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Influence of sequential application of herbicides on growth and yield of wet-direct seeded rice in *Kharif* season

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Abstract
Sustaining rice yield is crucial for the country's GDP, but the diverse weed flora poses a significant biotic threat to maintaining yields in the Direct Seeded Rice (DSR) system. From the germination of crop seedlings to panicle initiation, the crop experiences severe competition for resources with rapidly growing weeds leading to substantial yield losses. In such scenarios sequential spraying of herbicides will provide a broad spectrum of weed control. A field trial was performed on clay loamy soils of ICAR- Indian Institute of Rice Research, Rajendranagar, Hyderabad during *kharif* season of 2021 to assess the performance of MTU-1156 as persuaded by various weed management practices in wet-direct seeded rice. Amongst the weed management practices, hand weeding resulted in utmost plant height (118.0 cm), dry matter (14119.0 kg ha^{-1}), LAI (4.36), grain yield (6463 kg ha^{-1}) and straw yield (7589 kg ha^{-1}) and it was in similarity to pretilachlor 50EC @ 500 g a.i. ha^{-1} as pre-emergence (PE) within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as post emergence (PoE) at 15-20 DAS (T_9), pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* triafamone 20% + ethoxysulfuron 10%WDG @ 67.5 g a.i. ha^{-1} at 2-4 leaf stage of weeds (T_{10}) and pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* florpyrauxifen-benzyl (2%) + cyhalofop-butyl (10%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15-20 DAS (T_8). The increment in plant height with weed management practices was 11.3% to 25.1%, dry weight was 41.0 to 49.8%, grain yield was 45.6 to 54.0% and straw yield was 37.3 to 46.0%, over the weedy check. Sequential application of pretilachlor as PE and PoE application of herbicide combinations performed better in comparison to pyrazosulfuron-ethyl as PE and PoE application of herbicide combinations.

Keywords: Wet-direct seeded rice, sequential application, weed management, growth parameters, yield parameters

1. Introduction
Rice is extensively grown staple food crop of the globe and more than half of the population subsists on it. Rice output climbed globally from 496.5 mt in 2016-17 to 506.3 million tonnes in 2018-19 [6]. India is the second most producer of rice globally, with an annual production of 137.8 mt from an area of 46.4 m ha [5]. The *kharif* season alone contributes to 82% of rice production.

In recent years, paddy production systems have been undergoing significant changes, with one notable shift from traditional transplanted rice to direct-seeded rice. This change is driven by rising costs and shortage of labour during peak agricultural periods. An alternative, resource and labour saving method for stand establishment is the sowing of sprouted rice seeds in wet puddled soils known as wet-direct seeded rice (Wet-DSR), which offers a viable solution to the challenges posed by traditional transplanting. When appropriate management practices are followed, the yield of Wet-DSR will be on par with transplanted rice. Furthermore, Wet-DSR increases water productivity by 0.3 to 0.4 kg rice m^{-3} water [10]. Weeds pose a more significant challenge in DSR compared to transplanted rice, primarily due to the lack of the crop seedling size advantage and the absence of standing water to suppress the weed germination and growth [1]. This can lead to decrease in crop yield by up to 90% or even cause crop failure because of unfavorable soil conditions [12]. The shift to direct-seeded rice has led to changes in the relative abundance of weed species in rice fields. Notably, species such as *Echinochloa* spp., *Ischaemum*

rugosum, *Cyperus difformis*, and *Fimbristylis miliacea* have become more prevalent, as they are well-suited to the conditions associated with direct-seeded rice. [13, 16].

Hand weeding twice ensures a weed free environment during early stages of rice growth which provides competition free environment for the crop to access natural and applied resources thereby promoting quicker crop growth and smothering of weed at later stages [11]. While, hand weeding is an efficient way of weed control, it is extremely labour intensive. As a result, chemical control has become the most widely used and dependable approach for managing weeds in rice cultivation. Herbicides such as butachlor and anilofos are generally used for efficient weed management in transplanted rice. However, these herbicides have not proven effective in limiting weed growth in direct-seeded rice, as the weed intensity and diversity particularly with sedges tend to be much higher. Pre-emergence herbicides alone may not effectively control a broad range of weed species, as weeds emerge at various growth stages. Therefore, a more effective approach could be the sequential spraying of pre-emergence and post-emergence herbicides [18]. Keeping the above factors into consideration, the current trial was performed to analyze the effectiveness of various weed control methods on the growth and yield of wet-direct seeded rice.

