Original Research Article

Impact of Integrated Weed Management Strategies on Weed Density and Biomass in Rice (*Oryza sativa* L.)

Abstract

To assess the effectiveness of various weed management practices on controlling weed density and dry weight in rice (*Oryza sativa* L.). A field experiment was carried out during 2022 and 2023 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, in the Indo-Gangetic plains In Randomized Block Design (RBD) with 12 treatments, each replicated thrice. The treatments included a weedy check, a weed-free condition, farmer's practice of one hand weeding at 40 days after transplanting (DAT), Pyrazosulfuron applied at 150 g ai ha^{-1} as a pre-emergence herbicide, Pyrazosulfuron 150 gm ai ha^{-1} followed by one hand weeding at 40 DAT, Bispyribac sodium at 25 g ai ha^{-1} applied 15 days after transplanting as a post-emergence herbicide, Bispyribac sodium at 25 g ai ha^{-1} followed by one hand weeding at 40 DAT, Ethoxy sulfuron applied at 20 g ai ha^{-1} as a pre-emergence herbicide, Ethoxy sulfuron 20 gm active ingredient per hectare followed by one hand weeding at 40 DAT, Penoxsulam applied at 22 g ai ha^{-1}as a post-emergence herbicide, Penoxsulam 22 g active ingredient per hectare followed by one hand weeding, and a combination of Pyrazosulfuron 150 gm active ingredient per hectare as pre-emergence, followed by Penoxsulam 22 g ai ha^{-1} as post-emergence, and one hand weeding at 40 DAT. Weed density and dry weight were recorded at 30, 60, and 90 days after transplanting using quadrat sampling. The weed-free treatment consistently exhibited the lowest weed density and dry weight across both years, whereas the untreated weedy check resulted in the highest weed density and dry weight throughout the study. Among the herbicide treatments, the combination of Pyrazosulfuron and Penoxsulam with one hand weeding was found to be the most effective in significantly reducing weed density and dry weight.

Keywords: *Rice, Pyrazosulfuron, Bispyribac sodium, weed density, Integrated control*

Introduction

Rice (*Oryza sativa* L.) stands as one of the most significant staple crop worldwide, providing sustenance for about 60% of the global population. As a critical food grain, rice plays a pivotal role in food security, particularly in Asia, where more than 90% of the world's rice is produced and consumed. In India, rice is not just a food source but also a foundation for the economy, providing income and employment to millions of households. India ranks as the second-largest producer and consumer of rice globally, after China. With rice accounting for 43% of total food grain production and 46% of total cereal production in India, its significance in the Indian agricultural landscape is undeniable. In 2017, rice was cultivated over an area of 43.57 million hectares, producing 104.32 million tonnes with a productivity of approximately 2.98 tonnes per hectare [1]. Uttar Pradesh, the second-largest rice-producing state after West Bengal, contributed significantly to this total, with 58.6 lakh hectares under cultivation, producing 144.1 lakh tonnes of rice with an average productivity of 2460 kg ha^{-1}.

As demand for rice continues to grow, it is estimated that India will need to produce 140 million tonnes by 2025 to maintain self-sufficiency and meet future food demands. Achieving this requires enhancing rice productivity by at least 3% annually, a target complicated by several agronomic challenges, including weed infestations, fatigued natural resources, declining water tables, labor shortages, and escalating fuel prices. Among these, weed infestation poses one of the most significant threats to rice production. Weeds compete with rice for essential resources such as nutrients, light, water, and space, causing severe yield losses. In India, yield losses due to weed infestations in transplanted rice have been reported to range from 12% to 51% [2]. Weeds, by virtue of their rapid growth and competitive nature, reduce the potential productivity of rice crops, particularly during the vegetative phase, which is the most critical period for crop-weed competition [3].

Weeds account for more agricultural losses than any other pest category, responsible for about 45% of total annual losses of agricultural produce in India, surpassing losses caused by insects (30%), diseases (20%), and other pests (5%) [4]. This substantial impact underscores the importance of effective weed management strategies in rice cultivation. Traditional weed control methods, such as manual weeding, though effective, are labor-intensive and cost-prohibitive, especially on large scales. In the context of India, where labor shortages and high wages are increasingly problematic, alternative weed management strategies are necessary. Chemical weed control, particularly the use of herbicides, has emerged as a cost-effective and efficient solution for managing weeds in transplanted rice. Herbicides, especially pre-emergence applications, are commonly used to control weeds during the initial stages of crop growth. However, effective weed management requires maintaining weed populations below a critical threshold throughout the growing season, particularly during the periods of severe weed competition. The efficacy of herbicides depends largely on water management practices in rice fields, as standing water suppresses weed germination and growth, providing a competitive advantage to the rice crop. While pre-emergence herbicides are crucial during the initial phase, post-emergence herbicides are equally important for controlling weeds that escape early treatment and continue to grow alongside the crop [5].

