The Pharma Innovation Journal 2023; 12(7): 1265-1269

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(7): 1265-1269

www.thepharmajournal.com
Received: 24-04-2023
Accepted: 29-05-2023

Integrated weed management in direct seeded dry sown rice in red and lateritic belt of West Bengal

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Abstract
A field experiment was conducted during the *kharif* season of 2016 and 2017 at the Agricultural Farm of the Palli Siksha Bhavana, Visva-Bharati, Sriniketan, Birbhum, West Bengal to study the effect of integrated weed management on population dynamics and growth of weeds and productivity of dry direct seeded rice (DSR). Integrated use of closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} followed by (*fb*) bispyribac-Na at 25 g ha^{-1} considerably reduced the weed infestation-registering lower weed density, dry weight, weed index, higher weed control efficiency and yield of DSR and was comparable with pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1}, pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth in terms of yield of DSR.

Keywords: Closer spacing, herbicide, mulching, *Saccharum spontaneum*, sesbania, water hyacinth

1. Introduction
Rice (*Oryza sativa* L.) accounts for nearly 20% of the global dietary supply (Bin Rahman and Zhang, 2023) [1]. More than 60% of Indians eat rice as a staple food, playing a crucial role in the country's agricultural industry. It is mainly grown by transplanting in puddled soil which requires more water, labour, energy and destroys the soil structure. Puddled transplanted rice (PTR) is a significant source of greenhouse gases (GHGs), particularly methane, which contributes to global warming (Brye *et al*., 2013) [2]. Direct-seeded rice (DSR) is a viable option for reducing methane emissions in addition to saving water and labour. As compared to the PTR, the DSR requires 45 and 58% less labour and tractor power, respectively. Additionally, dry DSR uses 30-40% less water than traditional PTR (Yadav *et al*., 2011) [17]. One of the main reasons for lower productivity in DSR is the diversity and abundance of weeds. Aerobic soil conditions allow weeds to germinate in several flushes, which cause grain yield losses of 50–91% (Chakraborti *et al*., 2017; Dash and Duary, 2020; Jaiswal *et al*., 2022) [3, 5, 9] or even complete failure of the crop (Duary *et al*., 2005; Teja and Duary, 2018) [7, 16]. Weed management is an important aspect of successful cultivation of DSR. Manual hand weeding is effective and safe, but due to shortage of labour and high wages, it is not economically feasible. Herbicides are effective alternatives to hand weeding and also save time and money. Weed shift and development of resistance due to continuous use of herbicides may make those inefficient in the long run. Due to the aerobic conditions in DSR, weeds emerge at different times, and they cannot be managed with a single application of pre- or post-emergence herbicide. Integrated weed management using cultural approaches, making the crop more competitive with the use of competitive varieties, narrow crop row spacing and high crop seed rate and using crop residue as mulch are viable options for managing the diverse weed flora of DSR. There is also scope for integrating herbicides with cultural practices to improve the sustainable use of herbicides. Making the crop more competitive and reducing weed competitiveness by delaying emergence or suppressing weed growth should be the focus of weed management strategies in DSR (Chauhan and Johnson, 2010) [4]. The use of locally available weeds such as water hyacinth (*Eichhornia crassipes*) and *Saccharum spontaneum* as bio-organic mulch can be an option for suppressing weed growth in crop fields. Application of 2, 4-D to manage broadleaved weeds along with *Sesbania* sown broadcasted with rice is another important practice. There is no single weed management method that is both effective and sustainable in the long run for managing weeds in DSR. In this context, the current experiment was designed to investigate the impact of integrating various weed management practices on weed population dynamics, weed growth, and the productivity of DSR.

