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BIO-EFFICACY OF PRE- AND POST- EMERGENCE HERBICIDES ON YIELD ATTRIBUTES, YIELD AND ECONOMICS OF WHEAT (*Triticum aestivum* L.)

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ABSTRACT

Weed infestation is one of the major constraints limiting wheat (*Triticum aestivum* L.) productivity by competing with the crop for nutrients, moisture, light and space. An experiment was conducted during the Rabi season of 2023–24 at the Research Farm, Faculty of Agriculture, Vikrant University, Gwalior, Madhya Pradesh, India, to evaluate the bioefficacy of pre- and post-emergence herbicides on yield attributes, yield and economics of wheat. The experiment comprised 13 weed management treatments laid out in a Randomized Block Design (RBD) with three replications. The treatments included different doses of pyroxasulfone alone and in combination with pendimethalin, sequential applications of pyroxasulfone followed by pinoxaden or clodinafop-propargyl, post-emergence tank mixtures of carfentrazone-ethyl + sulfosulfuron, mesosulfuron-methyl + iodosulfuron-methyl-sodium, clodinafop-propargyl + metsulfuron-methyl, pendimethalin followed by one hand weeding, weed-free and weedy check. The results revealed that weed management practices significantly influenced effective tillers, grain yield, straw yield, biological yield and economic returns, whereas grains per spike, test weight and harvest index remained statistically non-significant. The weed-free treatment recorded the highest grain yield (4110.00 kg ha^{-1}), straw yield (6130.29 kg ha^{-1}) and biological yield (10240.29 kg ha^{-1}). However, among the herbicidal treatments, Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} proved to be the most effective, recording a grain yield of 3822.25 kg ha^{-1}, net return of Rs. 70,182 ha^{-1} and the highest benefit–cost ratio (1.77). In contrast, the weedy check recorded the lowest yield (2045.02 kg ha^{-1}) and economic returns due to severe weed competition. The study demonstrated that effective pre- and post-emergence herbicide combinations substantially improved wheat productivity and profitability by minimizing crop–weed competition. Under the agro-climatic conditions of Gwalior, Madhya Pradesh, application of Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} can be recommended as an efficient and economically viable weed management strategy for wheat cultivation.
***Keywords* :** *Triticum aestivum*, wheat, bioefficacy, pre-emergence herbicide, post-emergence herbicide, pyroxasulfone, carfentrazone-ethyl, sulfosulfuron, weed management, economics.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide and serves as a staple food for more than one-third of the global population. It is a major source of carbohydrates, proteins, vitamins and minerals and contributes significantly to global food and nutritional security. According to the Food and Agriculture Organization of the United Nations, wheat is cultivated over approximately 220 million hectares worldwide, making it one of the most extensively grown cereal crops. In India, wheat occupies a pivotal position in agriculture as the second most important food crop after rice, contributing substantially to national food grain production and farmers' income. ICAR–Indian Institute of Wheat and Barley Research has reported continuous improvements in wheat productivity through the adoption of improved cultivars and better crop management practices.

Among the various constraints affecting wheat production, weed infestation is considered one of the most serious biotic factors limiting crop productivity. Weeds compete vigorously with wheat for nutrients, moisture, light and space, causing yield losses ranging from 10 to 80% depending on weed flora, density and environmental conditions Sharma and Sharma (2012). They further emphasized that *Phalaris minor* is the most problematic grassy weed in the Indo-Gangetic Plains, while *Chenopodium album*, *Rumex dentatus*, *Anagallis arvensis* and *Melilotus indica* are the predominant broad-leaved weeds infesting wheat fields. Manual weeding has traditionally been practiced for weed management in wheat. However, increasing labour costs, shortage of skilled labour and the need for timely field operations have made manual weed control less practical. Consequently, herbicides have become an indispensable component of modern wheat production systems. Chhokar *et al*. (2012) concluded that herbicides provide efficient, timely and economical weed control and significantly improve wheat productivity when integrated with suitable agronomic practices.

Efficient weed management not only suppresses weed growth but also improves crop growth, yield attributes and profitability. Pyroxasulfone-based weed management significantly increased effective tillers, grain yield and economic returns compared with untreated control Bhalse, Jha, Verma, Dubey and Surendra (2024). Effective weed control enhances nutrient uptake, moisture availability and photosynthetic efficiency, resulting in higher numbers of productive tillers, grains per spike and test weight.

