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Mandira Chakraborti
Subject Matter Specialist (Agronomy), Krishi Vigyan Kendra, West Tripura, ICAR (RC) for NEH Region, Tripura, India

Buddhadeb Duary
Professor, Department of Agronomy, Palli Siksha Bhavana, Visva-Bharati, Sriniketan, West Bengal, India

Corresponding Author:
Mandira Chakraborti
Subject Matter Specialist (Agronomy), Krishi Vigyan Kendra, West Tripura, ICAR (RC) for NEH Region, Tripura, India

Sustainable weed management approaches for cultivation of upland rice under Tripura condition

Mandira Chakraborti and Buddhadeb Duary

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Abstract
A field experiment was carried out during the kharif seasons of 2013 and 2014 to develop sustainable weed management practices for upland rice in Tripura. The study included twelve treatments arranged in a randomized complete block design with three replications. The predominant weed species identified in the experimental area included *Amaranthus viridis*, *Hedyotis corymbosa*, *Spilanthes acmella*, *Ludwigia parviflora*, *Cleome rutidosperma*, and *Malvaestrum coromandalinum* among broadleaf weeds, as well as *Digitaria sanguinalis* among grasses and *Cyperus iria* among sedges. Among the various treatments, hand weeding three times at 15, 30, and 45 days after sowing (DAS) resulted in the lowest weed dry weight for all weed types in both years, followed by the combination of pendimethalin with one hand weeding and pendimethalin with bispyribac sodium. Although the highest grain and straw yields were achieved with the thrice hand weeding at 15, 30 and 45 DAS treatment during both years, it was not economically feasible. Among the different weed management strategies, the combination of pendimethalin at a rate of 1.0 kg ha-1 applied at 2 DAS and bispyribac sodium at a rate 25 g ha-1 applied at 20 DAS yielded the highest net returns and return per rupee invested, making it the most effective and profitable weed management approach, followed by the treatment of pendimethalin at 1.0 kg ha-1 at 2 DAS combined with one hand weeding at 30 DAS for direct-seeded upland rice in Tripura.

Keywords: Direct seeded rice, pendimethalin, weed management, grain yield, straw yield, netreturn

Introduction
In India, rice is primarily cultivated as puddle-transplanted rice, either under irrigated or rainfed conditions. This method of cultivation is characterized by its high demand for labor and energy. The traditional practice of transplanting after puddling significantly impacts the physical properties of the soil, leading to the disruption of soil aggregates, decreased permeability in subsurface layers, and the formation of a hard pan at shallow depths. These changes complicate land preparation and necessitate greater energy expenditure to achieve suitable soil tilth for subsequent crops. Additionally, the rising labor costs in India are diminishing the profitability of puddle-transplanted rice. Furthermore, this cultivation method is not environmentally sustainable, as it contributes to substantial methane emissions from lowland rice fields. To address these challenges, transitioning to direct-seeded rice cultivation emerges as a viable alternative.

Direct seeded rice (DSR) represents a cost-efficient method for establishing rice crops, wherein dry seeds are directly sown into unpuddled soil. This technique offers significant advantages, including a reduction in irrigation water usage by 12-35%, a decrease in labor requirements by up to 60%, and the potential for higher net returns while achieving yields comparable to those of transplanted rice (Kumar and Ladha, 2011) [7]. Furthermore, DSR is characterized by a shorter growth duration, lower labor requirement, reduced water consumption (Bhushan *et al*., 2007) [8], and diminished methane emissions (Wassmann *et al*., 2004) [10]. However, despite its numerous advantages, the issue of weed management poses a significant challenge to the successful implementation of dry direct seeded rice in South Asia (Kumar and Ladha, 2011; Rao *et al*., 2007; Singh *et al*., 2008) [7, 11, 13]. Controlling weeds in dry DSR is more complex than in conventional tillage-transplanted rice (CT-TPR), as weeds tend to emerge simultaneously with the rice seedlings in dry DSR, which are less competitive compared to the 30-35 day old

seedlings used in CT-TPR. Additionally, the initial flooding employed in CT-TPR helps in weed suppression, a benefit that is absent in dry DSR (Kumar and Ladha, 2011) [7]. In light of these challenges, a weed management package has been developed for upland rice to evaluate the effectiveness of various weed control practices under the conditions prevalent in Tripura.

