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Effect of herbicides on mixed weed flora in wheat (*Triticum aestivum* L.) and weed control efficiency

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Abstract
Wheat, essential for global food stability, is adversely affected by weed invasions, leading to considerable yield losses. This research, carried out over a two-year period at Sri Durga Ji P.G. College in Chandeswar, Azamgarh, U.P., assessed the effectiveness of different herbicidal treatments on wheat's growth and production. Notable strategies tested included a weed-free scenario (T_{12}), a mix of Sulfosulfuron and Metsulfuron (T_2), and Pendimethalin combined with manual weeding (T_{10}). The findings indicated that advanced weed management approaches, especially those involving multiple herbicides, markedly improved spike density, spike length, spikelets per spike, and total grain yield. Although the weed-free treatment consistently resulted in the best growth metrics and financial gains, it was also the most costly to maintain. In contrast, the weedy check (T_{11}) highlighted the negative impact of unchecked weed growth, exhibiting the poorest growth and yield results. Overall, proficient herbicide use not only boosts wheat productivity but also contributes to greater economic benefits, emphasizing the importance of careful weed management in wheat farming.

Keywords: Wheat, herbicide, growth, weeds, yield

Introduction
Wheat ranks as the second-most crucial cereal crop after rice, belonging to the Poaceae family and characterized by a hexaploid structure with 42 chromosomes. As a significant calorie and carbohydrate source containing virtually no fat, wheat stands as the foremost provider of vegetable protein in human diets globally, boasting about a 13% protein content, which is considerably high compared to other major cereals. It also offers abundant fiber, calcium, thiamine, niacin, iron, riboflavin, vitamin D, and other essential nutrients. Consumed whole, wheat delivers a comprehensive array of nutrients and dietary fiber. In India, wheat underpins national food security and is integral to the production of various food items including bread, cakes, biscuits, noodles, chapattis, and more. Wheat grains consist of starch (60–68%), protein (8–15%), fat (1.5–2.0%), cellulose (2.0–2.5%), and minerals (1.5–2.0%). Contributing over 50% of the calories for its most dependent populations, wheat plays a pivotal role in sustaining food security. Since 1960, global grain production, including wheat, has tripled and projections suggest continued growth through the mid-21st century. Accounting for a staple in the diets of 35% of the world's population, wheat is the most consumed crop globally. Its unique gluten qualities make it indispensable for processed foods, with increasing demand driven by global industrialization and shifts toward Western eating habits. By 2050, it is anticipated that demand for food grains like wheat will double. In the 2018-2019 season, global wheat cultivation spanned approximately 215.45 million hectares, producing around 730.90 million metric tons. India's forecast for the 2020-2021 season estimated production at about 107.59 million metric tons over 31.45 million hectares, with Uttar Pradesh, Punjab, and Madhya Pradesh as major contributors.
Weed infestations pose significant threats to wheat cultivation, especially with the introduction of high-yielding dwarf varieties. Weeds such as Phalaris minor and *Avena ludoviciana* can decrease wheat yields by 15-50%, depending on their density and type. Effective weed management techniques include manual weeding, mechanical methods, and herbicidal

application. However, challenges such as herbicide resistance, exemplified by Phalaris minor's resistance to Isoproturon, complicate control measures. Newer herbicides like Fenoxaprop, Clodinafop, and Sulfosulfuron have proven effective against resistant strains, though concerns about toxicity and impacts on subsequent crops persist.

Herbicides are crucial for managing wheat weeds, with agents like Sulfosulfuron and Metsulfuron-methyl being particularly notable. These herbicides are systemic and selective, targeting specific weeds without harming the wheat. Nonetheless, the continuous use of single herbicide formulations can lead to resistance and raise environmental issues. A mix and sequence of different herbicides are often required to effectively manage a diverse range of weed species. Overall, the global significance of wheat continues to escalate, accompanied by challenges such as weed management. Progress in agricultural practices and herbicide innovations are essential for maintaining wheat production in the face of growing demand and agricultural obstacles.