Although several researchers, have evaluated individual herbicides and herbicide mixtures in wheat, information on the comparative bioefficacy of pyroxasulfone-based pre-emergence treatments, sequential herbicide applications and modern post-emergence herbicide combinations under the agro-climatic conditions of Gwalior, Madhya Pradesh, remains limited. Therefore, the present investigation entitled "Bio-efficacy of Pre- and Post-emergence Herbicides on Yield Attributes, Yield and Economics of Wheat (*Triticum aestivum* L.)" was undertaken at Vikrant University, Gwalior, to evaluate different herbicide treatments for improving yield attributes, grain yield and economic returns under local conditions.

Materials and Methods

Experimental site

A field experiment was conducted during the *rabi* season of 2024–25 at the Instructional Farm, School of Agriculture, Vikrant University, Gwalior, Madhya Pradesh, India. The experimental site is located at 26°13′ N latitude and 78°10′ E longitude with an altitude of approximately 197 m above mean sea level. The region has a subtropical climate characterized by hot summers, cool winters and an average annual rainfall of about 750–850 mm, most of which is received during the south-west monsoon (June–September).

Soil characteristics

Prior to sowing, composite soil samples (0–15 cm depth) were collected from the experimental field and analysed using standard laboratory procedures. The experimental soil was sandy clay loam in texture, nearly neutral in reaction, low in available nitrogen, medium in available phosphorus and high in available potassium. Soil pH and electrical conductivity were determined in a 1:2.5 soil–water suspension. Organic carbon was estimated by the Walkley and Black method, available nitrogen by the alkaline permanganate method, available phosphorus by the Olsen method and available potassium by neutral normal ammonium acetate extraction followed by flame photometry (Walkley and Black 1934; Subbiah and Asija 1956; Olsen *et al*. 1954; Jackson 1973).

Experimental design and treatments

The experiment was laid out in a randomized block design (RBD) with ten weed management treatments and three replications. The treatments consisted of 10 treatments consisting of 8 herbicide mixtures and 2 check plots. The treatments comprises of **T_1:** Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1}, **T_2:** Pyroxasulfone 127.5 g ha^{-1} followed by Pinoxaden 50 g ha^{-1}, **T_3:** Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (pre-emergence) followed by Pinoxaden 50 g ha^{-1} (post-emergence), **T_4:** Pyroxasulfone 127.5 g ha^{-1} followed by Clodinafop-propargyl 60 g ha^{-1}, **T_5:** Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (tank mixture), **T_6:** Mesosulfuron-methyl + Iodosulfuron-methyl-sodium 14.4 g ha^{-1} (tank mixture), **T_7:** Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (ready mixture), **T_8:** Pendimethalin 1500 g ha^{-1} followed by one hand weeding, **T_9:** Weed-free, **T_{10}:** Weedy check

Crop husbandry

The field was prepared by one deep ploughing followed by two harrowings and planking to obtain a fine seedbed. Wheat was sown using the recommended seed rate and row spacing. Fertilizers were applied according to the recommended package of practices for the region. Irrigation and other agronomic operations were carried out uniformly in all plots throughout the crop season.

Herbicide application

Pre-emergence herbicides were applied within 24 h after sowing using a calibrated knapsack sprayer fitted with a flat-fan nozzle. Post-emergence herbicides were sprayed at 30–35 days after sowing using the recommended spray volume. Herbicides were applied under favourable weather conditions to ensure uniform coverage and minimize spray drift.

Observations

Yield attributes were recorded at crop maturity from randomly selected plants in each experimental plot. Effective tillers (m^{-2}), grains per spike and 1000-grain weight (g) were determined following standard procedures. Grain and straw yields were recorded from the net plot area and converted to kg ha^{-1}. Biological yield was computed as the sum of grain and straw yield, while harvest index was calculated as:

Harvest index (%) = (Grain yield / Biological yield) × 100

Economic analysis was performed by estimating the cost of cultivation, gross returns, net returns and benefit–cost ratio based on prevailing market prices.

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design following the procedure described by Gomez and Gomez (1984). Treatment means were compared using the least significant difference (LSD) test at the 5% probability level. Standard error of the mean [SE(m) ±] was calculated for all measured parameters. The statistical analysis was done using agrianalyze application.