2. Materials and Methods

The field trial was performed at ICAR-Indian Institute of Rice Research (ICAR-IIRR) Farm Rajendranagar, Hyderabad, Telengana during *Kharif*, 2021. The experimental soil was clay loamy with alkaline pH, normal EC, low in organic carbon, low in N, high in P and low in K. Pre-germinated seeds of Tarangini (MTU-1156) were line sown in the field at the rate of 25 kg ha^{-1} with spacing of 20 x 10 cm in well puddled and levelled soil. The recommended dose of nutrients of 120 kg N, 26 kg P and 48 kg K ha^{-1} were supplied through urea, single super phosphate and murate of potash, respectively to all the plots. Nitrogen was applied in two splits. Entire dose of phosphorous and potassium were applied as basal at the time of sowing. Nitrogen was applied in two equal splits as top dressing at active tillering and at panicle initiation stage of the crop. All other necessary agronomic and plant protection strategies were implemented as per the recommendations of ICAR-IIRR. Five healthy plants were tagged and all the biometrics were recorded from the same plant and at harvest entire net plots (14.71 m^{-2} each) were harvested and measured for grain and straw yields. The data recorded on various parameters of crop was analyzed statistically following the analysis of variance for randomized block design. The treatment details were given below which were replicated thrice.

Table 1: Weed management practices implemented in Wet Direct Seeded Rice during *kharif* 2021

	Treatment details
T_1	Unweeded check (Control).
T_2	Hand weeding at 20 and 40 DAS.
T_3	Pyrazosulfuron-ethyl 70%WDG @ 21 g a.i. ha^{-1} as PE 3 DAS *fb* bispyribac-sodium @ 25 g a.i. ha^{-1} as PoE at 15-20DAS
T_4	Pyrazosulfuron-ethyl 70%WDG @ 21 g a.i. ha^{-1} as PE within 3 DAS *fb* florpyrauxifen-benzyl (2%) + cyhalofop-butyl (10%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15-20 DAS.
T_5	Pyrazosulfuron-ethyl 70%WDG @ 21 g a.i. ha^{-1} as PE 3 DAS *fb* penoxsulam (1.02%) + cyhalofop-butyl (5.1%) ready mix @150 g a.i. ha^{-1} as PoE at 15- 20 DAS.
T_6	Pyrazosulfuron-ethyl 70%WDG @ 21 g a.i. ha^{-1} as PE within 3 DAS *fb* triafamone 20% + ethoxysulfuron 10%WDG @ 67.5 g a.i. ha^{-1} at 2-4 leaf stage of weeds.
T_7	Pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* bispyribac-sodium@ 25 g a.i. ha^{-1} as PoE at 15-20 DAS.
T_8	Pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* florpyrauxifen-benzyl (2%) + cyhalofop- butyl (10%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15-20 DAS.
T_9	Pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS.
T_{10}	Pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* triafamone 20% + ethoxysulfuron 10%WDG @ 67.5 g a.i. ha^{-1} at 2-4 leaf stage of weeds.

3. Results and Discussion

Weed flora

Echinochloa colonum, *Echinochloa crus-galli*, *Cyperus difformis*, *Cyperus iria*, *Fimbristylis miliacea*, *Ammania baccifera*, *Eclipta alba* and *Marsilea quadrifolia* were the dominant weeds observed at ICAR-IIRR.

Growth parameters (Table-2)

Plant height (118.0 cm) at harvest was found to be significantly highest with hand weeding twice at 20 and 40 DAS (T_2) and it was 25.1% higher than the weedy check. However, it was found to be on parity with T_9, T_{10} and T_8. The reduced competition for nutrients, water, space and light throughout the crop growth period due to hand weeding and sequential spraying of herbicides in remaining treatments resulted in enhanced plant height, over the weedy check (T_1). Similar findings were published by Yogananda *et al.* [17] with hand weeding and sequential application of herbicides.

Dry matter accumulation at harvest was found to be lowest (7096 kg ha^{-1}) with weedy check due to heavy weed infestation, which in turn reduced the availability of growth resources resulting in lower number of tillers m^{-2}, number and size of the leaves led to reduced dry matter production of rice. Increment in drymatter accumulation was 41.0-49.8% higher with weed management techniques over the control treatment. Maximum dry matter accumulation (14119 kg ha^{-1}) was noticed with hand weeding treatment (T_2) and it was comparable to T_9, T_{10} and T_8. The results were in similarity with findings of Choudhary *et al.* (2018) [2].