Materials and Methods

The experiment took place at Sri Durga Ji P.G. College in Chandeswar, Azamgarh, U.P., encompassing an area of 4234 square km, primarily dedicated to agriculture, with a focus on pulses, oilseeds, sugarcane, mangoes, and guavas. Azamgarh is located between 25°38' and 26°27' North latitude and 82°40' and 83°52' East longitude, bordered by Mau, Gorakhpur, Ghazipur, Jaunpur, Sultanpur, and Ambedkar Nagar. The region experiences a hot climate year-round, with temperatures ranging from 48°F to 103°F and an average annual precipitation of approximately 73.21 millimeters. The study involved analyzing soil samples from ten different locations within the field to evaluate their physicochemical properties and fertility status, as outlined in the tables. Industrial development in Azamgarh is limited, with prominent industries including sugar milling, Banarasi sari production, and black pottery.

The experimental crop in Azamgarh received uniform fertilization with 120 kg of nitrogen (N), 80 kg of phosphorus (P), and 80 kg of potassium (K) per hectare, utilizing urea, diammonium phosphate, and muriate of potash, respectively. At sowing, the entire dose of P and K, along with one-third of N, was applied, with the remaining N top-dressed after the first irrigation. Fertilizers were applied just before seeding to facilitate optimal uptake. Sowing was conducted using the HD-2967 wheat variety, planted at a rate of 100 kg per hectare with a row spacing of 20 cm, manually carried out on November 21 for the 2020–21 season and November 03 for the 2021–22 season. Treatment variations among plots addressed pre-emergence and post-emergence requirements. Irrigation was scheduled at critical growth stages, from 20 to 25 days after sowing (DAS), to prevent water stress. Weed management strategies were tailored to each plot based on specific treatment plans. Harvesting involved manual cutting with serrated-edge sickles once 85% of the panicles had matured spikelets. Following harvest, grains were sun-dried for 4-5 days and then threshed using both tractor-drawn equipment and manual labor. The biological yield was determined by weighing the produce post-threshing, and the grain yield was recorded after adjusting for a 14% moisture content.

Results and Discussion

Weed flora of experimental crop

Weed flora of the experimental field was collected and identified at different stages of crop growth. The weeds are classified as grassy weed, sedges and non-grassy weeds. There were several weed species recorded in the field. The major weeds of the experimental field were *Phalaris minor*, *Chenopodium album*, *Anagallis arvensis*, *Melilotus indica* and other weeds *viz. Avena fatua*, *Cynodon dactylon*, *Fumaria parviflora*, *Coronopus didymus*, *Rumex dentatus* and *Cyperus rotundus* which is given in Table 1. At various phases of crop growth, the experimental field's weed flora was collected and identified. The weeds are divided into grassy, sedges and non-grassy categories. In the field, a number of weed species were identified. *Phalaris minor*, *Chenopodium album*, *Anagallis arvensis*, *Melilotus indica* as well as additional weeds such *Avena fatua*, *Cynodon dactylon*, *Fumaria parviflora*, *Coronopus didymus*, *Rumex dentatus* and *Cyperus rotundus* was the main weeds found in experimental wheat crop field. These weeds are also listed in Table 1 which was found in experimental field.

Table 1: Weed flora of experimental crop in weedy check treatment

S.N.	Common name	Scientific name	Family	Habitat
A. Grasses				
1.	Canary grass	*Phalaris minor*	Poaceae	Annual
2.	Bermuda grass	*Cynodon dactylon*	Poaceae	Perennial
B. Sedges				
1.	Nut sedge	*Cyperus rotundus*	Cyperaceae	Perennial
C. Broad leaf weeds				
1.	Lambs quarter	*Chenopodium album* L.	Chenopodiaceae	Annual
2.	Field binder	*Convolvulus arvensis* L.	Convolvulaceae	Perennial
3.	Sweet clover	*Melilotus alba*	Leguminaceae	Annual
4.	Common vetch	*Vicia hirsute*	Leguminaceae	Annual
5.	Dock	*Rumex spp.*	Polygonaceae	Perennial
6.	Blue pimpernel	*Anagallis arvensis* L.	Primulaceae	Annual
7.	Blue dandelion, Chicory	*Cichorium intybus*	Asteraceae	Perennial

Herbicide treatments significantly influenced the density and dry matter accumulation of various weeds in wheat crops, as measured at 30, 60, and 90 days after sowing (DAS) across different experimental periods.