Over-reliance on chemical herbicides poses several challenges, including environmental concerns, herbicide resistance, and changes in weed flora. Continuous use of the particular herbicide can lead to the evolution of resistant weed species, which further complicates weed management in rice fields. Furthermore, many herbicides target only a specific type of weeds, such as grasses, leaving other weed groups like sedges and broad-leaved weeds unchecked. This necessitates an integrated weed management (IWM) approach that combines chemical, cultural, mechanical, and biological weed control methods to achieve long-term, sustainable weed management. Integrated weed management (IWM) systems are designed to optimize the effectiveness of weed control while reducing the negative impacts associated with any single method. IWM combines multiple strategies, such as the use of herbicides with manual or mechanical weeding, crop rotation, and water management, to provide season-long control of a broad spectrum of weed species. In rice cultivation, IWM has proven to be particularly effective, as it reduces reliance on labor-intensive methods like manual weeding and mitigates the risks associated with continuous herbicide use. The integration of manual weeding with chemical herbicides offers a synergistic effect, as herbicides control the bulk of the weed population, while manual weeding removes any surviving weeds that escape herbicidal action. This approach not only reduces weed density but also minimizes weed biomass, leading to higher yields and more efficient use of inputs. Weed management practices in rice have evolved significantly in recent years, with the development of new herbicides and more efficient application techniques. These advancements have focused on improving the precision and timing of herbicide application to minimize crop injury while maximizing weed control. Additionally, innovations in mechanical weeders, such as rice transplanters with built-in weeding attachments, have further reduced labor requirements and improved weed control efficiency. The integration of modern agronomic tools with traditional knowledge offers a comprehensive solution for weed management in rice cultivation, ensuring sustainable productivity gains in the future.

Post-emergence herbicides like Bispyribac sodium have been shown to effectively control *Echinocloa crusgalli* (barnyard grass), one of the most problematic weed species in rice fields [6]. Against sedges when applied at both 15 and 25 days after sowing (DAS), further supporting the use of post-emergence herbicides in IWM systems. However, even with these advancements, no single method can provide season-long, sustainable weed control under all conditions. This has led to the widespread adoption of IWM practices in many rice-growing regions, particularly in Asia, where labor shortages and rising herbicide prices have driven the need for more efficient and economical weed management systems. In

India, rice cultivation practices vary widely depending on geographic location, climatic conditions, and available resources. The eastern region of the country, which covers the largest rice-growing area, faces unique challenges related to weed infestation, water management, and labor availability. Transplanted rice, the dominant method of rice cultivation, is particularly susceptible to weed competition, especially from barnyard grass, sedges, and broad-leaved weeds. Weed infestations are typically more severe in transplanted rice than in other rice establishment methods, such as direct-seeded rice or upland rice. This is because the puddled conditions in transplanted rice fields create an ideal environment for both crop and weed growth. Recent studies have reported yield losses of up to 34% in transplanted rice, 45% in direct-seeded rice, and 67% in upland rice due to unchecked weed infestations [7]. These findings highlight the importance of effective weed management strategies in maintaining rice productivity, particularly in areas where labor shortages and high production costs limit the feasibility of traditional weed control methods. The integration of pre-emergence and post-emergence herbicides with manual weeding offers a practical solution for controlling a broad range of weed species, while also addressing the labor and cost constraints associated with rice cultivation.

Material and Method

The field experiment was carried at the Crop Research Centre (CRC) farm of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, during years, 2022 and 2023, located in the Indo-Gangetic plains of Western Uttar Pradesh. Situated about 70 km from Delhi, the experimental site lies at 29°40′ N latitude and 77°42′ E longitude, with an elevation of 237 meters above mean sea level. The climate of the region is semi-arid and sub-tropical, marked by hot summers and cold winters. In both years, temperature patterns were similar, with a steady decline in both minimum and maximum temperatures starting from mid-November and reaching their lowest in December and January before rising again in February and peaking by late March. Occasional frost was observed during late December and early January in both years. The weekly mean maximum temperature during the crop-growing season ranged from 37.6°C to 15.4°C, while the mean minimum temperature varied between 5.9°C and 20.7°C, providing a stable environment for crop growth and ensuring consistency in weather conditions for the study.