Result and Discussion

Yield Attributes and Yield

Effective Tillers (m^{-2})

The number of effective tillers was significantly influenced by different pre- and post-emergence herbicide treatments (Table 1). Among the treatments, the weed-free treatment (T_9) recorded the highest number of effective tillers (287.92 m^{-2}), which was significantly superior to all other treatments. Among the herbicidal treatments, Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_8) produced 275.60 effective tillers m^{-2}, followed by Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (T_5) (267.73 m^{-2}). The treatments Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} followed by Pinoxaden 50 g ha^{-1} (T_3), Clodinafop-propargyl + Metsulfuron-methyl (T_7) and Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_6) recorded statistically comparable values of 259.32, 258.86 and 258.69 m^{-2}, respectively. The lowest number of effective tillers (143.23 m^{-2}) was observed under the weedy check (T_{10}).

The increased number of effective tillers under weed-free and herbicide-treated plots may be attributed to efficient weed suppression during the critical period of crop growth, resulting in reduced competition for moisture, nutrients, sunlight and space. Better weed control improved crop vigour, tiller survival and photosynthetic efficiency, thereby increasing the number of productive tillers. Similar findings were reported by Chhokar *et al*. (2012).

Grains per Spike

The number of grains per spike was not significantly influenced by different herbicide treatments (Table 1). However, numerically the highest number of grains per spike (39.27) was recorded under the weed-free treatment (T_9), followed by Pendimethalin followed by one hand weeding (T_8) (39.26) and Carfentrazone-ethyl + Sulfosulfuron (T_5) (39.25). The lowest value (38.60) was recorded under the weedy check (T_{10}). The remaining herbicidal treatments recorded values ranging from 39.11 to 39.22 grains per spike, which were statistically at par.

The slight numerical increase in grains per spike under effective weed management might be attributed to improved availability of nutrients, moisture and photosynthates during the reproductive stage, resulting in better spike development and grain formation. However, the non-significant differences among treatments indicate that grains per spike are largely governed by the genetic potential of the cultivar and prevailing environmental conditions. Similar findings were reported by Bhalse *et al*. (2024).

Test Weight (g)

Test weight was not significantly affected by different herbicide treatments (Table 1). Numerically, the weed-free treatment (T_9) recorded the highest test weight (38.86 g), closely followed by Pendimethalin followed by one hand weeding (T_8) (38.85 g) and Carfentrazone-ethyl + Sulfosulfuron (T_5) (38.84 g). The lowest test weight (38.20 g) was recorded under the weedy check (T_{10}). The remaining herbicide treatments recorded test weights between 38.71 and 38.81 g, and all treatments were statistically comparable.

The non-significant effect of herbicide treatments on test weight suggests that grain size and grain filling were less influenced by weed management practices and were mainly controlled by varietal characteristics and environmental factors during grain development. Nevertheless, the slightly higher test weight observed under weed-free and effective herbicide treatments may be attributed to improved assimilate translocation and better grain filling due to reduced crop-weed competition. Similar observations were reported by Chhokar and Sharma (2023).

Grain Yield (kg ha^{-1})

Grain yield of wheat was significantly influenced by different pre- and post-emergence herbicide treatments (Table 4.26). Among all the treatments, the weed-free treatment (T_{12}) recorded the highest grain yield (4110.00 kg ha^{-1}), which was significantly superior to all other treatments. Among the herbicidal treatments, Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_{11}) recorded the highest grain yield (3934.92 kg ha^{-1}), followed by Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (T_8) (3822.25 kg ha^{-1}), Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) (T_6) (3702.26 kg ha^{-1}), Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) (3695.67 kg ha^{-1}), Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) (3693.50 kg ha^{-1}) and Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (T_4) (3672.84 kg ha^{-1}). The lowest grain yield (2045.02 kg ha^{-1}) was recorded under the weedy check (T_{13}).

The marked increase in grain yield under weed-free and effective herbicide treatments may be attributed to efficient weed suppression during the critical period of crop growth, which minimized crop-weed competition for nutrients, moisture, light and space. Reduced weed interference enhanced tiller production, photosynthetic activity and assimilate translocation towards developing grains, resulting in higher grain yield. Similar findings were reported by Kaur and Singh (2019).