1. **Phalaris minor:** The lowest densities were consistently found under the weed-free treatment (T_{12}) and Pendimethalin with hand weeding (T_{10}), particularly notable at 30 DAS. In contrast, the untreated plots (T_{11}) showed the highest weed densities.
2. **Chenopodium album:** Similarly affected by herbicides, its lowest densities were in plots treated with T_{12} and T_{10}, whereas the highest were in T_{11} across all growth stages. Ashiq *et al.* (2007) [28] also reported that the combination of bromoxynil + MCPA exhibited the highest WCE against

broadleaf weeds such as Chenopodium album, C. murale, Fumaria indica, and Convolvulus arvensis in wheat.

3. **Convolvulus arvensis:** Followed the same pattern, with minimum density under T_{12} and T_{10} and maximum under the weedy check T_{11} at each measurement interval.
4. **Melilotus alba:** Exhibited a significant reduction in density with T_{12} and T_{10}, especially at 30 DAS, compared to other herbicide treatments.
5. **Other Weeds:** Their density was notably less in T_{12} and T_{10} plots at all examined stages, with T_{11} showing the highest weed densities. Hussain *et al.* (2013) [29] also observed that the post-emergence application of bromoxynil + MCPA and triasulfuron herbicides led to an increase in the number of grains per wheat spike, attributed to improved weed control.
6. **Total Weeds:** T_{12} and T_{10} treatments resulted in significantly lower weed densities, showing effective control compared to other treatments. Meena and Singh (2013) [30] also noted an increased efficiency in weed control with the combined tank-mix application of herbicides compared to using them individually.
7. **Dry Matter Accumulation:** The accumulation of dry matter in weeds was lowest in plots under T_{12} and T_{10}, and highest in the weedy check (T_{11}) throughout the study.

These results indicate that consistent and targeted herbicide applications, especially when combined with mechanical weeding, effectively reduce weed competition and manage growth in wheat fields, which is critical for optimizing crop yields. Singh *et al.* (2015) [25] also reported a decrease in dry matter accumulation by weeds in wheat when herbicides were applied in a tank-mix.

The data on nutrient uptake by weeds in wheat fields, influenced by different herbicide treatments, are summarized below:

Nutrient Uptake by Weeds:

1. **Nitrogen:** Maximum nitrogen uptake by weeds occurred in the weedy check treatment (T_{11}), which significantly surpassed all other treatments post-harvest in both experimental years. The lowest uptake was noted under the weed-free treatment (T_{12}).
2. **Phosphorus:** Similar to nitrogen, phosphorus uptake was highest in the weedy check (T_{11}) and lowest in the weed-free scenario (T_{12}) at the harvest stage.
3. **Potassium:** Potassium uptake followed the same pattern, with the highest uptake under the weedy check (T_{11}) and the lowest under the weed-free treatment (T_{12}).

Weed Control Efficiency

The weed-free treatment (T_{12}) and the treatment combining Pendimethalin with hand weeding at 30 DAS (T_{10}) displayed the highest weed control efficiency throughout all growth stages of the wheat, significantly outperforming other treatments. The weedy check (T_{11}) showed the lowest efficiency. Khaliq *et al.* (2014) also noted that the highest HEI was achieved using the urea-based herbicide isoproturon + Carfentrazone ethyl at a dosage of 1000 g a.i. per hectare, in comparison to all other herbicides.

Weed Index

The lowest weed index, indicating effective weed control, was recorded in the weed-free treatment (T_{12}), significantly better than all other herbicide treatments. In contrast, the highest weed index was observed under the weedy check (T_{11}).

These findings highlight the effectiveness of herbicide application in reducing nutrient competition from weeds and improving weed control efficiency in wheat cultivation.

Table 2: Effect of different herbicides application on density of total weeds (m-2) in wheat crop at different growth stages