The experimental design was a Randomized Block Design (RBD) applied in both years, with 12 treatment combinations and three replications. Treatments included different weed management strategies such as the weedy check, weed-free conditions, farmer's practice of one hand weeding at 40 days after transplanting (DAT), and herbicide applications. The herbicides used included Pyrazosulfuron, Bispyribac sodium, Ethoxy sulfuron, and Penoxsulam, either applied alone or in combination with hand weeding at 40 DAT. The plots measured 5 x 4 m^2 in gross size, with a net plot size of 4.2 x 3 m^2, and rice was planted at a spacing of 20 x 10 cm. The variety used in both 2022 and 2023 was PB-1637, ensuring uniformity across the study.

Weed density was measured periodically in both years using a 1 x 1 m^2 quadrat, which was randomly placed in each plot at 30, 60, and 90 days after sowing (DAS) or at critical growth stages of rice. Weeds were counted and classified into broad-leaved weeds, sedges and grasses, with the total weed density expressed as the number of weeds per square meter. Separate data were recorded for each weed category in both years. After counting, the weeds were uprooted, cleaned, and oven-dried at 65°C for 72 hours until a constant weight was achieved. The weed dry weight was then measured using an electronic balance and recorded in grams per square meter. These measurements were taken at 30, 60 and 90 DAS during both years to evaluate the efficacy of the treatments over time.

Data from 2022 and 2023 on weed density and dry weight were statistically analysed using ANOVA through software such as SPSS. The analysis helped assess the effects of different treatments across the two years, with treatment means compared using the least significant difference (LSD) test at a 5% probability level [8]. This allowed for a comprehensive evaluation of the effectiveness of weed management strategies implemented in the two growing seasons.

Result and Discussion

Total weed density

The Data presented in (Table 1) demonstrate the significant influence of various weed management practices on total weed density at different stages of rice growth. Across both years (2022-23 and 2023-24), the weedy check treatment (T1: untreated control) consistently exhibited the highest weed density, with values ranging from 386.9 to 476.3 weeds m^{-2} at different stages, underscoring the ineffectiveness of this treatment in controlling weed populations. Conversely, the weed-free treatment (T2: maintained weed-free throughout the crop cycle) showed the lowest weed density, maintaining a consistent zero across all stages and years, reflecting its superiority in eliminating weed pressure. Among herbicide treatments, Pyrazosulfuron 150 g a.i. ha^{-1} applied pre-emergence followed by one hand weeding at 40 days after transplanting (DAT) (T5) and the combined application of Pyrazosulfuron 150 g a.i. ha^{-1} pre-emergence and Penoxsulam 22 g a.i. ha^{-1} post-emergence along with one hand weeding at 40 DAT (T12) proved to be highly effective, showing substantial reductions in weed density, with values as low as 52.1 to 63.5 m^{-2}. Other treatments, such as Bispyribac sodium @ 25 g a.i. ha^{-1} applied post-emergence at 15 DAT with one hand weeding at 40 DAT (T7) and Ethoxy sulfuron @ 20 g a.i. ha^{-1} applied pre-emergence with one hand weeding at 40 DAT (T9), also demonstrated significant control over weeds, albeit not as efficiently as the aforementioned combinations. Hand weeding alone (T3: farmer's practice of one hand weeding at 40 DAT) proved moderately effective but was outperformed by integrated herbicide treatments, which aligns with previous studies highlighting the efficacy of combining chemical and mechanical weed management approaches in rice [9], [10], [11].