2. Materials and Methods

A field experiment was conducted to study the effect of integrated weed management on population dynamics and growth of weeds and productivity of dry DSR during *kharif* season of 2016 and 2017 in the Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal. The soil of the experimental field was sandy loam (*Ultisol*) in texture, medium to low fertility with acidic reaction. The field experiment was carried out in randomized block design (RBD) with ten treatments replicated thrice. The treatments under experimentation were pendimethalin at 0.75 kg ha^{-1} + one hand weeding at 35 DAS (T_1), pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum* (T_2), pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3), pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D sodium salt at 400 g ha^{-1} (T_4), bispyribac-Na at 25 g ha^{-1} (T_5), pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6), closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7), closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} (T_8), hand weeding at 15, 30 and 45 DAS (T_9) and un-weeded control (T_{10}). The herbicide pendimethalin at 0.75 kg ha^{-1} was applied as pre-emergence. Bispyribac-Na at 25 g ha^{-1} was applied at 18 DAS as early post-emergence. Again 2, 4-D was applied as post-emergence at 30 DAS. All the herbicides were sprayed with manually operated knap-sac sprayer fitted with flat fan nozzle using 500 liters of water per hectare. Rice variety 'MTU 1010' with a seed rate of 40 kg ha^{-1} was line sown with a row to row spacing of 20 cm in the second week of July. The crop was fertilized with 80 kg N, 40 kg each of P_2O_5 and K_2O per hectare. One third quantity of nitrogen and full amount of phosphorus and potassium were applied in each plot as basal on the day of sowing. Rest two third quantity of N was applied in two splits as top dressing *i.e.* one third of nitrogen was top dressed at 30 DAS and rest one third of nitrogen was top dressed at 55 DAS. All other recommended agronomic practices and plant protection measures were adopted to raise the crop. Observations on weed population dynamics, dry weight was recorded at 45 and 60 DAS. Weed control efficiency was worked out using the dry weight of weeds (Mani *et al*., 1973) [11].

$$\text{WCE} = \frac{\text{WDWc} - \text{WDWt}}{\text{WDWc}} \times 100$$

Where,
WCE = Weed control efficiency
WDW_C= Weed dry matter (aerial parts) production in weedy check
WDW_t = Dry matter (aerial parts) production in treated plot.
Weed index was determined by using the following formula (Gill and Vijayakumar, 1966) [8] and expressed in percentage.

$$\text{WI} = \frac{\text{Ywfc} - \text{Yt}}{\text{Ywfc}} \times 100$$

Where,
WI = Weed index
Y_{Wfc} = Yield of the crop in weed free check
Y_t = Yield of the crop under treatment

Rice yield and yield attributes were recorded during the growing period and analyzed statistically (pooled analysis).

3. Results and Discussion

Cynodon dactylon, *Ludwigia parviflora*, *Spilanthes acmella*, *Melochia corchorifolia*, *Commelina benghalensis*, *Fimbristylis miliacea* and *Cyperus iria* were predominant weed throughout the cropping period. These observations were in the same line as reported by Duary *et al*. (2005) [7], Chakraborti *et al.* (2017) [3] and Malik *et al.* (2021) [10].