Symbol	Treatments	30 DAS		60 DAS		90 DAS	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
T_1	Sulfosulfuron 25 g a.i. ha^{-1}	9.13 (82.53)	9.50 (89.23)	8.73 (75.26)	9.09 (81.65)	8.18 (65.99)	8.68 (74.37)
T_2	Sulfosulfuron 25 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	5.94 (34.33)	6.54 (41.72)	5.01 (24.07)	5.77 (32.25)	4.67 (20.97)	5.51 (29.34)
T_3	Sulfosulfuron 25 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	8.15 (65.37)	8.56 (72.26)	7.58 (56.41)	8.08 (64.29)	6.95 (47.36)	7.40 (53.82)
T_4	Clodinafop 60 g a.i. ha^{-1}	8.52 (71.61)	8.96 (79.35)	8.08 (64.35)	8.61 (73.13)	7.56 (56.21)	8.07 (64.16)
T_5	Clodinafop 60 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	6.86 (46.17)	7.33 (52.80)	6.16 (36.99)	6.66 (43.31)	5.50 (29.24)	6.20 (37.49)
T_6	Clodinafop 60 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	7.30 (52.29)	7.35 (53.01)	6.72 (44.23)	7.29 (52.10)	5.96 (34.52)	6.48 (40.98)
T_7	Fenoxaprop 9 EC 240 g a.i. ha^{-1}	8.73 (79.55)	9.34 (86.29)	8.44 (70.18)	8.79 (76.32)	7.87 (60.89)	8.38 (69.31)
T_8	Fenoxaprop 9 EC 240 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	6.47 (40.91)	6.96 (47.53)	5.80 (32.69)	6.48 (40.96)	5.06 (24.66)	5.65 (30.96)
T_9	Fenoxaprop 9 EC 240 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	7.72 (58.69)	8.14 (65.31)	7.18 (50.61)	7.68 (58.01)	6.62 (42.79)	7.23 (51.23)
T_{10}	Pendimethalin 1.0 kg a.i. ha^{-1} pre- emergence followed by hand weeding at 30 DAS	2.20 (3.85)	2.35 (4.53)	3.92 (14.35)	4.76 (21.69)	3.35 (10.23)	4.19 (16.55)
T_{11}	Weedy check	10.36 (106.44)	10.68 (113.21)	12.24 (149.26)	12.69 (159.91)	15.56 (242.78)	15.78 (249.57)
T_{12}	Weed free	1.84 (2.39)	1.97 (2.90)	1.74 (2.01)	1.79 (2.21)	1.58 (1.50)	1.64 (1.70)
	SEm±	0.13	0.14	0.17	0.17	0.27	0.27
	C.D.	0.40	0.42	0.51	0.52	0.82	0.82

Table 3: Effect of different herbicides application on weed control efficiency (WCE) (%) and weed index (%) of wheat crop at different growth stage

Symbol	Treatments	WCE (30 DAS)		WCE (60 DAS)		WCE (90 DAS)		Weed Index (%)	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
T_1	Sulfosulfuron 25 g a.i. ha^{-1}	10.67	9.03	9.67	8.47	9.85	8.19	19.59	20.16
T_2	Sulfosulfuron 25 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	69.27	61.29	58.40	49.96	54.13	49.97	4.93	4.88
T_3	Sulfosulfuron 25 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	34.74	27.02	19.28	18.17	26.27	22.76	14.90	15.00
T_4	Clodinafop 60 g a.i. ha^{-1}	28.05	21.73	15.82	14.15	22.78	21.04	16.73	16.91
T_5	Clodinafop 60 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	53.33	45.69	53.52	45.43	41.90	36.91	10.69	10.69
T_6	Clodinafop 60 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	46.06	38.96	42.93	37.35	38.37	35.14	12.08	12.11
T_7	Fenoxaprop 9 EC 240 g a.i. ha^{-1}	20.75	14.84	13.04	12.04	16.01	14.15	18.03	18.02
T_8	Fenoxaprop 9 EC 240 g a.i. ha^{-1} + Metsulfuron 20 g a.i. ha^{-1}	60.49	52.22	46.70	47.17	50.57	45.84	6.88	7.04
T_9	Fenoxaprop 9 EC 240 g a.i. ha^{-1} + Carfentrazone 50 g a.i. ha^{-1}	38.31	31.85	68.81	25.34	31.74	28.69	13.37	13.58
T_{10}	Pendimethalin 1.0 kg a.i. ha^{-1} pre- emergence followed by hand weeding at 30 DAS	99.90	99.86	73.09	63.11	67.76	62.59	3.23	3.38
T_{11}	Weedy check	0.00	0.00	0.00	0.00	0.00	0.00	50.77	53.76
T_{12}	Weed free	100.00	99.99	99.89	99.86	99.24	99.30	0.00	0.00
	SEm±	1.87	1.75	1.68	1.53	1.59	1.52	0.87	0.91
	C.D.	5.53	5.17	4.97	4.51	4.70	4.48	2.57	2.70

