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Effect of integrated weed management on growth and yield of Wheat (*Triticum aestivum* L.)

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Abstract
A field experiment was conducted during the Rabi season of 2025–26 at the Agricultural Farm of Career Point University, Kota (Rajasthan), to evaluate the effect of integrated weed management practices on growth and yield of wheat (*Triticum aestivum* L.). The experiment comprised ten treatments including pre- and post-emergence herbicides, mulching, and weed-free and control treatments, arranged in a Randomized Block Design with three replications. The results revealed that weed management practices significantly influenced growth parameters such as plant height, number of tillers, and dry matter accumulation. The highest values were recorded under weed-free conditions, which were statistically at par with the combined application of Clodinafop-propargyl + metsulfuron-methyl (T_8) and integrated herbicidal treatments (T_9 and T_{10}). Maximum grain yield (52.00 q ha^{-1}), straw yield (75.00 q ha^{-1}), and biological yield (127.00 q ha^{-1}) were also observed under weed-free treatment, followed closely by T_8. Effective weed control minimized crop-weed competition, resulting in better resource utilization and improved yield attributes. The study concludes that integrated weed management involving selective herbicides can effectively enhance wheat productivity and serve as a practical alternative to labor-intensive weed-free conditions.

Keywords: Wheat, integrated weed management, herbicides, grain yield, weed control

1. Introduction

Wheat (*Triticum aestivum* L.) stands as one of the most vital cereal crops globally, serving as a staple food for over one-third of the world's population. Its adaptability across diverse agro-climatic zones and its nutritional value make it indispensable to global food security. In India, wheat occupies a central role in the agricultural economy, ranking second in global production with an annual output of approximately 87 million tonnes from nearly 30 million hectares [1]. Major wheat-producing states such as Uttar Pradesh, Punjab, Haryana, and Rajasthan contribute significantly to this figure, with average productivity hovering around 3533 kg ha^{-1} [2]. Despite its prominence, wheat cultivation faces several biotic and abiotic challenges, among which weed infestation is a major constraint. Weeds compete with wheat for essential resources such as nutrients, water, light, and space, leading to substantial yield losses. Studies have shown that unchecked weed growth can reduce wheat yields by 20–40%, depending on the weed flora, crop management practices, and environmental conditions. The presence of both grassy and broadleaf weeds, including *Phalaris minor*, *Avena ludoviciana*, and *Chenopodium album*, complicates weed management due to their varied growth habits and resistance profiles.

Historically, chemical herbicides have been the primary tool for weed control in wheat due to their cost-effectiveness and ease of application. Pre-emergence herbicides like pendimethalin and metribuzin, and post-emergence options such as clodinafop-propargyl and metsulfuron-methyl, have demonstrated efficacy against a broad spectrum of weeds. However, the indiscriminate and continuous use of these chemicals has led to the emergence of herbicide-resistant weed populations, posing a serious threat to sustainable wheat production. This scenario necessitates a shift toward Integrated Weed Management (IWM)- a holistic approach that combines chemical, cultural, mechanical, and biological methods to manage weeds effectively while minimizing environmental impact. IWM emphasizes the use of multiple tactics tailored to specific agro-ecological conditions, thereby reducing reliance on any single method and enhancing long-term weed control efficacy.

Cultural practices such as timely sowing, optimal seed rate, crop rotation, and the selection of competitive cultivars can significantly suppress weed growth. For instance, early sowing allows wheat to establish before weed emergence, giving it a competitive edge. Similarly, higher seed rates and narrow row spacing increase canopy cover, reducing light availability for weeds. Mechanical methods, including hand weeding and inter-row cultivation, remain effective in small-scale or organic farming systems. Although labor-intensive, these techniques offer precise weed removal without chemical residues. However, their feasibility diminishes in large-scale operations due to labor shortages and high costs.

Mulching with crop residues- such as rice straw, wheat straw, or other organic materials -has emerged as a promising strategy in IWM. Mulch acts as a physical barrier, reducing light penetration to the soil surface and thereby inhibiting weed germination. Mulching reduced weed density and biomass by 12–16% in wheat fields. Beyond weed suppression, mulching improves soil moisture retention, regulates temperature, enhances nutrient cycling, and increases soil organic carbon, contributing to overall soil health [3]. In rice–wheat systems, residue retention combined with conservation tillage has been shown to improve microbial activity, reduce weed seed banks, and enhance system productivity. Long-term studies confirm that mulching not only aids in weed control but also supports sustainable intensification of wheat production.