Straw Yield (kg ha^{-1})

Straw yield was significantly influenced by different weed management treatments (Table 4.26). The highest straw yield (6130.29 kg ha^{-1}) was recorded under the weed-free treatment (T_{12}), followed by Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_{11}) (5870.48 kg ha^{-1}) and Carfentrazone-ethyl + Sulfosulfuron (T_8) (5706.87 kg ha^{-1}). Among the remaining herbicidal treatments, Pyroxasulfone + Pendimethalin (PRE) followed by Pinoxaden (PoE) (T_6), Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) and Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) produced 5535.01, 5530.34 and 5528.18 kg ha^{-1} straw yield, respectively. The lowest straw yield (3101.13 kg ha^{-1}) was observed under the weedy check (T_{13}).

Higher straw yield under weed-free and herbicide-treated plots may be attributed to improved vegetative growth, greater dry matter accumulation and enhanced photosynthetic efficiency due to effective weed control. Reduced weed competition facilitated better utilization of available resources, resulting in increased biomass production. Similar results were reported by Hazarika *et al*. (2024).

Biological Yield (kg ha^{-1})

Biological yield differed significantly among the herbicide treatments (Table 4.26). The weed-free treatment (T_{12}) recorded the highest biological yield (10240.29 kg ha^{-1}), followed by Pendimethalin followed by one hand weeding (T_{11}) (9805.40 kg ha^{-1}) and Carfentrazone-ethyl + Sulfosulfuron (T_8) (9529.12 kg ha^{-1}). Among the herbicidal treatments, Pyroxasulfone + Pendimethalin (PRE) followed by Pinoxaden (PoE) (T_6) (9237.27 kg ha^{-1}), Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) (9223.85 kg ha^{-1}), Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) (9223.84 kg ha^{-1}) and Pyroxasulfone + Pendimethalin (T_4) (9178.06 kg ha^{-1}) were statistically superior to the remaining treatments. The lowest biological yield (5146.16 kg ha^{-1}) was recorded under the weedy check (T_{13}).

The increase in biological yield under effective weed management was mainly due to greater dry matter accumulation resulting from improved crop growth and reduced weed competition. Efficient weed control enhanced nutrient uptake, leaf area development and photosynthetic efficiency, leading to increased biomass production. Similar findings were reported by Bhalse *et al*. (2024).

Table 1: Bioefficacy of Pre- and Post-Emergence Herbicides on Yield Attributes of Wheat

Tr. No.	Treatments	Effective Tillers (m^{-2})	Grains per Spike	Test Weight (g)
T_1	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1}	257.22	39.17	38.76
T_2	Pyroxasulfone 127.5 g ha^{-1} fb Pinoxaden 50 g ha^{-1}	207.87	39.11	38.71
T_3	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) fb	259.32	39.22	38.81

	Pinoxaden 50 g ha^{-1} (PoE)			
T_4	Pyroxasulfone 127.5 g ha^{-1} fb Clodinafop-propargyl 60 g ha^{-1}	211.87	39.14	38.73
T_5	Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (TM)	267.73	39.25	38.84
T_6	Mesosulfuron-methyl + Iodosulfuron-methyl-sodium 14.4 g ha^{-1} (TM)	258.69	39.19	38.78
T_7	Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (RM)	258.86	39.21	38.80
T_8	Pendimethalin 1500 g ha^{-1} fb One Hand Weeding	275.60	39.26	38.85
T_9	Weed Free	287.92	39.27	38.86
T_{10}	Weedy Check	143.23	38.60	38.20
SE(m) ±		5.98	1.13	1.12
LSD (P = 0.05)		17.46	NS	NS