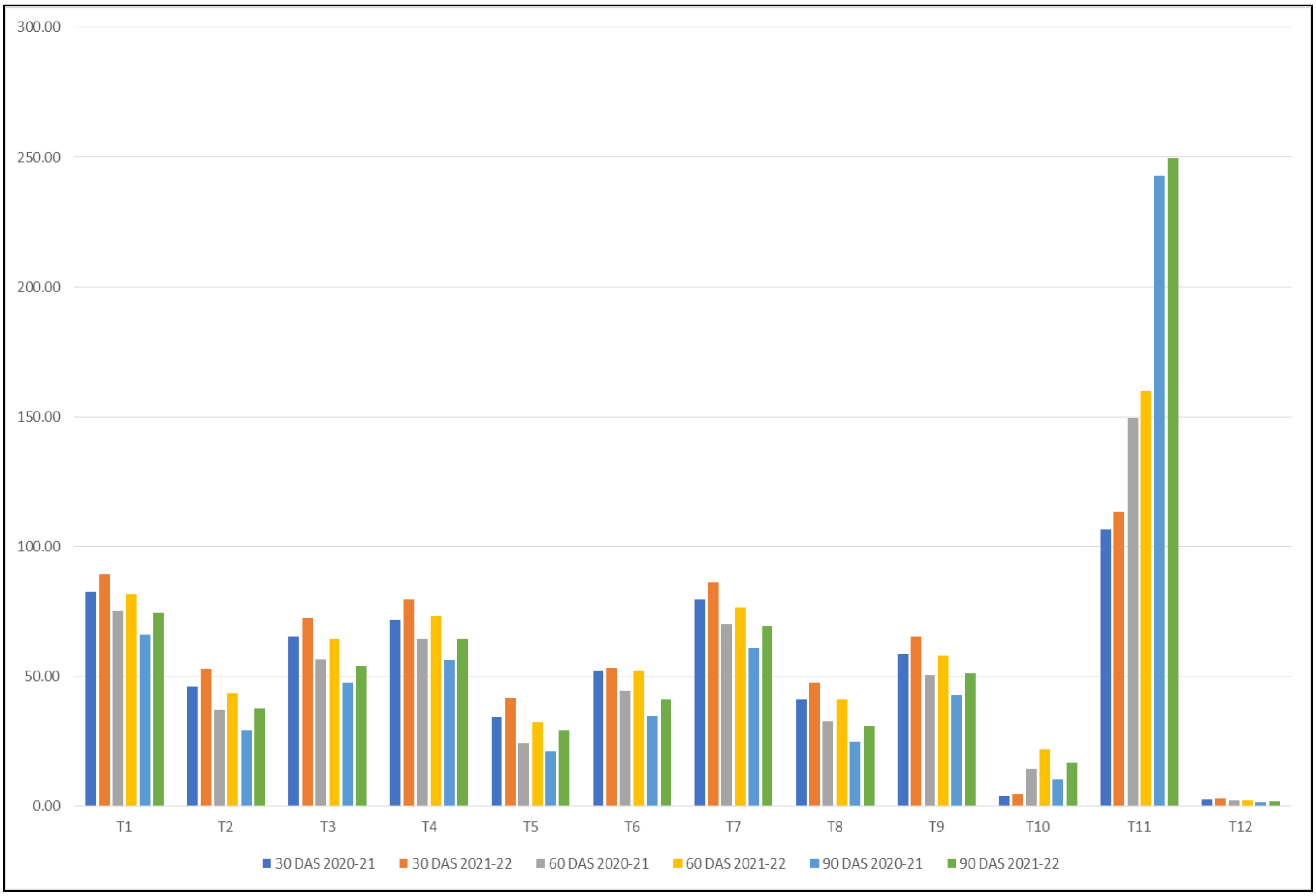

Fig 1: Effect of different herbicides application on density of total weeds (m^{-2}) in wheat crop at different growth stages