3.1 Effect on weed density and biomass

The density and biomass of weeds were significantly influenced by the different treatments (Table 1). The lowest number of total weeds was observed in hand weeding at 15, 30 and 45 DAS. Among the other treatments closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) registered the lowest number of total weeds (93.7-96.4% reduction in density of total weed) which was statistically at par with pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6) (88.3 and 95.2% reduction in density of total weed at 45 and 60 DAS, respectively). All the treatments caused significant reduction in weed dry weight as compared to unweeded control during the entire growing period of DSR. At 45 DAS the lowest weed biomass was recorded with the treatment closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) which was statistically at par with pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6). As expected, no dry weight of weeds was observed in the treatment hand weeding at 15, 30 and 45 DAS (T_9) as the observation was recorded after the hand weeding at 45 DAS in this treatment. On the other hand, the highest weed biomass was registered in unweeded control (T_{10}) followed by closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} (T_8). The results were in conformity with Sharma *et al*. (2004) [14], Mann *et al*. (2007) [12], Singh *et al*. (2009) [15] and Jaiswal *et al.* (2022) [9]. The treatments pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum* (T_2) and pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3) were statistically at par with respect to weed biomass. However, pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum* (T_2) recorded higher weed density (25.0 and 14.4% at 45 and 60 DAS, respectively). At 45 DAS the treatment closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) registered the highest weed control efficiency (99) but was very close to T_5, T_6 followed by T_1, T_4, T_3 and T_2 (Figure 1). At 60 DAS also the treatment closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) registered the highest weed control efficiency followed by pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6), bispyribac-Na at 25 g ha^{-1} (T_5), pendimethalin at 0.75 kg ha^{-1} + one hand weeding at 35 DAS (T_1) and pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D sodium salt at 400 g ha^{-1} (T_4) (Figure 2). The lowest value of weed index was recorded in pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3) (-1.6) followed by pendimethalin at 0.75 kg ha^{-1}, bispyribac-Na at 25 g ha^{-1} (T_6) (5.7) and closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) (7.6) (Table 1). The weed index value in the treatment T_3 was negative to that of hand weeding at 15, 30 and 45 DAS (T_9) because of its higher yield than the later. Unweeded control (T_{10}) recorded the highest value of weed index followed by closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} (T_8), pendimethalin at 0.75 kg ha^{-1} + one hand weeding at 35 DAS (T_1) and bispyribac-Na at 25 g ha^{-1} (T_5).

3.2 Effect on crop

The highest plant height at harvest was recorded under the treatment pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3) which was statistically at par with hand weeding at 15, 30 and 45 DAS (T_9) (Table 2). Though the density and the dry weight of weeds were not the lowest but the performance of the crop was not affected much under this treatment, rather it was comparable with three-hand weeding (T_9). This might be probably due to the supplement of different macro and micronutrients from the decomposed water hyacinth and favorable microbial activities, in addition to weed suppression by mulching resulting in higher nutrient uptake and greater light interception by rice. The data on effective tillers m^{-2} revealed that the highest number of panicles m^{-2} was recorded with closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7) and was followed by hand weeding at 15, 30 and 45 DAS (T_9), pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6) and pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3) (Table 2). Efficient and timely weed management practices by application of herbicide and mulch effectively controlled different spectrums of weeds appearing in differing flushes during the crop growing period and thereby promoted tillering and panicle formation of rice. The highest number of grains penicle^{-1} was recorded in hand weeding at 15, 30 and 45 DAS (T_9) which was statistically at par with pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum* (T_2), pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3), pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D sodium salt at 400 g ha^{-1} (T_4), pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6) and closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_7). No significant difference among the various treatments was observed on test weight of rice. The grain yield varied significantly among the treatments. There was about 53% yield reduction due to weed competition in DSR. This trend of reduction was also observed by Dhanapal *et al.* (2018) [6] and Saravanane *et al.* (2020) [13]. Malik *et al.* (2021) [10] recorded 57% yield reduction in dry DSR which is almost similar to the present experimental result. The highest grain yield (4.61 t ha^{-1}) was recorded under the treatment pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth (T_3) and it was statistically at par with hand weeding at 15, 30 and 45 DAS (T_9) (4.53 t ha^{-1}), pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} (T_6) (4.27 t ha^{-1}), closer spacing (16 cm row to row) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1}(T_7) (4.20 t ha^{-1}) and pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D sodium salt at 400 g ha^{-1} (T_4) (4.17 t ha^{-1}) and was closely followed by pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum* (T_2) (3.92 t ha^{-1}). These treatments controlled whole spectrum of weeds effectively as evident from the data on weed density, dry weight and weed controlled efficiency. Beside these, water hyacinth and *Saccharum spontaneum* were supposed to provide additional macro and micro nutrients, growth promoting substances and thus better soil environment. The competition between rice and weed for nutrient, water, light and space was less under the above treatments, which facilitated greater utilization of sunlight, higher synthesis of carbohydrates and better partitioning of photosynthates towards grain formation and ultimately leading to higher grain yield of rice. The highest value of harvest index (45.9) was computed under hand weeding at 15, 30 and 45 DAS (T_9) which was statistically at par with all the other treatments except unweeded control (T_{10}). The lowest harvest index (32.7) was recorded in unweeded control (T_{10}).