Chemical herbicides remain indispensable in IWM, especially for managing dense weed populations. Pre-emergence herbicides like metribuzin inhibit weed seed germination, while post-emergence options such as clodinafop-propargyl target actively growing weeds. The integration of herbicides with cultural practices enhances weed control efficiency and crop performance. However, the development of herbicide resistance-particularly in *Phalaris minor* and *Avena* spp.- has raised concerns. Resistance evolves due to repeated use of the same mode of action, necessitating herbicide rotation and mixture strategies. Diversifying weed control tactics is essential to delay resistance development and maintain herbicide efficacy [4].

Recent research highlights the synergistic benefits of combining mulching with selective herbicides. Integrated treatments significantly improved weed control efficiency, enhanced wheat growth parameters, and increased grain yield compared to sole methods. Such integration reduces herbicide dosage requirements, minimizes environmental impact, and promotes sustainable crop production [5]. According to a study, straw mulching with rotary tillage improved spike number, grains per spike, and thousand-grain weight, resulting in a 20.5% increase in wheat yield over conventional tillage without mulch [6]. These findings underscore the potential of integrated approaches in optimizing resource use and enhancing productivity.

IWM not only improves agronomic outcomes but also offers economic benefits. By reducing weed-related yield losses and optimizing input use, farmers can achieve higher net returns and better benefit-cost ratios. Moreover, reduced herbicide dependence lowers the risk of environmental contamination and promotes biodiversity in agroecosystems. In regions like Rajasthan, where wheat is a major crop, adopting IWM can address local challenges such as water scarcity, soil degradation, and labor constraints. Tailoring weed management strategies to regional conditions ensures their effectiveness and sustainability.

Based on the format and concise length of the "Materials and Methods" section in the reference image (image_042af3.png), here is your detailed text condensed to match that exact structure and brevity:

2. Materials and Methods

The field experiment was conducted at the Agricultural Farm of Career Point University, Alaniya, Kota (Rajasthan), during the *rabi* season of 2025-26. The site is located at a latitude of 25° 11' N and longitude of 75° 54' E, with an elevation of 273 meters above mean sea level. Geographically, it falls within the Humid South Eastern Plain Zone (Zone V) of Rajasthan.

The soil of the experimental field was clay-loam in texture. It had an alkaline pH of 8.35 (Potentiometric method), EC 0.26 ds m^{-1} (Conductivity Bridge Method), low organic carbon at 0.42% (Walkley and Black's method), low available N at 177 kg ha^{-1} (Alkaline Permanganate Method), medium available P at 14.6 kg ha^{-1} (Olsen's method), and high available K at 321 kg ha^{-1} (Flame Photometric method). The ten treatments comprising various weed management practices (Control, varying doses of PE Metribuzine, PoE Metsulfuron-methyl, Clodinafop-propargyl, and rice/wheat straw mulching) were laid out in a Randomized Block Design (RBD) with 3 replications.

The crop was uniformly fertilized with 120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1}. One-third dose of nitrogen and the full doses of phosphorus and potassium were applied as a basal dressing. The remaining two-thirds of nitrogen was top-dressed in two equal splits after the first irrigation and at the panicle initiation stage. The wheat crop was sown in rows spaced 20 cm apart, using a seed rate of 100 kg ha^{-1} on November 21, 2025, with the help of a seed drill. Herbicides were applied at 30 DAS using a knap-sack sprayer with a flat-fan nozzle. The crop was harvested at full maturity on April 12, 2026.

2.1 Growth, Weed, and Development Studies

Plant height was measured (in cm) from the base to the highest terminal point from five tagged plants and averaged. Tillers were counted on a per square meter basis at periodic intervals. For yield attributes, the length of spike, number of spikelets per spike, and number of grains per spike were recorded from randomly selected spikes. A representative grain sample was drawn to count and weigh 1000 seeds. Additionally, weed density and total dry weed biomass (g m^{-2}) were recorded using a 0.25 m^2 quadrate at 30, 60, and 90 DAS to calculate weed control efficiency.

2.2 Yield Studies

The grain yield from the net plot was recorded after sun-drying and threshing, and then converted into grain yield (q ha^{-1}). The straw yield was computed by deducting the grain yield from the total biological yield (biomass) of the net plot and then converted into q ha^{-1}.