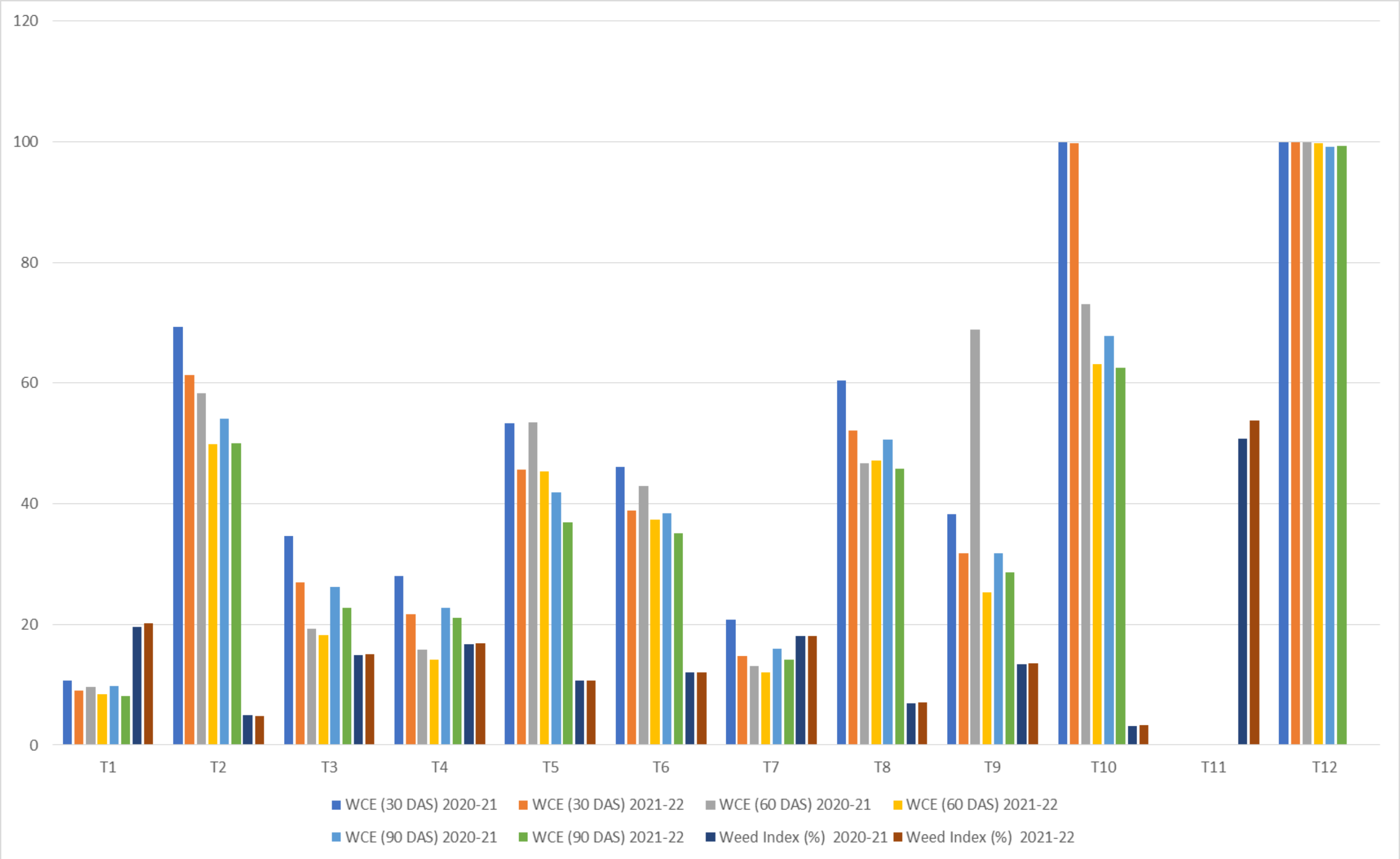

Fig 2: Effect of different herbicides application on weed control efficiency (WCE) (%) and weed index (%) of wheat crop at different growth stages

Conclusion

Herbicide treatments had a significant impact on the growth, yield, and weed control of wheat across two experimental years. The weed-free treatment (T_{12}) consistently showed superior growth metrics, yield outcomes, and economic returns, closely followed by treatments T_{10} (Pendimethalin pre-emergence followed by hand weeding), T_2 (Sulfosulfuron with Metsulfuron), and T_8 (Fenoxaprop with Metsulfuron). These treatments effectively minimized weed density and maximized weed control efficiency. In contrast, the weedy check (T_{11}) demonstrated the lowest growth and yield, coupled with the highest weed density and nutrient uptake by weeds, highlighting the detrimental effects of unmanaged weeds. While the weed-free treatment and other effective treatments involved higher cultivation costs, they also resulted in the highest gross returns. Notably, treatment T_2 provided the highest net returns and the best benefit-cost ratio, marking it as the most economically viable among the top-performing herbicide treatments. In summary, proficient herbicide management not only boosts crop growth and yield but also enhances economic returns by adeptly managing costs against benefits.

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