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Growth, Yield Performance, And Post-Harvest Soil Response To Weed Control In Late-Sown Wheat (*Triticum Aestivum* L.)

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Abstract
This study investigated the impact of weed management strategies on growth performance, yield attributes, and soil status in late-sown wheat (Triticum aestivum L.). The experimental treatments included: (i) a weed-free control, (ii) pre-emergence application of Pendimethalin followed by hand weeding at 30 days after sowing (DAS), and (iii) an untreated weedy check. Both the weed-free control and the Pendimethalin + hand weeding treatment significantly improved plant height, tiller density, dry matter accumulation, and leaf area index compared to the weedy check. Yield components such as the number of spikes per square meter and grains per spike were also markedly enhanced under these treatments. Although spike length and test weight did not differ significantly among treatments, they were numerically superior in the integrated weed management plots. The reduction in crop–weed competition under effective weed control promoted better resource utilization, improved crop establishment, and ultimately increased grain yield. Postharvest soil analysis indicated that integrated weed control practices helped preserve soil health. These findings highlight compare with the importance of timely and integrated weed management—particularly the use of Pendimethalin followed by manual weeding—in maximizing wheat productivity and maintaining soil quality under delayed sowing conditions.
Key words: *Late-sown wheat, Weed management, Herbicide resistance, Broad-spectrum herbicides.*

INTRODUCTION

Wheat (*Triticum aestivum* L.) functions as a cornerstone of global food security, ranking as the second most important cereal crop after rice. In India, it plays a vital role in ensuring caloric intake and livelihood security for millions. Despite considerable expansion in cultivation area and advancements in agricultural inputs, India's wheat productivity (~3.5 t/ha) continues to lag behind that of developed countries such as China and the USA, where yields surpass 5 t/ha (FAOSTAT, 2022). Among the multiple biophysical constraints, weed infestation remains one of the major yield-limiting factors, especially in late-sown wheat. Weeds compete with crops for nutrients, moisture, light, and space, leading to yield losses ranging from 15% to as high as 51%, depending on the severity of infestation and management practices (Chhokar et al., 2012; Rao, 2000).

Traditionally, Isoproturon was widely used as a post-emergence (PoE) herbicide in wheat. However, the continuous and indiscriminate use of Isoproturon has led to the development of resistance, particularly in *Phalaris minor* and other grass weeds, which dominate the wheat agroecosystem in northwestern India (Chhokar and Malik, 2002). This has rendered it ineffective as a standalone solution, necessitating a re-evaluation of current weed control strategies.

In response, alternative herbicides such as Clodinafop-propargyl, 2,4-D, and Pendimethalin have been introduced either alone or in sequential applications. While Pendimethalin (a pre-emergence herbicide) controls annual grasses and some broadleaf weeds, its efficacy declines under dry conditions, common in late-sown wheat. Similarly, post-emergence herbicides such as Clodinafop (grass-specific) and 2,4-D (broadleaf-specific) suffer from narrow weed spectrum and require precise timing for application. Moreover, antagonistic effects have been reported when certain combinations (e.g., Clodinafop + Isoproturon) are used, often resulting in reduced efficacy or phytotoxicity (Yadav et al., 2017).

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In late-sown wheat, the challenges intensify further due to:Compressed growth period, which reduces crop competitiveness against weeds; shifts in weed flora, favouring hardy and late-emerging species; moisture stress and reduced herbicide efficacy during the winter season.
Hence, the existing chemical control options are no longer sufficient to manage the increasingly complex and resistant weed flora. Manual weeding is effective but labour-intensive, costly, and impractical on a large scale, especially under rural labour scarcity conditions. These constraints have created a critical research gap in identifying integrated and effective weed management strategies that are both economically viable and environmentally sound for late-sown wheat production systems.
Therefore, the present investigation was undertaken to evaluate the efficacy of different herbicide combinations, hand weeding, and integrated approachesfor sustainable weed management in late-sown wheat. By assessing weed control efficiency, crop growth, and yield attributes under these treatments, the study aims to provide recommendations that could contribute to sustainable intensification of wheat production while addressing the issue of herbicide resistance and weed shifts.