Materials and Methods

The field experiment was carried out in the villages of South Tripura district during the kharif seasons of 2013-2014 and 2014-2015 to investigate the impact of various weed management practices on direct seeded upland rice under the conditions prevalent in Tripura. The agricultural farm is located at approximately 22°57' to 23°45' N latitude and 91°19' to 91°53' E longitude, with an average elevation of 120 meters above sea level. This farm is situated within the Mid Tropical Plain zone (NEH-6) of Tripura. The experimental site lies in the semi-arid and sub-humid lateritic belt of the South Tripura District. The soil in the experimental field is characterized as sandy loam, exhibiting low fertility and an acidic reaction. During the crop growing period from June 2013 to March 2014, the average maximum and minimum temperatures ranged from 25.2°C to 34.2°C and 10.1°C to 25.3°C, respectively, in the first year, while in the second year, they ranged from 25.8°C to 35.9°C and 12.2°C to 25.4°C. Additionally, fluctuations in relative humidity were noted during the cropping seasons of 2013-14 and 2014-15, with values ranging from 55% to 86% in 2013-14 and from 72% to 90% in 2014-15. The South-West monsoon typically begins in South Tripura around mid-June and lasts upto October, often accompanied by intermittent dry spells. Over 80% of the total annual rainfall occurs during the monsoon months (June to September). The total rainfall recorded during the rice growing season was 1156.1 mm in 2013 and 1461.8 mm in 2014.

The field experiment was conducted using a randomized block design that included twelve treatments and three replications. Different treatments were pendimethalin @ 1.0 kg ha-1 at 2 DAS, bispyribac sodium @ 25 g ha-1 at 25 DAS, pendimethalin @ 1.0 kg ha-1 at 2 DAS+ one hand weeding at 30 DAS, pendimethalin @ 1.0 kg ha-1 at 2 DAS + bispyribac sodium @ 25 g ha-1 at 20 DAS, metsulfuron methyl+ chlorimuron ethyl (Almix) @ 4 g at 10 DAS followed by bispyribac sodium @ 25 g at 20 DAS, pyrazosulfuron ethyl @ 25 g ha-1 at 3 DAS followed by bispyribac sodium @ 25 g at 20 DAS, fenoxaprop-p-ethyl @ 60 g ha-1 + metsulfuron methyl + chlorimuron ethyl (Almix) @ 4 g ha-1 at 15 DAS, stale seed bed + smother crop (cowpea) in between two rows of rice, stale seed bed + one hand weeding at 30 DAS, sesbania (broadcast) @ 25 kg ha-1 during sowing of rice + 2,4-D @ 500 g ha-1 at 25 DAS, hand weeding at 15, 30 and 45 DAS, weedy check were assigned in a randomized block design replicated thrice. Rice variety NDR-97 was used for the experimental purpose. The upland rice was fertilized as per recommended package of practices in Tripura. Five tonnes of Farm Yard Manure were applied at the time of field preparation for both the crop. Chemical fertilizers were applied to meet 60 kg nitrogen in the form of urea, 40 kg phosphorus in the form of single superphosphate and 40 kg potassium in the form of muriate of potash in the rice.

Weed assessments were conducted at various growth stages (15, 30, 60 days, and at harvest) by randomly placing quadrats across three locations within each plot to determine the average weed count. Samples collected from each quadrat were categorized into grasses, broad-leaved weeds, and sedges, then dried and weighed. The dry matter of weeds was reported in grams per square meter for each category. Additionally, data regarding growth parameters, yield attributes, and overall rice yield were recorded. The economic analysis of various weed management strategies was also performed.

The experimental data pertaining to each characteristic of crops and weeds were subjected to statistical analysis using the technique of "Analysis of Variance." The significance of the results was evaluated through the variance ratio, specifically at the 5% level of significance, as outlined by Gomez and Gomez (2010) [5]. The tables include the standard error of means (S.Em.±), the critical differences (C.D.) for comparing mean differences, and the coefficient of variability (C.V.).

Results and Discussion

Weed flora and dryweight of weeds

The prevalent weed species identified in the experimental field included *Amaranthus viridis*, *Hedyotis corymbosa*, *Spilanthes acmella*, *Ludwigia parviflora*, *Cleome rutidosperma*, and *Malvestrum coromondalianeum* among the broadleaf weeds, *Digitaria sanguinalis* among the grasses, and *Cyperus iria* among the sedges. A similar composition of weed flora in direct-seeded rice has been documented by Duary *et al*. (2005) [2], Duary and Mukherjee (2013) [3], and Duary *et al*. (2016) [4]. The impact of various weed management strategies on the dry weight of grasses, broadleaf weeds, sedges, and total weed biomass exhibited highly significant differences at 60 days after seeding, as presented in Table 1.