2.3 Statistical Analysis

The data pertaining to weed dynamics, crop growth, yield, and chemical composition were subjected to statistical analysis using SPSS software to determine the significance of the impacts of different treatments. The Fisher's 'F' test was utilized for this purpose. The interpretation of the results relies on the statistical significance of the derived 'F' value at a 5% probability level. A critical difference (CD) was determined for examining significant differences between treatments as described by Gomez and Gomez.

3.1 Growth Attributes

3.1.1 Initial Plant Population (m^{-2})

The initial plant population recorded at 15 DAS was not significantly influenced by the various weed management practices. This uniform establishment is attributed to the consistent seed rate utilized across all plots. The non-significant variation in the initial plant stand across all treatments was primarily because a uniform, recommended seed rate (100 kg ha^{-1}) was used for sowing in all plots. At 15 DAS, crop-weed competition for essential resources (light, space, and nutrients) had not yet reached a critical threshold to cause any mortality or hinder the germination of wheat seeds. Similar findings confirming the non-dependence of initial plant stand on post-sowing weed management were reported by [7].

3.1.2 Plant Height (cm)

Plant height increased progressively with crop age, with the most pronounced growth occurring between 30 and 90 DAS. At harvest, the maximum plant height (96.00 cm) was recorded in the weed-free treatment, which was statistically at par with Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. ha^{-1} (T_8) and PE Metribuzine + PoE Clodinafop propargyl (T_9). The unweeded control produced the shortest plants (92.00 cm). The significant increase in plant height under effective weed management practices (like weed-free and T_8) is attributed to the elimination or severe reduction of crop-weed competition. In the absence of aggressive weeds, the wheat crop had greater, uninterrupted access to essential soil nutrients, moisture, and solar radiation. This optimal availability of resources facilitated higher cell division and elongation, resulting in the profuse vegetative growth of the plants. Conversely, severe weed competition in the unweeded control restricted vertical growth. These observations are in close conformity with the findings of [7, 8, 11].

3.1.3 Number of Tillers (m^{-2})

Weed management practices significantly enhanced the number of tillers at all growth stages except 30 DAS. The maximum number of tillers at harvest (355.0 m^{-2}) was recorded under weed-free conditions, remaining statistically at par with T_8, T_9, and T_{10}. This indicates better nutrient and space availabili Tillering is a crucial growth phase that is highly sensitive to resource scarcity. The significant enhancement in the number of tillers under weed-free and effective herbicidal treatments was due to the timely suppression of competitive weed flora. This created a conducive micro-climate with better availability of nitrogen, space, and light for the crop during the active tillering stage. Reduced competition allowed the wheat plants to express their maximum tillering potential. These results corroborate the findings of [9, 12]. under effectively weeded conditions compared to the weedy check (323.0 m^{-2}).

3.1.4 Dry Matter Accumulation (g m^{-2})

Similar to tillering, dry matter accumulation was significantly affected from 60 DAS onwards. At harvest, the weed-free treatment recorded the highest dry matter accumulation (1350.0 g m^{-2}), which was statistically equivalent to T_8 (1332.5 g m^{-2}), T_9, and T_{10}. This was significantly superior to the unweeded control (1210.0 g m^{-2}). Dry matter accumulation is the cumulative reflection of all physiological growth parameters, including plant height, number of shoots/tillers, and leaf area index. The effective control of weeds minimized nutrient depletion by weed flora, allowing the crop canopy to expand fully. A larger and healthier crop canopy intercepted more photosynthetically active radiation (PAR), leading to a higher rate of photosynthesis and more synthesis of food materials (photosynthates). The continuous and increased translocation of these photosynthates to various plant parts resulted in higher dry matter production [10, 13] have also reported a similar increase in dry matter production with herbicide application compared to a weedy check.

3.2 Yield Studies

3.2.1 Grain Yield (q ha^{-1})

All weed management practices significantly increased wheat grain yield over the weedy check. The highest grain yield (52.00 q ha^{-1}) was recorded in the weed-free treatment, which was statistically at par with Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. ha^{-1} (49.82 q ha^{-1}). This significant enhancement is attributed to the effective smothering of weeds, allowing better translocation of resources to the grain. Grain yield is the final outcome of the complex interplay between vegetative growth and yield-attributing characters. The substantial and significant increase in grain yield under treatments like weed-free and T_8 is the direct result of the effective smothering of weed flora. Complete or near-complete weed eradication minimized competitive stress, which maximized the number of spikes m^{-2}, grains per spike, and test weight. The synergistic effect of these enhanced yield components, driven by excellent source-to-sink translocation of synthesized carbohydrates, culminated in superior grain yield. These findings are strongly supported by [12, 13].