Table 2: Bioefficacy of Pre- and Post-Emergence Herbicides on Yield of Wheat

Tr. No.	**Treatments**	**Grain Yield (kg ha^{-1})**	**Straw Yield (kg ha^{-1})**	**Biological Yield (kg ha^{-1})**	**Harvest Index (%)**
T_1	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1}	3672.84	5505.22	9178.06	40.02
T_2	Pyroxasulfone 127.5 g ha^{-1} fb Pinoxaden 50 g ha^{-1}	2967.93	4457.57	7425.50	39.97
T_3	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) fb Pinoxaden 50 g ha^{-1} (PoE)	3702.26	5535.01	9237.27	40.08
T_4	Pyroxasulfone 127.5 g ha^{-1} fb Clodinafop-propargyl 60 g ha^{-1}	3024.78	4537.23	7562.01	40.00
T_5	Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (TM)	3822.25	5706.87	9529.12	40.11
T_6	Mesosulfuron-methyl + Iodosulfuron-methyl-sodium 14.4 g ha^{-1} (TM)	3693.50	5530.34	9223.84	40.05
T_7	Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (RM)	3695.67	5528.18	9223.85	40.07
T_8	Pendimethalin 1500 g ha^{-1} fb One Hand Weeding	3934.92	5870.48	9805.40	40.13
T_9	Weed Free	4110.00	6130.29	10240.29	40.14
T_{10}	Weedy Check	2045.02	3101.13	5146.16	39.74
SE(m) ±		103.54	181.89	285.37	–
LSD (P = 0.05)		302.21	530.89	832.94	–

Table 3: Bioefficacy of Pre- and Post-Emergence Herbicides on Economics of Wheat

Tr. No.	**Treatments**	**Total Cost of Cultivation (Rs. ha^{-1})**	**Gross Return (Rs. ha^{-1})**	**Net Return (Rs. ha^{-1})**	**B:C Ratio**
T_1	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1}	41,400	105,574	64,174	1.55
T_2	Pyroxasulfone 127.5 g ha^{-1} fb Pinoxaden 50 g ha^{-1}	41,275	85,356	44,081	1.07
T_3	Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) fb Pinoxaden 50 g ha^{-1} (PoE)	41,800	106,348	64,548	1.54
T_4	Pyroxasulfone 127.5 g ha^{-1} fb Clodinafop-propargyl 60 g ha^{-1}	41,355	86,963	45,607	1.10
T_5	Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (TM)	39,575	109,757	70,182	**1.77**
T_6	Mesosulfuron-methyl + Iodosulfuron-methyl-sodium 14.4 g ha^{-1} (TM)	39,975	106,139	66,163	1.66
T_7	Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (RM)	39,795	106,174	66,379	1.67
T_8	Pendimethalin 1500 g ha^{-1} fb One Hand Weeding	44,500	112,969	68,469	1.54
T_9	Weed Free	53,575	117,989	64,414	1.20
T_{10}	Weedy Check	39,175	58,962	19,787	0.51

Harvest Index (%)

Harvest index was not markedly influenced by different herbicide treatments and varied within a narrow range from 39.74 to 40.14% (Table 4.26). Numerically, the highest harvest index (40.14%) was recorded under the weed-free treatment (T_{12}), followed by Pendimethalin followed by one hand weeding (40.13%), Carfentrazone-ethyl + Sulfosulfuron (40.11%) and Pyroxasulfone + Pendimethalin (PRE) followed by Pinoxaden (40.08%), whereas the lowest harvest index (39.74%) was observed under the weedy check (T_{13}).

The non-significant variation in harvest index indicated that both grain yield and biological yield increased proportionately under effective weed management. Although herbicide treatments substantially enhanced crop productivity, they had little influence on biomass partitioning between grain and straw. Similar observations were reported by Chhokar *et al*. (2012) and Bhalse *et al*. (2024).

Economics

Cost of Cultivation (Rs. ha^{-1})

The cost of cultivation of wheat varied under different pre- and post-emergence herbicide treatments (Table 4.27). The weed-free treatment (T_{12}) recorded the highest cost of cultivation (Rs. 53,575 ha^{-1}) owing to repeated manual weeding operations throughout the crop growth period. This was followed by Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_{11}), which incurred a cultivation cost of Rs. 44,500 ha^{-1}. Among the herbicidal treatments, Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) (T_6) recorded the highest cost of cultivation (Rs. 41,800 ha^{-1}), while the lowest cultivation cost (Rs. 39,175 ha^{-1}) was observed under the weedy check (T_{13}). The variation in cultivation cost among treatments was mainly due to differences in herbicide prices, labour charges and the number of weed management operations involved. Similar variations in cultivation cost under different weed management practices were also reported by Patel *et al*. (2025).