Table 1: Dry weight of grasses, broad leaved, sedges and total weed at 60 DAS

Treatment	Weed dry weight (gm^{-2})							
	Grasses		Broad leaved		Sedges		Total weed	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Pendimethalin @ 1.0 kg ha^{-1} at 2 DAS (T_1)	76.91	72.02	39.49	36.45	29.17	26.15	145.57	134.61
Bispyribac sodium @25 g ha^{-1} at 20 DAS (T_2)	95.69	91.08	43.90	40.72	9.09	8.49	148.67	140.28
Pendimethalin @ 1.0 kg ha^{-1} + one hand weeding at 30 DAS (T_3)	28.39	23.21	23.55	20.40	9.39	6.49	61.33	50.10
Pendimethalin @ 1.0 kg ha^{-1} at 2 DAS + bispyribac sodium at 25 g ha^{-1} at 20 DAS (T_4)	29.85	23.84	26.01	20.50	9.58	7.48	65.44	51.82
Metsulfuron + chlorimuron (Almix) @ 4 g at 10 DAS followed by bispyribac sodium @ 25 g at 20 DAS (T_5)	88.81	84.29	43.33	40.55	8.89	7.71	141.03	132.55
Pyrazosulfuron ethyl @ 25 g ha^{-1} at 3 DAS followed by bispyribac sodium @ 25 g at 20 DAS (T_6)	78.70	73.94	37.39	34.65	16.77	14.08	132.87	122.67
Fenoxaprop @ 60 g ha^{-1} + metsulfuron + chlorimuron (Almix) @ 4 g ha^{-1} at 15 DAS) (T_7)	82.44	77.88	40.74	37.34	15.90	12.85	139.08	128.07
Stale seed bed + smother crop (cowpea) (T_8)	117.16	111.51	40.44	36.94	30.40	27.72	188.00	176.17
Stale seed bed + one hand weeding at 30 DAS (T_9)	92.95	88.03	41.89	38.38	23.76	21.19	158.60	147.60
Sesbania (broadcast) + 2,4-D @ 500 g ha^{-1} at 25 DAS (T_{10})	113.14	108.87	37.18	33.88	29.76	27.30	180.08	170.05
Hand weeding at 15, 30 and 45 DAS (T_{11})	24.89	20.12	18.99	15.63	5.14	2.84	49.02	38.59
Weedy check (T_{12})	141.09	136.27	67.67	64.66	42.81	40.51	251.57	241.44
S.Em (±)	2.64	2.61	1.42	1.38	1.15	1.14	2.82	3.05
CD(P=0.05)	7.76	7.66	4.16	4.05	3.37	3.35	8.26	8.96
CV (%)	5.66	5.96	6.41	6.83	10.37	11.70	3.53	4.14

There were no significant changes observed in the dry weight of grasses, broadleaved plants, sedges, and total weeds over the two-year period. The data clearly indicates that, in both years, the dry weight of weeds, including grasses, broadleaved, sedges, and total weeds, was highest in the weedy check (T12) compared to the other treatments evaluated (Table 1). The lowest dry weight was noted in the treatment involving hand weeding conducted three times at 15, 30, and 45 days after sowing (DAS) (T11), which was closely followed by the treatments of pendimethalin combined with one hand weeding (T3) and pendimethalin combined with bispyribac sodium (T4). These results align with the findings reported by Duary *et al*. (2005) [2] and Bhurer *et al*. (2013) [1].

Effect of weed management practices on yield and economics

Yield and economics of rice as affected by different weed management practices are given in Table 2.