MATERIALSANDMETHODS

The experiment was conducted at the Agronomy Farm of GD Goenka University Sohna (Gurugram) during Rabi January 2022. The field was well-levelled with good soil conditions. Sohna, Gurugram, is geographically located in a subtropical climate at 27°37' North latitude and 77°36' East longitude, with an altitude.During the crop season, weekly minimum and maximum temperatures ranged from 5.5°C to 37.6°C. Average relative humidity ranged from 53.00% to 76.6%, evaporation from 2.6 to 7.2 mm per day, and sunshine hours from 3.6 to 9.6 hours per day. The total rainfall received during the crop period was 61.5 mm.The mechanical composition of the soil was determined using the hydrometer method (Bouyoucos, 1936). The soil texture was classified using the triangular method (Lyon et al., 1952). The soil was classified as sandy loam.The chemical analysis indicated that the soil was low in nitrogen, organic carbon, and phosphorus, and rich in potassium. The soil reaction was slightly alkaline.The treatments consisted of different weed management practices in wheat crops. All herbicides were applied as post-emergence treatments at 30 days after sowing (DAS). The treatments included eight weed-management practices were as follows: T1: Pendimethalin + Hand weeding 30 DAS (Pendimethalin 30%EC) 1-1.5 kg/acre PE, T2: Clodinafop +Isoproturon (clodinafop propargyl 15% WP, T3: 24-D (200ml per acre)38% EC, T4: Hand weeding, T5: Pendimethalin (30% EC), T6: Isoproturon (75 % WP) 200-400gm/acre (PoE), T7: Weedy check, T8: Weed Free. The layout plan of the experiment was design in Randomized Block Designwith three replications, eight treatments.

RESULTS AND DISCUSSION

The results obtained from a study on weed management in a late-sown wheat crop (*Triticumaestivum* L.). The data includes observations on weed flora, wheat growth, yield attributes, yield, economics, and nutrient uptake.

Weed Flora

The weed flora of the experimental field was identified and categorized at 30, 60, and 90 days after sowing (DAS). The weeds were classified into grassy weeds, sedges, and non-grassy weeds (Table1). The predominant weed species included *Phalaris minor*, *Chenopodium*

Table-1: Weed flora in experimental field (species)at30,60and90DAS.

	species	Common name	Family	Habitat
A-WeedGrasses				
1.	*Phalaris minor*	Canary grass	Poaceae	Annual
2.	*Avena fatua*	Wildoat	Poaceae	Annual
3.	*Cynodondactylon*	Bermudagrass	Poaceae	Annual
B-Sedges				
1.	*Cyperusrotundus*	Nutsedge	Cyperaceae	Perennial
C-Broadleafweeds				
1.	*Chenopodiumalbum* L.	Lambisquarter	Chenopodiaceae	Annual
2.	*Convolvulusarvensis* L.	Fieldbinder	Convolvulaceae	Annual
3.	*Anagallisarvensis*L.	Bluepimpernal	Primulaceae	Annual

4.	*Melilotusalba* Medikus	Sweetclover	Leguminaceae	Annual
5.	*Coronopusspp.*	Lesserswine-cress	Brassicaceae	Annual
6.	*Rumexspp.*	Dock	Polygonaceae	Perennial

album, *Anagallis arvensis*, and *Melilotus indica*. Other weeds observed were *Avena fatua*, *Cynodon dactylon*, *Convolvulus arvensis*, *Cronopus didymus*, *Rumex dentatus*, and *Cyperus rotundus*.

The presence of diverse weed flora, including grassy weeds like *Phalaris minor*, *Cynodon dactylon*, and *Avena fatua*, broadleaf weeds like *Chenopodium album*, *Convolvulus arvensis*, *Anagallis arvensis*, *Melilotus alba*, *Rumex spp*, and *Vicia hirsuta*, and sedges like *Cyperus rotundus*, aligns with weed flora compositions reported in other studies of wheat crops under both normal and late-sown conditions (Bharat et al., 2012; Bhullar et al., 2012; Singh et al., 2017).