3.2.2 Straw Yield (q ha^{-1})

Straw yield was significantly higher across all management practices compared to the control. The highest straw yield (75.00 q ha^{-1}) was recorded in the weed-free treatment, remaining statistically at par with T_8 (71.85 q ha^{-1}), T_9 (69.90 q ha^{-1}), and T_{10}. Straw yield is directly proportional to the vegetative biomass produced by the crop. The significant increase in straw yield under superior weed management practices was logically driven by the enhanced vegetative growth parameters discussed earlier- namely, taller plants, a higher number of tillers, and maximum dry matter accumulation per unit area. Better resource utilization led to a robust plant canopy, which translated into higher stover/straw yield at harvest. This is in agreement with [12, 13].

3.2.3 Biological Yield (q ha^{-1})

The cumulative effect of enhanced growth and yield attributes resulted in significant biological yield differences. The maximum biological yield (127.00 q ha^{-1}) was achieved in the weed-free plots, which was statistically on par with T_8, T_9, and T_{10}, and significantly superior to the weedy check (76.84 q ha^{-1}). Biological yield is the mathematical sum of economic yield (grain) and stover yield (straw). The effective weed control by mechanical (weed-free) and chemical (Clodinafop-propargyl + metsulfuron-methyl) methods enhanced both the source components (number of leaves, tillers, dry matter before anthesis) and sink components (number of spikelets, length of spike, test weight). Because both grain and straw yields were optimized due to the lack of biotic stress (weeds), the overall biological yield naturally peaked in these treatments. Similar mechanisms were reported by [10, 11, 13].

3.2.4 Harvest Index (%)

The effect of the varying weed management practices on the harvest index was non-significant. All treatments, including the unweeded control and weed-free plots, maintained an identical harvest index of 40.94%, demonstrating that the proportional partitioning of dry matter into grain and straw was unaffected by the treatments. The Harvest Index (HI) reflects the physiological efficiency of a crop in partitioning dry matter into its economic (grain) and non-economic (straw) parts. The non-significant variation indicates that while weed management practices significantly altered the *total volume* of biomass produced (biological yield), they did not alter the *proportional distribution* of that biomass. The crop maintained its intrinsic genetic efficiency in dry matter partitioning regardless of the weed control method applied.

Table 1: Effect of different treatment on initial plant population of wheat

Symbol	Treatment	Initial Plant population (m−2)
T_1	Control (Weedy check)	121.50
T_2	Weed free	124.00
T_3	Rice straw mulch 5 t $^{ha\ -1}$	118.50
T_4	Wheat straw mulch 5 t $^{ha\ -1}$	119.20
T_5	PoE Metsulfuron-methyl @ 4 g $^{ha\ -1}$	122.30
T_6	PoE Clodinafop-propargyl @ 60 g $^{ha\ -1}$	123.10
T_7	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$	117.80
T_8	Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	121.00
T_9	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + PoE Clodinafop propargyl at 60 g a.i $^{ha\ -1}$	116.50
T_{10}	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	118.00
SE m±		5.35
CD at 5%		NS

Table 2: Effect of different treatment on initial plant height of wheat

Symbol	Treatment	30 DAS	60 DAS	90 DAS	At harvest
T_1	Control (Weedy check)	28.00	74.00	91.00	92.00
T_2	Weed free	30.00	80.00	95.00	96.00
T_3	Rice straw mulch 5 t $^{ha\ -1}$	28.60	75.80	92.20	93.20
T_4	Wheat straw mulch 5 t $^{ha\ -1}$	28.50	75.50	92.00	93.00
T_5	PoE Metsulfuron-methyl @ 4 g $^{ha\ -1}$	29.00	77.00	93.00	94.00
T_6	PoE Clodinafop-propargyl @ 60 g $^{ha\ -1}$	28.90	76.70	92.80	93.80
T_7	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$	29.25	77.75	93.50	94.50
T_8	Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	29.75	79.25	94.50	95.50
T_9	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + PoE Clodinafop propargyl at 60 g a.i $^{ha\ -1}$	29.60	78.80	94.20	95.20
T_{10}	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	29.50	78.50	94.00	95.00
SEm±		1.25	2.40	2.80	2.65
CD at 5%		NS	7.15	8.35	7.95