Total weed dry weight

The Data shown in (Table 2) indicate the impact of different weed management practices on total weed dry weight (g m^{-2}) in rice at various growth stages across two consecutive years (2022 and 2023). The weedy check treatment (T1: untreated control) consistently exhibited the highest weed dry weight at all stages, with values increasing from 92.0 g m^{-2} at 30 DAT to 280.6 g m^{-2} at 90 DAT in 2023, emphasizing the lack of weed control. The weed-free treatment (T2: maintained weed-free throughout the crop cycle) showed a constant zero weed dry weight across both years, demonstrating the treatment's effectiveness in preventing weed growth. Among herbicide-based treatments, Pyrazosulfuron 150 g a.i. ha^{-1} applied pre-emergence followed by one hand weeding at 40 days after transplanting (DAT) (T5) and the combined treatment of Pyrazosulfuron 150 g a.i. ha^{-1} pre-emergence with Penoxsulam 22 g a.i. ha^{-1} post-emergence and one hand weeding at 40 DAT (T12) showed significantly reduced weed dry weights, with values as low as 24.5 g m^{-2} at 30 DAT in 2022 and 75.2 g m^{-2} at 90 DAT in 2023. Other treatments, such as Bispyribac sodium 25 g a.i. ha^{-1} applied post-emergence at 15 DAT combined with one hand weeding at 40 DAT (T7), and Ethoxy Sulfuron 20 g a.i. ha^{-1} applied pre-emergence with one hand weeding at 40 DAT (T9), also demonstrated effective reductions in weed dry weight, although they were less effective than the aforementioned combinations. The farmer's practice of one hand weeding at 40 DAT (T3) provided moderate control, with weed dry weights significantly higher than those under integrated treatments, which is consistent with prior research showing that combining chemical and manual weed control methods can enhance weed suppression in rice [12], [13], [14], [15]. These results underscore the importance of integrated weed management strategies, particularly the combination of pre- and post-emergence herbicides with manual weeding, for reducing weed biomass and enhancing weed control efficacy in rice fields.

Table 1 Effect of weed management practices on total weeds density (m^{-2}) in rice at different stages

	Treatments	Total weed density (m^{-2})					
		30 DAT		60 DAT		90 DAT	
		2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1	Weedy check	19.70(386.9)	20.97(438.7)	20.52(420.0)	21.85(476.3)	18.72(349.6)	19.97(397.9)
T_2	Weed free	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
T_3	Farmers practices (One hand weeding 40 DAT)	11.63(134.3)	12.38(152.3)	12.20(147.8)	12.98(167.4)	11.55(132.3)	12.31(150.5)
T_4	Pyrazosulfuron 150 g a.i. ha^{-1} (Pre emergence)	9.63(91.8)	10.26(104.2)	10.94(118.7)	11.65(134.7)	10.33(105.8)	11.02(120.5)
T_5	Pyrazosulfuron 150 g a.i. ha^{-1} (Pre emergence) + one hand weeding 40 DAT	8.72(75.1)	9.28(85.2)	9.33(86.1)	9.93(97.7)	8.70(74.7)	9.27(85.0)
T_6	Bispyribac sodium @25 g a.i. ha^{-1} 15 DAT (Post- emergence)	11.43(129.7)	12.16(146.9)	10.30(105.0)	10.95(119.0)	9.65(92.1)	10.29(104.8)
T_7	Bispyribac sodium @25 g a.i. ha^{-1} 15 DAT (Post- emergence) + one hand weeding 40 DAT	9.29(85.3)	9.89(96.8)	10.40(107.1)	11.06(121.3)	9.87(96.4)	10.52(109.7)
T_8	Ethoxy sulfuron @20g a.i. ha^{-1} (pre-emergence)	11.53(131.9)	12.27(149.5)	11.75(137.0)	12.50(155.2)	11.10(122.1)	11.83(138.9)
T_9	Ethoxy sulfuron @20g a.i. ha^{-1} (pre-emergence) + + one hand weeding 40 DAT	11.72(136.3)	12.47(154.6)	12.53(156.1)	13.35(177.1)	11.91(140.8)	12.69(160.0)
T_{10}	Penoxsulam 22 g a.i. ha^{-1} (post emergence)	10.33(105.8)	11.00(120.0)	10.97(119.3)	11.67(135.3)	10.24(103.8)	10.91(118.1)
T_{11}	Penoxsulam 22 g a.i. ha^{-1} (post emergence) + One hand weeding	7.94(62.0)	8.44(70.3)	8.70(74.7)	9.27(84.9)	8.24(66.9)	8.78(76.1)
T_{12}	Pyrazosulfuron 150 g ai.ha^{-1} (pre emergence) + Penoxsulam 22 g a.i. ha^{-1} post emergence + One hand weeding	7.29(52.1)	7.76(59.2)	7.97(62.5)	10.66(112.6)	7.54(55.9)	8.03(63.5)
	SEm+	**0.37**	**0.40**	**0.41**	**0.43**	**0.37**	**0.40**
	C.D.(P=0.05)	**1.08**	**1.14**	**1.17**	**1.24**	**1.07**	**1.15**