Table 2: Yield and economics of rice

Treatments	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Net return (Rs. ha^{-1})		Return rupee^{-1} invested	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Pendimethalin @ 1.0 kg ha^{-1} at 2 DAS (T_1)	2.15	2.36	3.89	4.21	14297	1.55	1.55	1.70
Bispyribac sodium @25 g ha^{-1} at 20 DAS(T_2)	2.21	2.26	3.65	4.22	11830	1.49	1.49	1.54
Pendimethalin @ 1.0 kg ha^{-1} + one hand weeding at 30 DAS (T_3)	3.30	3.59	5.03	5.28	25573	1.81	1.81	1.96
Pendimethalin @ 1.0 kg ha^{-1} at 2 DAS + bispyribac sodium at 25 g ha^{-1} at 20 DAS (T_4)	3.26	3.41	4.87	5.17	26010	2.02	2.02	2.11
Metsulfuron + chlorimuron (Almix) @ 4 g at 10 DAS followed by bispyribac sodium @ 25 g at 20 DAS (T_5)	2.49	2.65	3.72	4.65	16542	1.60	1.60	1.73
Pyrazosulfuron ethyl @ 25 g ha^{-1} at 3 DAS followed by bispyribac sodium @ 25 g at 20 DAS (T_6)	2.71	2.80	4.04	4.81	18490	1.73	1.73	1.82
Fenoxaprop @ 60 g ha^{-1} + metsulfuron + chlorimuron (Almix) @ 4 g ha^{-1} at 15 DAS) (T_7)	1.89	1.98	3.82	3.98	9188	1.39	1.39	1.45
Stale seed bed + smother crop (cowpea) (T_8)	1.86	2.01	3.79	4.01	6613	1.19	1.19	1.28
Stale seed bed + one hand weeding at 30 DAS (T_9)	1.86	2.10	3.71	3.89	5203	1.07	1.07	1.20
Sesbania (broadcast) + 2,4-D @ 500 g ha^{-1} at 25 DAS (T_{10})	1.81	1.93	3.75	3.74	9083	1.38	1.38	1.46
Hand weeding at 15, 30 and 45 DAS (T_{11})	3.45	3.60	5.16	5.43	19713	1.54	1.54	1.61
Weedy check (T_{12})	0.58	0.74	2.90	2.80	-3450	0.66	0.66	0.78
S.Em (±)	0.11	0.13	0.22	0.17	1783	0.07	0.07	0.08
CD (P=0.05)	0.34	0.37	0.64	0.49	5230	0.22	0.22	0.23
CV (%)	8.62	8.93	9.40	6.70	23.29	8.39	8.39	8.95

The data presented in Table 2 clearly indicated that various weed management practices positively influenced the yield and economics of upland rice. Among the treatments evaluated, the method of hand weeding conducted three times at 15, 30, and 45 days after sowing (T_{11}) achieved the highest grain and straw yields over both years. This approach was comparable to the treatments involving pendimethalin combined with one hand weeding (T_3) and pendimethalin paired with bispyribac sodium (T_4). The effective and timely implementation of weed management strategies in these treatments led to a reduction in weed dry weight, thereby providing the crop with adequate space, light, nutrients, and moisture, ultimately resulting in increased grain and straw yields.

The findings of the current study indicated that the profitability from rice cultivation was significantly influenced by the weed management strategies implemented. The combination of pendimethalin at a rate of 1.0 kg ha^{-1} applied at 2 days after sowing (DAS) along with bispyribac sodium at 25 g ha^{-1} applied at 20 DAS (T_4) yielded the highest net returns, amounting to Rs. 23847/- in the first year and Rs. 26010/- in the second year, as well as the best return per rupee invested (2.02 and 2.11) across both years, establishing it as the most profitable weed management approach. The treatment involving pendimethalin @ 1.0 kg ha^{-1} combined with one hand weeding at 30 DAS (T_3) produced net returns of Rs. 21427/- and Rs. 25573/- in the first and second years, respectively, making it the second most effective treatment. This success can be attributed to the higher grain and straw yields achieved with these methods. A similar conclusion was drawn by Yakadri *et al*. in 2016 [14]. Although the highest rice yield and gross returns were observed with hand weeding at 15, 30, and 45 DAS (T_{11}), the analysis of net income and return per rupee invested indicated that this method was less profitable compared to the treatments involving pendimethalin at 1.0 kg ha^{-1} at 2 DAS combined with bispyribac sodium @25 g ha^{-1} at 20 DAS (T_4) and pendimethalin at 1.0 kg ha^{-1} with one manual weeding at 30 DAS (T_3). This suggests that conducting three hand weedings throughout the crop's growth period may be economically unfeasible and unnecessary. The net income was negative in the weedy check treatment due to increased competition between rice and weeds, which adversely affected crop growth and resulted in lower grain and straw yields. This further underscores the critical role of effective weed management in achieving profitable rice production. This aligns with the findings of Prashanth *et al*. in 2016, [9] who noted that the lowest net returns and benefit-cost ratio were associated with the unweeded check in rice. Additionally, Kashid *et al.* in 2015 [6] reported that the highest net returns and return per rupee invested were achieved through the pre-emergence application of herbicides in conjunction with one hand.

Conclusion

A cropping system that is economically sustainable is generally embraced by farmers. The current study demonstrated that the growth and yield of direct-seeded upland rice were significantly affected by various weed management strategies. Among the treatments evaluated, the combination of pendimethalin and bispyribac sodium (T4) yielded the highest net returns and the best return on investment, establishing it as the most profitable weed management approach for direct-seeded aerobic rice in the upland conditions of Tripura.

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