4.94 t ha^{-1} and 6.98 t ha^{-1}), T_4 *i.e*. Bispyribac sodium 10% SC @ 30 g *a.i*. ha^{-1} at 14 DAT (4.72 t ha^{-1} and 6.86 t ha^{-1}), T_3 *i.e*. Bispyribac sodium 10% SC @ 20 g *a.i*. ha^{-1} at 14 DAT (4.61 t ha^{-1} and 6.63 t ha^{-1}) and T_{10} *i.e*. Pretilachlor 0.60 kg *a.i*. ha^{-1} at 3 DAT + Almix @ 20 g *a.i*. ha^{-1} at 21 DAT (4.50 t ha^{-1} and 6.54 t ha^{-1}). The lowest grain yield (2.07 t ha^{-1}) and straw yield (3.61 t ha^{-1}) was recorded with the weedy check (Table 5).

The post-emergence application of Bispyribac sodium at 25 g *a.i*. ha^{-1} recorded grain yield of 6.84 and 6.51 t ha^{-1} during 2010 and 2011, respectively which was at par with higher doses of Bispyribac-sodium and significantly superior than Butachlor application [14].

3.4 Yield Attributes and Yield of Mustard

A perusal of the data clearly indicates that different chemical weed control treatments adopted in transplanted rice brought about significant variation on the production of number of siliqua per plant in mustard.

The maximum number of siliqua $plant^{-1}$ was produced from the plots under weed free *i.e*. T_2 (77.00) treatment in rice being statistically at par with the plots under treatment T_{11} *i.e*. Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT (75.62) in rice, plots under treatment T_4 (74.45) *i.e*. Bispyribac sodium 10% SC @ 30 g *a.i* ha^{-1} at 14 DAT in rice and proved to be significantly superior to other weed control treatments adopted in rice. Plots from weedy check *i.e*. T_1 produced significantly least number of siliqua $plant^{-1}$ (61.98) among all the treatments adopted in rice (Table 6).

Different chemical weed control practices adopted in rice brought about marked variation on number of seeds $siliqua^{-1}$, 1000 seed weight, seed yield and stover yield in mustard. It was evident from the data that plots having the treatments (rice) like weed free *i.e*. T_2, recorded maximum number of seed $siliqua^{-1}$(20.41), 1000 seed weight (3.14 g), seed yield (1067.46 kg ha^{-1}) and stover yield (2157.40 kg ha^{-1}) which were statistically at par with T_{11} *i.e*. Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT. In general, all the herbicidal treatments in rice resulted in significantly higher number of seeds $siliqua^{-1}$, seed yield and stover yield in mustard over the plots having the treatment weedy check *i.e*. T_1 (16.39, 602.23 kg ha^{-1} and 1494.61 kg ha^{-1} respectively) in rice (Table 6).

3.5 Economics of Rice-Mustard Cropping System

In rice – mustard cropping system, highest total variable cost of cultivation (Rs. 74,800.00 ha^{-1}) was incurred in T_2 *i.e*. weed free followed by T_4 (Rs. 65,494.00 ha^{-1}) and T_{11} (Rs. 65,172.00 ha^{-1}), gross return (Rs. 1,28,433.00 ha^{-1}) was obtained from T_2 *i.e*. weed free followed by T_{11} (Rs. 1,26,029.00 ha^{-1}) and

Table 6. Effect of herbicide treatment in transplanted rice on the siliqua $plant^{-1}$, seeds $siliqua^{-1}$, 1000 seeds weight (g), seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) of Mustard

Treatment	Siliqua $plant^{-1}$	Seeds $siliqua^{-1}$	1000 seeds wt. (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1	61.98	16.39	2.78	602.23	1494.61
T_2	77.00	20.41	3.14	1067.46	2157.40
T_3	73.37	19.93	3.10	1028.67	2038.24
T_4	74.45	20.17	3.11	1046.69	2068.06
T_5	65.01	18.67	2.82	827.98	1725.98
T_6	71.90	20.02	3.10	998.57	1988.29
T_7	70.64	20.02	3.07	978.78	1910.96
T_8	67.16	20.10	3.08	963.35	1863.48
T_9	66.09	18.75	3.01	782.61	1766.90
T_{10}	67.88	19.93	3.07	931.49	1834.08
T_{11}	75.62	20.41	3.13	1061.97	2112.97
T_{12}	69.58	18.52	3.04	868.31	1811.53
S. Em (±)	1.21	0.05	0.01	9.43	52.60
C.D. (0.05)	3.58	0.14	0.02	26.29	148.75

Table 7. Effect of herbicide treatment in kharif rice on the cost of cultivation, gross return, net return and ICBR of Rice - Mustard cropping system

Treatment	Variable cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	ICBR
T_1	62416	59784	-2632	1:-0.04
T_2	74800	128433	53633	1:0.72
T_3	64554	119232	54678	1:0.85
T_4	65494	121888	56394	1:0.86
T_5	63034	95964	32930	1:0.52
T_6	63274	98703	35429	1:0.56
T_7	63532	112801	49269	1:0.78
T_8	63472	109424	45952	1:0.72
T_9	63424	87879	24455	1:0.39
T_{10}	63952	113550	49598	1:0.78
T_{11}	65172	126029	60857	1:0.93
T_{12}	63274	101097	37823	1:0.60

ICBR- Incremental Cost Benefit Ratio

T_4 (Rs. 1,21,888.00 ha^{-1}) & net return (Rs. 60,857.00 ha^{-1}) was obtained from T_{11} followed by T_4 (Rs. 56,394.00 ha^{-1}). Lowest cost of cultivation (Rs. 62,416.00 ha^{-1}), gross return (Rs. 59,784.00 ha^{-1}) and net return (Rs.-2632.00 ha^{-1}) were obtained from control treatment *i.e*. weedy check (Table 7).

The highest Incremental Cost Benefit Ratio (ICBR) was obtained from T_{11} *i.e.* Butachlor 1.5 kg *a.i.* ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT (1:0.93) followed by T_4 *i.e.* Bispyribac sodium 10% SC @ 30 g *a.i*. ha^{-1} at 14 DAT (1:0.86) and T_3 *i.e.* Bispyribac sodium 10% SC @ 20 g *a.i*. ha^{-1} at 14 DAT (1:0.85). Lowest ICBR was obtained from control treatment *i.e.* weedy check (1: - 0.04).

It was also reported that higher net income and benefit-cost ratio were associated with the application of bispyribac-sodium at 25 g/ha [14].

4. CONCLUSION

Based on the finding of the present study it can be concluded that combination of pre-emergence & post-emergence herbicide like T_{11} *i.e.* Butachlor 1.5 kg *a.i*. ha^{-1} at 3 DAT + Bispyribac sodium 10% SC @ 20 g *a.i.* ha^{-1} at 21 DAT or single application of Bispyribac sodium 10% SC @ 20-30 g *a.i* ha^{-1} at 14 DAT can be opted for sufficient control of weeds in transplanted *kharif* rice under rice-mustard cropping system in *terai* zone of West Bengal to maximize the economic return.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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