Table 1: Effect of treatments on weed density and biomass and weed index of direct seeded rice (pooled data)

Treatments		Weed density (No.m^{-2})		Weed biomass (g m^{-2})		Weed index (%)
		45 DAS	60 DAS	45 DAS	60 DAS	
T_1	Pendimethalin at 0.75 kg ha^{-1} +1 HW at 35 DAS	5.87 (34)	6.92 (47)	2.72 (6.89)	4.30 (17.97)	21.8
T_2	Pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum*	10.18 (104)	8.72 (76)	4.70 (21.65)	4.93 (23.89)	10.1
T_3	Pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth	8.88 (78)	8.10 (65)	4.65 (21.21)	4.82 (22.77)	-1.6
T_4	Pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D-Na salt	5.21 (27)	4.78 (22)	3.11 (9.15)	2.57 (6.10)	8.0
T_5	Bispyribac-Na at 25 g ha^{-1} at 20 DAS	3.79 (14)	4.32 (18)	2.13 (4.04)	1.77 (2.73)	20.1
T_6	Pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} at 20 DAS	2.90 (8)	3.62 (13)	1.81 (2.78)	1.54 (1.90)	5.7
T_7	Closer-spacing (16 cm) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1}	2.47 (6)	2.73 (7)	1.66 (2.29)	1.27 (1.12)	7.6
T_8	Closer-spacing (16 cm) + pendimethalin at 0.75 kg ha^{-1}	13.04 (170)	10.60 (112)	8.33 (69.28)	6.61 (43.13)	23.0
T_9	Three HW at 15, 30 and 45 DAS	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0
T_{10}	Unweeded control	19.19 (368)	15.18 (231)	15.86 (251.20)	14.50 (210.19)	53.0
LSD (P=0.5)		0.74	0.93	0.46	0.51	-

Figures in parentheses are the original values. The data was transformed to SQRT (x + 0.5) before analysis; HW= Hand weeding; DAS= Days after sowing; *fb*=followed by.

Table 2: Effect of treatments on plant height, yield components and yield of direct seeded rice (Pooled data)

	Treatments	Plant height (cm) at harvest	No. of effective tillers m^{-2}	No. of filled grains $panicle^{-1}$	Test weight (g)	Grain yield ($t\ ha^{-1}$)	HI (%)
T_1	Pendimethalin at 0.75 kg ha^{-1} +1 HW at 35 DAS	100.8	277	74	25.8	3.54	43.9
T_2	Pendimethalin at 0.75 kg ha^{-1} + mulching with *Saccharum spontaneum*	109.8	274	91	26.4	3.92	46.6
T_3	Pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth	121.0	301	93	26.9	4.61	44.9
T_4	Pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2,4-D-Na salt	105.8	290	92	26.2	4.17	45.7
T_5	Bispyribac-Na at 25 g ha^{-1} at 20 DAS	98.8	288	68	26.5	3.66	44.4
T_6	Pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} at 20 DAS	105.1	301	92	26.3	4.27	45.4
T_7	Closer-spacing (16 cm) + pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25g ha^{-1}	99.2	303	85	26.0	4.20	44.2
T_8	Closer-spacing (16 cm) + pendimethalin at 0.75 kg ha^{-1}	96.8	267	68	25.8	3.49	43.4
T_9	Three HW at 15, 30 and 45 DAS	116.3	301	93	26.7	4.53	45.9
T_{10}	Unweeded control	95.9	208	56	26.0	2.13	32.7
	LSD (P=0.5)	7.9	31	14	NS	0.59	7.2

HW= Hand weeding; DAS= Days after sowing; *fb*=followed by.