Table 3: Effect of different treatment on number of tillers of wheat

Symbol	Treatment	30 DAS	60 DAS	90 DAS	At harvest
T_1	Control (Weedy check)	204.0	320.0	328.0	323.0
T_2	Weed free	220.0	360.0	360.0	355.0
T_3	Rice straw mulch 5 t $^{ha\ -1}$	208.8	332.0	337.6	332.6
T_4	Wheat straw mulch 5 t $^{ha\ -1}$	208.0	330.0	336.0	331.0
T_5	PoE Metsulfuron-methyl @ 4 g $^{ha\ -1}$	212.0	340.0	344.0	339.0
T_6	PoE Clodinafop-propargyl @ 60 g $^{ha\ -1}$	211.2	338.0	342.4	337.4
T_7	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$	214.0	345.0	348.0	343.0
T_8	Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	218.0	355.0	356.0	351.0
T_9	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + PoE Clodinafop propargyl at 60 g a.i $^{ha\ -1}$	216.8	352.0	353.6	348.6
T_{10}	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	216.0	350.0	352.0	347.0
SEm±		9.15	10.60	7.55	14.20
CD at 5%		27.5	31.50	22.40	42.20

Table 4: Effect of different treatment on dry matter accumulation of wheat

Symbol	Treatment	30 DAS	60 DAS	90 DAS	At harvest
T_1	Control (Weedy check)	81.0	620.0	1030.0	1210.0
T_2	Weed free	85.0	700.0	1150.0	1350.0
T_3	Rice straw mulch 5 t $^{ha\ -1}$	82.2	644.0	1066.0	1252.0
T_4	Wheat straw mulch 5 t $^{ha\ -1}$	82.0	640.0	1060.0	1245.0
T_5	PoE Metsulfuron-methyl @ 4 g $^{ha\ -1}$	83.0	660.0	1090.0	1280.0
T_6	PoE Clodinafop-propargyl @ 60 g $^{ha\ -1}$	82.8	656.0	1084.0	1273.0
T_7	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$	83.5	670.0	1105.0	1297.0
T_8	Clodinafop-propargyl + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	84.5	690.0	1135.0	1332.5
T_9	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + PoE Clodinafop propargyl at 60 g a.i $^{ha\ -1}$	84.2	684.0	1126.0	1322.0
T_{10}	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$ + metsulfuron-methyl @ 60 g a.i. $^{ha\ -1}$	84.0	680.0	1120.0	1315.0
SEm±		1.65	19.10	42.85	38.80
CD at 5%		NS	56.60	127.10	115.50

Table 5: Effect of different treatment on yield of wheat

Symbol	Treatment	Biological Yield (q ha−1)	Grain Yield (q ha−1)	Straw Yield (q ha−1)	Harvest Index (%)
T_1	Control (Weedy check)	76.84	31.46	45.38	40.94
T_2	Weed free	127.00	52.00	75.00	40.94
T_3	Rice straw mulch 5 t $^{ha\ -1}$	90.81	37.18	53.63	40.94
T_4	Wheat straw mulch 5 t $^{ha\ -1}$	87.38	35.78	51.60	40.94
T_5	PoE Metsulfuron-methyl @ 4 g $^{ha\ -1}$	104.39	42.74	61.65	40.94
T_6	PoE Clodinafop-propargyl @ 60 g $^{ha\ -1}$	102.62	42.02	60.60	40.94
T_7	PE Metribuzine at 0.175 kg a.i $^{ha\ -1}$	108.59	44.46	64.13	40.94
T_8	Clodinafop-propargyl + metsulfuron-methyl @ 60	121.67	49.82	71.85	40.94
T_9	PE Metribuzine at 0.175 + PoE Clodinafop propargyl	118.36	48.46	69.90	40.94
T_{10}	PE Metribuzine at 0.175 + metsulfuron-methyl @ 60	117.48	48.10	69.38	40.94
SE m±		5.60	1.05	2.40	-
CD at 5%		16.65	3.10	7.10	-

Conclusion

Integrated weed management significantly improved growth and yield of wheat (*Triticum aestivum* L.). The weed-free treatment recorded the highest productivity, remaining at par with Clodinafop-propargyl + metsulfuron-methyl (T_8). Hence, the use of effective herbicidal combinations offers a practical and efficient alternative for achieving higher wheat yield under field conditions.

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Competing Interests

Authors have declared that no competing interests exist.

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