Density of *Phalarisminor* (m^{-2})

The density of *Phalaris minor* was significantly influenced by weed control methods at all stages of crop growth (Table 2). The lowest density was observed in the two-hand weeding (30 and 60 DAS) and weed-free treatments, while the highest density was found in the weedy check and Isoproturon (75 % WP) 200-400gm/acre (PoE) treatments.

The effectiveness of hand weeding and weed-free treatments in reducing *Phalaris minor* density can be attributed to the removal of the initial flush of weeds, preventing subsequent flushes from attaining full growth under the wheat canopy. The lower weed density in the weed-free treatment, which used herbicides, is likely due to the broad-spectrum activity of the herbicides, effectively controlling both narrow and broadleaf weeds, as similarly reported by Singh et al. (2011).

Density of *Anagalis arvensis* (m^{-2}):

The density of *Anagalis arvensis* was have been presented in Table 3 and illustrated as per result indicated that the density of *Anagalis arvensis* at 30 & 60 DAS was observed significantly lowest with the Two hand weeding (30 and 60 days after sowing) and weed free over other treatments. At 60 and 90 DAS density of *Anagalis arvensis* was found significantly lowest with Two hand weeding (30 and 60 days after sowing) while highest density of *Anagalis arvensis* Weedy check and 2,4-D (200ml per acre)38% EC over other treatments. It seems that successive growth stages of crop, two hand weeding (30 and 60 days aftersowing) and weed free recorded lowest weed density might be due to the first flush of weeds were hand weeded (in 30 DAS), after that the next flushes of weeds could not attain full growth under the shade of wheat plant. While in herbicides treated plot, lowest weed density was found in Weed free treatment, this might be due to broad- spectrum activity of herbicide particularly on established plants of both narrow and broad leaf weeds, something similar finding reported by Singh et al. (2011).

Table-2 Phalarisminordensity (m^{-2}) at successive growth stages as affected by different weed control methods in wheat crop:

Treatments	***P.minor*(m^{-2})**		
	30DAS	**60DAS**	**90DAS**
T1-Pendimethalin+Handweeding30DAS (Pendimethalin30%EC)1-1.5kg/acrePE	2.34** (5.00)*	3.08 (9.00)	3.22 (9.90)
T2- Clodinafop +Isoproturon (Clodinafoppropargyl 15%WP	1.87 (3.01)	3.67 (13.01)	3.96 (15.20)
T3-24-D(200ml per acre)38%EC	4.52 (19.99)	4.24 (17.49)	4.61 (20.81)
T4-Handweeding (30&60DAS)	1.58 (2.01)	2.91 (8.01)	2.91 (8.01)
T5-Pendimethalin(30%EC)	1.86 (2.99)	3.38 (10.99)	3.62 (12.64)
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	4.79 (22.52)	4.12 (16.51)	4.90 (19.36)
T7-Weedycheck	4.74 (21.99)	5.95 (34.99)	6.78 (45.49)

T8-WeedFree	1.58 (2.01)	1.87 (3.01)	1.91 (3.16)
SE(m)	0.303	0.343	0.518
C.D.	0.927	1.049	1.586

Table3:- Density of *Anagalisarvensis* (m^{-2}) at successive growth stages as affected by different weed control methods in wheat crop:

Treatments	*Anagalisarvensis*(m^{-2})		
	30DAS	60DAS	90DAS
T1- Pendimethalin + Hand weeding 30 DAS(Pendimethalin30%EC) 1-1.5 kg/acrePE	2.11** (3.99)*	2.33 (4.99)	2.44 (5.49)
T2-Clodinafop+Isoproturon(clodinafoppropargyl15% WP	1.87 (3.01)	2.74 (7.01)	2.94 (8.20)
T3-24-D(200mlperacre)38%EC	3.93 (14.99)	3.87 (14.49)	4.23 (17.46)
T4-Handweeding (30&60DAS)	1.86 (3.01)	3.16 (10.01)	3.42 (11.21)
T5-Pendimethalin(30%EC)	1.86 (2.99)	2.85 (7.65)	3.11 (9.19)
T6-Isoproturon(75% WP)200-400gm/acre(PoE)	3.67 (13.01)	3.46 (11.51)	3.75 (13.61)
T7-Weedycheck	3.67 (12.99)	4.74 (21.99)	5.07 (25.25)
T8-WeedFree	1.22 (1.01)	1.58 (2.01)	1.61 (2.11)
SE(m)	0.459	0.732	1.310
C.D.	1.407	2.243	4.013