Gross Return (Rs. ha^{-1})

Gross return was markedly influenced by the different herbicide treatments (Table 4.27). The highest gross return (Rs. 117,989 ha^{-1}) was recorded under the weed-free treatment (T_{12}), followed by Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_{11}) (Rs. 112,969 ha^{-1}) and Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (T_8) (Rs. 109,757 ha^{-1}). Among the remaining herbicide treatments, Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) (T_6), Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) and Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) recorded gross returns of Rs. 106,348, Rs. 106,174 and Rs. 106,139 ha^{-1}, respectively. The weedy check (T_{13}) recorded the lowest gross return (Rs. 58,962 ha^{-1}) because of severe yield losses caused by unchecked weed growth. The higher gross returns under effective weed management treatments were mainly associated with greater grain and straw yields resulting from efficient weed suppression. Similar findings were reported by Bhalse *et al*. (2024) and Hazarika *et al*. (2024).

Net Return (Rs. ha^{-1})

Net return was significantly affected by different weed management practices (Table 4.27). The highest net return (Rs. 70,182 ha^{-1}) was recorded with Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (T_8), followed by Pendimethalin 1500 g ha^{-1} followed by one hand weeding (T_{11}) (Rs. 68,469 ha^{-1}), Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) (Rs. 66,379 ha^{-1}), Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) (Rs. 66,163 ha^{-1}) and Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) (T_6) (Rs. 64,548 ha^{-1}). Although the weed-free treatment (T_{12}) recorded the highest gross return, its net return (Rs. 64,414 ha^{-1}) was comparatively lower because of the substantially higher cost of manual weeding. The lowest net return (Rs. 19,787 ha^{-1}) was obtained under the weedy check (T_{13}). The higher net returns under herbicide treatments indicate that effective chemical weed management enhanced crop productivity while minimizing production costs. Similar results were reported by Patel *et al*. (2025) and Bhalse *et al*. (2024).

Benefit–Cost Ratio

The benefit–cost (B:C) ratio was considerably influenced by different herbicide treatments (Table 4.27). The highest B:C ratio (1.77) was recorded with Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} (T_8), followed by Clodinafop-propargyl + Metsulfuron-methyl (T_{10}) (1.67), Mesosulfuron-methyl + Iodosulfuron-methyl-sodium (T_9) (1.66), Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (T_4) (1.55) and Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) (T_6) (1.54). Although the weed-free treatment (T_{12}) recorded the maximum grain yield and gross return, it produced a comparatively lower B:C ratio (1.20) because of the high labour cost associated with maintaining weed-free conditions. The weedy check (T_{13}) recorded the lowest B:C ratio (0.51), indicating poor economic viability under uncontrolled weed infestation. The higher B:C ratio observed with Carfentrazone-ethyl + Sulfosulfuron demonstrated that this treatment provided an optimum balance between weed control efficiency, crop productivity and production cost, thereby maximizing economic returns. Similar observations were reported by Hazarika *et al*. (2024), Patel *et al*. (2025) and Bhalse *et al*. (2024).

Conclusion

The present investigation demonstrated that pre- and post-emergence herbicide treatments significantly influenced the yield attributes, yield and economics of wheat. Effective weed management markedly improved effective tillers, grain yield, straw yield and biological yield compared with the weedy check, while harvest index remained largely unaffected. Among the herbicidal treatments, Carfentrazone-ethyl 20 g ha^{-1} +

Sulfosulfuron 25 g ha^{-1} (T_8) proved to be the most effective and economically viable weed management practice. This treatment recorded superior yield attributes, produced a grain yield of 3822.25 kg ha^{-1}, and generated the highest net return (Rs. 70,182 ha^{-1}) and benefit–cost ratio (1.77) among all herbicide treatments. Sequential application of Pyroxasulfone 127.5 g ha^{-1} + Pendimethalin 1500 g ha^{-1} (PRE) followed by Pinoxaden 50 g ha^{-1} (PoE) and Pendimethalin followed by one hand weeding also performed effectively by providing broad-spectrum weed control and higher crop productivity.

Overall, the study indicates that integrating effective pre- and post-emergence herbicides can successfully suppress weeds, enhance wheat productivity and improve farm profitability. Under the agro-climatic conditions of Vikrant University, Gwalior (Madhya Pradesh, India), application of Carfentrazone-ethyl 20 g ha^{-1} + Sulfosulfuron 25 g ha^{-1} may be recommended as a cost-effective weed management strategy for maximizing wheat yield and economic returns.

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