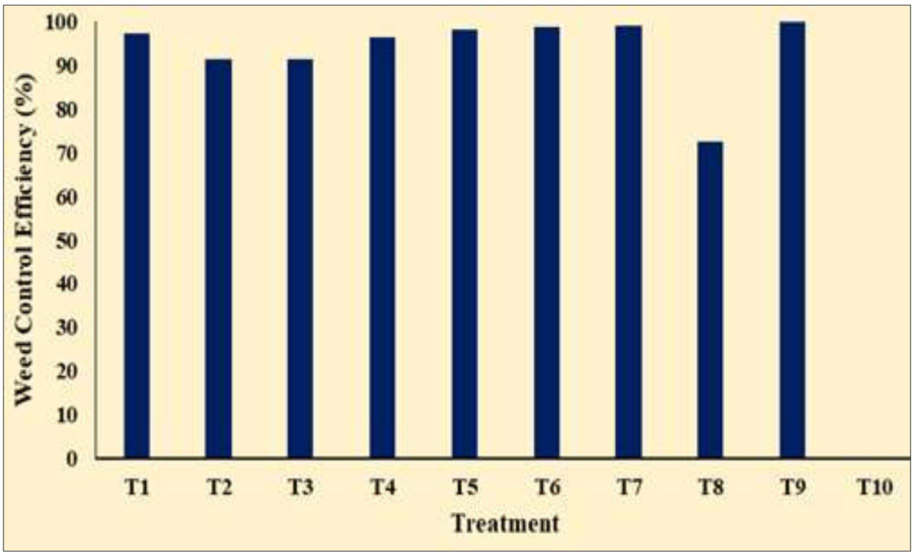

Fig 1: Effect of treatments on weed control efficiency at 45 DAS

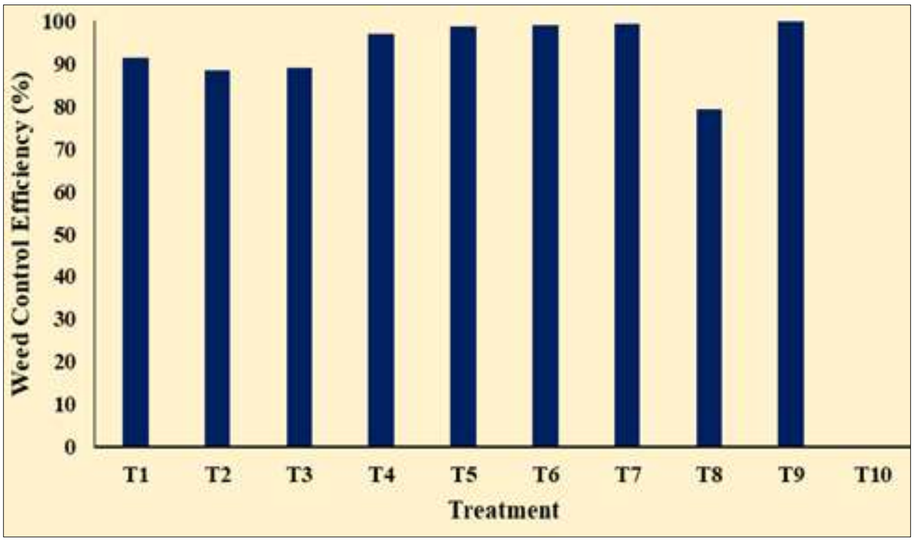

Fig 2: Effect of treatments on weed control efficiency at 60 DAS

4. Conclusions

Thus, based on two years of field experiments it can be concluded that the application of pendimethalin at 0.75 kg ha^{-1} + mulching with water hyacinth appeared to be promising weed management practice for higher weed control efficiency and yield of DSR in lateritic soil of West Bengal. In addition to this, pendimethalin at 0.75 kg ha^{-1} and *Sesbania* + 2, 4-D-Na salt at 400 g ha^{-1} or pendimethalin at 0.75 kg ha^{-1} *fb* bispyribac-Na at 25 g ha^{-1} also appeared to be effective alternatives.

5. Acknowledgements
The authors are very thankful to the Department of Agronomy, Institute of Agriculture, Visva-Bharati for providing the necessary facilities to conducting the field experiments and other related research work.

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