Density of *Avenafatua*(m^{-2}):

Density of *Avena fatua* was recorded at the 30th, 60th, 90th DAS of crop growth have been presented in Table4 as per result in dicated that the density of *Avenaf atua* were significantly affected by weed control methods al all the stages of crop growth.

At 30 & 60 DAS the lowest density of *Avena fatua* was observed with the Two hand weeding (30 and 60 days after sowing) and weed free which was significantly in ferioroverrest of the treatments. However, 60 DAS *Avena fatua* was found significantly lowest density under application of Two hand weeding (30and60 days after sowing) overrest of the treatment. At 90 DAS same trends was found in case of 30 DAS. Weed free treatmentlowest density over rest of the treatments. Among the treatments, the lowest density of *Avenafatua* was reduce with the application weed free and two hand weeding significantly. This might be due to first flushof weed swere hand weeded(30DAS),after that the next flush es of weeds could not attain full growth under the shade of wheat plant. In case of herbicides, lower weed density was found withT1-Pendimethalin +Handweeding 30 DAS (Pendimethalin 30%EC) 1-1.5 kg/acre PE, this might be due to due to broad-spectrum activity of herbicide particularly narrowand broad leaf weeds, some similar finding reported by Singh *etal*. (2011).

Table 4: - Density (m-2) of *Avena fatua* at successive growth stages as affected by different weed control methods in wheat crop.

Treatments	*Avenafatua*(m^{-2})		
	30DAS	60DAS	90DAS
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC) 1-1.5 kg/acrePE	2.33** (4.99)*	2.11 (3.99)	3.54 (12.07)
T2- Clodinafop +Isoproturon (Clodinafoppropargyl 15%WP	2.35 (5.01)	2.34 (5.01)	3.43 (11.24)

T3-24-D(200mlperacre)38%EC	3.38 (10.99)	3.08 (8.99)	2.81 (9.06)
T4-Handweeding (30&60DAS)	2.34 (5.01)	2.12 (4.01)	3.09 (9.03)
T5-Pendimethalin(30%EC)	2.54 (5.99)	2.11 (3.99)	3.54 (12.10)
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	3.16 (10.01)	3.54 (9.01)	3.33 (10.65)
T7-Weedycheck	3.16 (10.01)	3.93 (15.01)	3.82 (14.11)
T8-WeedFree	1.57 (1.99)	1.57 (1.99)	1.68 (2.34)
SE(m)	0.255	0.562	0.582
C.D.	0.781	1.722	1.782

Density of other weeds(m^{-2}):

Data pertain in gon density of other weeds have been presented in Table 5 as per result indicated that the density of other weeds were significantly affected by weed control methods at all the successive growth stages of wheat crop. The density of other weeds has been observed significantly lowest under the application of two-hand weeding (30 and 60 days after sowing) and weed free treatment. This was significantly inferior over rest of the treatment at 30 and 90 DAS. In case of herbicide lowest density found under Pendimethalin+ Handweeding30DAS(Pendimethalin30%EC)1-1.5 kg/acre PE over rest of treatments. At 60 DAS the lowest density of other weeds wasre corded with of two hand weeding (30 and 60 days after sowing) and weed free. This might be due to the first flush of weeds being hand weeded(DAS), after that then extflushes of weeds could not attain full growth under the shade of the wheat plant.

Table5:- Density of otherweeds (m^{-2})at successive growth stages asaffected by different weed control methods in wheatcrop.