Original values in parenthesis. Values are square root $\sqrt{X + 1.0}$

Table 2 Effect of weed management practices on total weed dry weight (g m^{-2}) in rice at different stages

	Treatments	**Total weed dry weight (g m^{-2})**					
		30 DAT		**60 DAT**		**90 DAT**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**
T_1	Weedy check	9.64(92.0)	10.74(114.4)	13.84(190.5)	15.18(229.3)	15.35(234.7)	16.78(280.6)
T_2	Weed free	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
T_3	Farmers practices (One hand weeding 40 DAT)	7.09(49.3)	7.91(61.6)	10.09(100.9)	11.07(121.6)	10.77(115.0)	11.76(137.4)
T_4	Pyrazosulfuron 150 g a.i. ha^{-1} (Pre emergence)	6.69(43.8)	7.46(54.7)	8.23(66.7)	9.02(80.4)	8.97(79.4)	9.80(95.1)
T_5	Pyrazosulfuron 150 g a.i. ha^{-1} (Pre emergence) + one hand weeding 40 DAT	5.40(28.2)	6.02(35.2)	7.84(60.4)	8.60(72.9)	8.72(75.0)	9.52(89.7)
T_6	Bispyribac sodium @25 g a.i. ha^{-1} 15 DAT (Post- emergence)	6.87(46.2)	7.66(57.6)	9.72(93.4)	10.65(112.5)	10.32(105.4)	11.27(126.0)
T_7	Bispyribac sodium @25 g a.i. ha^{-1} 15 DAT (Post- emergence) + one hand weeding 40 DAT	5.92(34.1)	6.59(42.4)	8.45(70.4)	9.25(84.6)	8.93(78.7)	9.76(94.2)
T_8	Ethoxy sulfuron @20g a.i. ha^{-1} (pre-emergence)	7.01(48.1)	7.80(59.9)	9.93(97.6)	10.89(117.5)	10.55(110.3)	11.53(132.0)
T_9	Ethoxy sulfuron @20g a.i. ha^{-1} (pre-emergence) + + one hand weeding 40 DAT	7.17(50.4)	7.99(62.9)	10.18(102.6)	11.16(123.5)	10.88(117.4)	11.89(140.3)
T_{10}	Penoxsulam 22 g a.i. ha^{-1} (post emergence)	6.51(41.4)	7.25(51.6)	9.55(90.2)	10.46(108.4)	10.26(104.3)	11.22(124.8)
T_{11}	Penoxsulam 22 g a.i. ha^{-1} (post emergence) + One hand weeding	5.17(25.7)	5.74(32.0)	7.62(57.1)	8.35(68.7)	8.56(72.2)	9.34(86.2)
T_{12}	Pyrazosulfuron 150 g ai.ha^{-1} (pre emergence) + Penoxsulam 22 g a.i. ha^{-1} post emergence + One hand weeding	5.05(24.5)	5.60(30.4)	7.11(49.5)	7.78(59.6)	7.99(62.8)	8.73(75.2)
	SEm+	**0.23**	**0.26**	**0.32**	**0.35**	**0.35**	**0.38**
	C.D.(P=0.05)	**0.66**	**0.73**	**0.92**	**1.01**	**1.00**	**1.09**

Original values in parenthesis. Values are square root $\sqrt{(\mathbf{X+1.0})}$

Conclusion

The integrated weed management (IWM) practices significantly reduced weed density and biomass in rice fields over two consecutive years. The treatment combining Pyrazosulfuron 150 g a.i. ha^{-1} pre-emergence and Penoxsulam 22 g a.i. ha^{-1} post-emergence with one hand weeding at 40 DAT was the most effective, reducing weed density to as low as 52.1 weeds m^{-2} at 30 DAT and total weed dry weight to 24.5 g m^{-2} at 30 DAT. The weedy check treatment had the highest weed density (476.3 weeds m^{-2}) and biomass (229.3 g m^{-2}) by 60 DAT in the second year. The results indicate that integrating chemical herbicides with manual weeding provides superior weed control compared to herbicides or manual weeding alone. This IWM approach enhances rice productivity, reduces the labor burden, and limits the negative environmental impacts, making it a sustainable weed management solution for rice cultivation.

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