Similarly, the leaf area index (LAI) was significantly highest (4.36) with hand weeding (T_2). In case of chemical treatments, pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS (T_9) has significantly higher LAI and it was on par with T_{10} and T_8 treatment. The highest LAI recorded may be attributed to appropriate weed control at the germination stage from pre-emergence herbicides and also at later stages due to combination of herbicides resulted in effective utilization of moisture, nutrients and light that helped in the production of greater amount of photosynthates there by producing larger leaf area of rice. Lowest LAI (1.61) was observed from weedy check (T_1).

The highest number of tillers per m^{-2} (304) were resulted with hand weeding treatment (T_2). Among the chemical treatments, pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS (T_9) produced the maximum number of tillers (290) which was statistically similar to T_5 and T_6. The increase in tillers ranged from 29.2% to 51.3% with weed control practices in comparison to the weedy check (148). Similar results were reported by Dhaker *et al*. (2022) [3] with hand weeding and sequential application of herbicides.

Table 2: Growth parameters of Wet-Direct Seeded Rice as affected by various weed management practices

Treatment	Plant height (cm)	Dry matter (kg ha^{-1})	LAI	Number of tillers m^{-2}
T_1	88.3	7096.0	1.61	148.0
T_2	118.0	14119.0	4.36	304.0
T_3	99.6	12032.0	2.66	209.0
T_4	105.2	12563.0	3.32	243.0
T_5	107.7	12680.0	3.54	252.0
T_6	106.8	12589.0	3.45	250.0
T_7	101.5	12405.0	3.09	225.0
T_8	113.3	13277.0	3.78	263.0
T_9	116.5	13845.0	4.11	290.0
T_{10}	114.2	13474.0	4.09	272.0
S.Em ±	2.96	392.12	0.19	13.58
CD (p=0.05)	9.46	1254.39	0.6	43.45

Yield parameters and yield (Table-3)

Yield attributes *viz*., number of panicles m^{-2}, number of grains $panile^{-1}$ and filled grains $panicle^{-1}$ of rice were significantly varied with weed management practices and maximum yield attributes (287, 134 and 118 respectively) were recorded with two hand weeding's (T_2) and it was comparable to chemical management treatments of T_9, T_{10} and T_8. This might be due to effective and prolonged control of weeds, enhanced weed control efficiency as well as dry matter production of rice that lead to increased nutrient uptake of rice with more sink capacity. Test weight was not significantly influenced by the weed management practices. While the minimum yield attributes (139, 105 & 89.3 respectively) were observed with weedy check (T_1) due to more competition of the weeds with the crop plants [8].

All the weed management treatments resulted in significantly utmost grain yield over the weedy check. Weedy check (2967 kg ha^{-1}) showed 54.0% decrease in grain yield due to intense competition offered by uncontrolled growth of weeds for the nutrients, soil moisture, space and light. Among the weed control treatments, significantly utmost grain yield (6463 kg ha^{-1}) was obtained with hand weeding (T_2). With respect to herbicide treatments, utmost grain yield (6306.0 kg ha^{-1}) was recorded with pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS (T_9) and it was on parity with remaining herbicide applied treatments except pyrazosulfuron-ethyl 70%WDG @ 21 g a.i. ha^{-1} as PE 3 DAS *fb* bispyribac-sodium @ 25 g a.i. ha^{-1} as PoE at 15-20 DAS (T_3). The increment in grain yield with weed management treatments was 45.6-54.0% over the control treatment (T_1). The enhancement in grain yield was attributed due to the reduced density and biomass of weeds at all stages of crop growth, which resulted in increased biomass of rice and enhanced yield parameters, *viz*., number of panicles m^{-2}, number of grains $panile^{-1}$ and filled grains $panicle^{-1}$ and 100-seed weight [17]. These results were comparable to the findings of Dhanapal *et al*. (2018) [4] and Sunil *et al*. (2010) [14], who reported 50–75% enhancemet in grain yield of rice due to sequential spraying of herbicides as compared to unweeded check. The combination of herbicides effectively reduced competition for moisture, space, light, and nutrients between the crop and weeds, leading to better weed suppression and higher yields which was also observed by Upasani *et al*. (2012) [15]. (Fig 1)