Treatments	Otherweeds(m^{-2})		
	30DAS	**60DAS**	**90DAS**
T1- Pendimethalin + Hand weeding 30 DAS(Pendimethalin30%EC) 1-1.5 kg/acrePE	2.11** (3.99)*	2.54 (5.99)	2.83 (7.51)
T2-Clodinafop+Isoproturon(Clodinafoppropargyl15% WP	2.12 (4.01)	2.91 (8.01)	3.21 (9.84)
T3-24-D(200ml per acre)38%EC	2.82 (7.49)	3.23 (9.99)	4.23 (17.45)
T4-Handweeding (30&60DAS)	2.34 (5.01)	2.34 (5.01)	3.75 (13.57)
T5-Pendimethalin(30%EC)	2.34 (4.99)	2.54 (5.99)	3.66 (12.91)
T6-Isoproturon(75% WP)200-400gm/acre(PoE)	2.64 (6.51)	3.53 (12.01)	4.35 (18.47)
T7-Weedycheck	2.55 (6.01)	3.53 (12.01)	3.80 (14.01)
T8-WeedFree	1.57 (1.99)	1.86 (2.99)	1.72 (2.46)
SE(m)	0.373	0.415	0.862
C.D.	1.141	1.271	2.640

In herbicides, highest weed density was observed in Isoproturon (75 % WP) 200-400gm/acre (PoE), which was due toresistant of herbicide particularly by established weeds, some similar finding reported by Singh et al. (2011).

Density of total weeds(m^{-2}):

Density of total weeds was recorded at 30th, 60th, 90th DAS of crop growth have been presented in Table 6 as per result indicated that the densityof other weeds was significantly affected by weed control methods at all the stages ofcrop growth.

The lowest density of total weeds at 30 & 60 DAS was observed with the two-handweeding (30 and 60 days after sowing) and weed free treatment. In case of herbicides, Pendimetha lin+ Handweeding 30DAS (Pendimethalin30%EC)1-1.5kg /acr ePE found significantly lowest density with over other treatment. At60 and 90DAS total weeds was found significantly lowest density with weed free overrest of the treatment.

Table6:-Density of total weeds (m^{-2})at successive growth stage as affected by different weed control methods in wheatcrop:

Treatments	Totalweeds(m^{-2})		
	30DAS	60DAS	90DAS
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC) 1-1.5 kg/acrePE	4.52** (19.99)*	5.14 (25.99)	5.39 (28.59)
T2- Clodinafop +Isoproturon (Clodinafoppropargyl 15%WP	4.30 (18.01)	6.51 (42.01)	7.04 (49.15)
T3-24-D(200ml per acre)38%EC	8.21 (66.99)	7.84 (60.99)	8.59 (73.31)
T4-Handweeding (30&60DAS)	4.18 (17.01)	5.61 (31.01)	5.93 (34.73)
T5-Pendimethalin(30%EC)	4.63 (20.99)	6.04 (35.99)	6.47 (41.39)
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	8.07 (64.67)	7.64 (58.01)	8.29 (68.31)
T7-Weedycheck	7.90 (62.01)	10.12 (102.01)	11.53 (132.61)
T8-WeedFree	3.53 (11.99)	3.93 (14.99)	4.02 (15.74)
SE(m)	0.531	0.594	1.061
C.D.	1.627	1.819	3.248

*The value in parent hesis is original value

**Value transformed by$\sqrt{X}$+0.5.

At 30, 60 and 90 DAS of crop growth, among all the treatments, two hand weeding (30 and 60 days after sowing) recorded lowest weed density because of the first flush of weeds were hand weeded (30 DAS), after that the next flushes of weeds could not attain full growth under the shade of wheat plant. In herbicides, highest weed density was found with Isoproturon (75 % WP) 200-400gm/acre (PoE) and 24-D (200ml per acre)38% EC treated plot, which was due to broad- spectrum activity of herbicide particularly on established plants of both narrow and broad leaf weeds, almost similar finding reported by Singh et al. (2011).