Significantly higher straw yield (7589 kg ha^{-1}) was noticed with hand weeding at 20 and 40 DAS (T_2). This was in conformity with the findings of Lipishmita (2016) [7]. Among the chemical control treatments, highest straw yield (7572 kg ha^{-1}) was recorded with pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS (T_9) and it was on parity with treatments T_{10}, T_8 and T_5. The increment in straw yield among weed management practices was 37.3% to 46.0%, over the control treatment (4095 kg ha^{-1}). Sequential spraying of herbicides and combinations resulted in broad spectrum of weed control for a longer period resulting in reduced crop-weed competition and better growth parameters resulting in higher straw yield [9]. (Fig 1)

Table 3: Yield parameters and yield of Wet-Direct Seeded Rice as affected by various weed management practices

Treatment	No of Panicles m^{-2}	Total no of grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
T_1	139.0	105.0	89.3	19.9	2967.0	4095.0	41.9
T_2	287.0	134.0	118.0	22.5	6463.0	7589.0	46.0
T_3	200.0	117.0	101.0	21.4	5462.0	6537.0	45.6
T_4	229.0	120.3	103.6	21.0	5872.0	6746.0	46.5
T_5	237.0	121.0	106.0	20.4	5921.0	6791.0	46.6
T_6	235.0	120.6	105.6	20.3	5879.0	6762.0	46.5
T_7	219.0	118.6	103.0	21.2	5806.0	6599.0	46.8
T_8	254.0	125.3	108.3	20.1	6113.0	7200.0	45.9
T_9	278.0	127.3	110.0	22.5	6306.0	7572.0	45.4
T_{10}	258.0	126.0	111.3	21.0	6166.0	7316.0	45.7
S.Em ±	12.08	3.63	3.46	19.89	166.32	247.06	1.19
CD (p=0.05)	38.63	11.62	11.08	NS	532.04	790.34	3.81

Significantly maximum harvest index (HI) of 46.8 was reported from pretilachlor 50EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* bispyribac sodium@ 25 g a.i. ha^{-1} as PoE at 15-20 DAS (T_7) and it was comparable to remaining treatments with the only exception being weedy check (T_1) which has attained lowest HI (41.9).

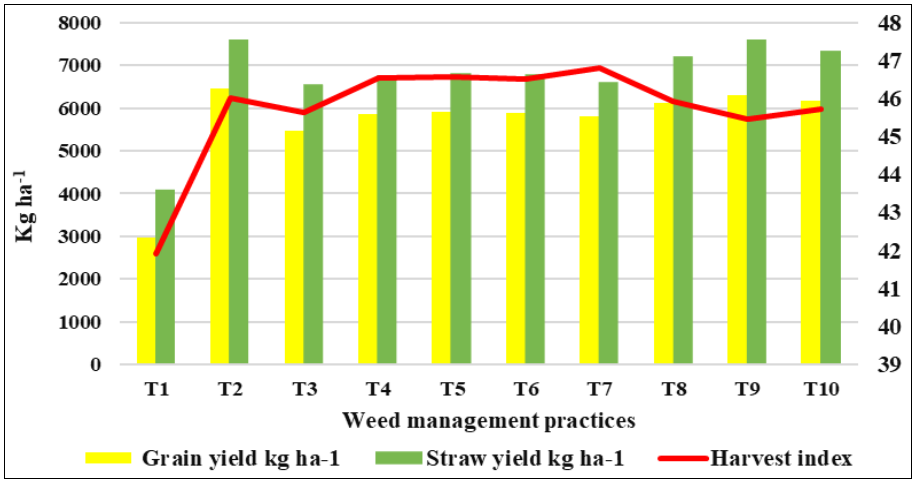

Fig 1: Influence of weed management practices on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}) and harvest index of Wet-Direct Seeded Rice

Conclusion

All the weed management practices enhanced the growth and yield attributes of rice. Hand weeding found to be best, however pretilachlor 50 EC @ 500 g a.i. ha^{-1} as PE within 3 DAS *fb* penoxsulam (1.02%) + cyhalofop- butyl (5.1%) ready mix @ 150 g a.i. ha^{-1} as PoE at 15- 20 DAS performed similarly. Pretilachlor as pre-emergence application along with different post emergence test herbicides or combinations except bispyribac-sodium was found superior and recorded highest grain yield over pyrazosulfuron-ethyl as pre-emergence herbicide along with all the post emergence test herbicides or combinations. Amongst all the post emergence herbicides or combinations penoxsulam + cyhalofop-butyl was found statistically superior and bispyribac-sodium was found to be least effective for growth parameters and yield.

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