Dry weight of weeds(gm^{-2})

Dry weight of weeds was recorded at 30th, 60th, 90th DAS of crop growth have been presentedin Table7 as per result in dicated that the weed control methods were significantly affected on dry weight of weed sat 30and 60DAS crop growth and non- significantly effected at90 DAS(Table7)

At 30 DAS lowest dry weight of weeds was observed with Two hand weeding (30 and 60 days after sowing) and weed free treatment which found significantly over other treatments. At 60 DAS dry weight of weeds were found significantly lowest with Two hand weeding (30and 60 days after sowing) and weed free treatment over rest of the treatments. At 90DAS the weed control methods were nonsignificantly affected on dry weight of weeds.

As weeds density reduces, in case of herbicide lowest density found Pendimethalin + Hand weeding 30DAS (Pendimethalin30%EC)1-1.5kg /acre PE treatment .something Similar findings were also reported by Singh *etal*.(2010), Singh*etal*.(2011). Meena and Singh(2011).

Weed control efficiency (%)

Weed control efficiency have been recorded and presented in Table 8 as per result indicated that the weed control methods were significantly affected on weed control efficiency.

At 90 DAS Weed control efficiency recorded highest (89.92%) with weed free in cause of herbicide Pendimethalin + Hand weeding 30 DAS over rest of the treatments.This was mainly due to lowest weed dry weight under the effects of above treatment. something Similar finding was reported by Meena and Singh (2011), Tomar and Tomar (2014).

Table7:-Weeds dry weight(gm^{-2}) at successive growth stage as affected by different weed control methods in wheat crop:

Treatments	Dry weight of weed(gm^{-2})		
	30 DAS	60 DAS	90 DAS
T1-Pendimethalin+Handweeding30DAS(Pendimethalin 30%EC) 1-1.5kg/acrePE	2.91** (7.99) *	4.01 (15.59)	4.20 (17.15)
T2-Clodinafop+Isoproturon(Clodinafoppropargyl15% WP	2.78` (7.21)	5.07 (25.21)	5.47 (29.49
T3-24-D(200ml per acre)38%EC	5.20 (26.59)	6.09 (36.59)	6.51 (41.92)
T4-Handweeding (30&60DAS)	2.70 (6.81)	4.37 (18.61)	4.61 (20.84)
T5-Pendimethalin(30%EC)	2.98 (8.39)	4.70 (21.59)	5.03 (24.83)
T6-Isoproturon(75% WP)200-400gm/acre(PoE)	5.12 (25.81)	5.94 (34.81)	6.29 (39.17)
T7-Weedycheck	5.02 (24.79)	7.85 (61.19)	8.77 (76.55)
T8-WeedFree	2.48 (5.69)	3.53 (12.02)	3.11 (9.23)
SE(m)	0.422	1.025	1.389
C.D.	1.292	3.138	4.253

*The value in parent hesisis original value

**Value transformed by$\sqrt{X}$+0.

Plant Height (cm)

Plant height measurements of wheat at 30, 60, and 90 days after sowing (DAS) and at harvest are presented in Table 9 The data indicate that weed management practices significantly influenced plant height at all growth stages except at 30 DAS. At 60 DAS, significantly taller plants were recorded in the treatments Weed Free (92.40 cm) and Pendimethalin + Hand Weeding at 30 DAS (83.99 cm), compared to the other treatments.

The tallest plants across all stages were observed in the Weed Free treatment, likely due to reduced weed competition, which enhanced the availability of soil moisture and nutrients, thereby promoting better vegetative growth. These results are in agreement with the findings of Chaudhary et al. (2020) and Kumar et al. (2021), who reported that effective weed control leads to increased plant height due to enhanced resource availability.

Table 8: -Weed control efficiency (%) as affected by different weed control methods in wheat crop:

Treatments	Weed control Efficiency (%)
T1- Pendimethalin + Hand weeding 30 DAS (Pendimethalin 30%EC) 1-1.5 kg/acre PE	78.41
T2- Clodinafop + Isoproturon (Clodinafop propargyl 15% WP	62.95
T3- 24-D (200ml per acre)38% EC	53.07

T4- Hand weeding (30 & 60 DAS)	73.82
T5 -Pendimethalin (30% EC)	68.77
T6- Isoproturon (75 % WP) 200-400gm/acre (PoE)	56.55
T7- Weedy check	00.00
T8- Weed Free	89.92
SE (m)	0.609
C.D.	1.865

Number of Tillers (m⁻²)

Tillering data at different crop growth stages are summarized in Table 9. Weed management practices significantly affected the number of tillers at all stages. The highest number of tillers was recorded under the Weed Free (335 m^{-2}) and Pendimethalin + Hand Weeding at 30 DAS (319 m^{-2}) treatments.This increase in tiller production can be attributed to effective early-season weed suppression, which reduced intra-species competition and enabled the wheat plants to utilize nutrients more efficiently. Similar results were reported by Yadav et al. (2018) and Patel et al. (2022), who observed that herbicide treatments coupled with hand weeding improved the tiller density in late-sown wheat.

Dry Matter Accumulation (kg/ha)

Dry matter accumulation (DMA) values at 60, 90 DAS and harvest are presented in Table 9. Weed Free plots showed significantly higher DMA (1258 kg/ha), followed closely by Pendimethalin + Hand Weeding at 30 DAS (1204 kg/ha), while the lowest accumulation was observed in the Weedy Check (884 kg/ha).The improvement in DMA under effective weed management is likely due to cumulative effects of increased photosynthetic activity, greater leaf area, and better plant growth. According to Verma et al. (2020) and Rana et al. (2023), dry matter accumulation is a reliable indicator of biomass productivity and is positively influenced by integrated weed control measures.

Table 9:- Plant height (cm)at successive growth stages as affected by different weed control methods in wheat crop:

Treatments	Plant Height	No. of tillers	Dry matter accumulation	LAI at 90DAS
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC)1-1.5 kg/acrePE	83.99	319.00	1204.0	3.97
T2-Clodinafop +Isoproturon (clodinafoppropargyl 15%WP	73.01	273.00	1049	3.79
T3-24-D(200ml per acre)38%EC	70.49	249.00	951.0	5.65
T4-Handweeding (30&60DAS)	75.01	289.00	1119.0	3.89
T5-Pendimethalin(30%EC)	73.89	284.00	1098.0	3.80
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	72.11	259.00	982.0	5.73
T7-Weedycheck	67.31	232.00	884.0	2.96
T8-WeedFree	92.40	335.00	1258.0	4.35
SE(m)	1.15	0.535	2.138	0.263
C.D.	3.54	1.637	6.548	0.824

Leaf Area Index (LAI)

LAI recorded at 90 DAS is summarized in Table 9. The highest LAI was observed in Isoproturon (5.73) and 2,4-D (5.65) treatments, followed by Weed Free (4.35) and Pendimethalin + Hand Weeding (3.97). The lowest LAI was observed in the Weedy Check (2.96).An increase in LAI under effective weed control treatments may be attributed to reduced weed competition, resulting in better leaf expansion, higher photosynthetically active radiation (PAR) interception, and enhanced chlorophyll content. The results align with findings by Sharma and

Kaur (2019) and Pandey et al. (2022), who concluded that optimum LAI plays a crucial role in maximizing biomass and yield in wheat.

Yield Attributes

Number of Spikes m^{-2}

The results with respect to the number of spikes per m^2 are presented in Table 10. Weed control methods significantly influenced spike density. The highest number of spikes per m^2 was recorded under the Weed Free treatment, followed by the Pendimethalin + Hand Weeding at 30 DAS treatment. These findings suggest that timely and effective weed control improves crop stand and productive tillering, thereby enhancing spike formation. Similar observations have been reported by Kumar et al. (2021) and Rana et al. (2023), who emphasized that weed-free environments increase spike-bearing tillers due to reduced competition for light, nutrients, and moisture.

Length of Spike (cm)

Data on spike length revealed no significant differences among treatments. However, the maximum spike length (10.90 cm) was observed in the Weed Free treatment, followed by Pendimethalin + Hand Weeding at 30 DAS. Although not statistically significant, the trend reflects the overall improved crop health and assimilate partitioning under reduced weed pressure. These trends are consistent with findings of Patel et al. (2022) and Sharma and Singh (2020), who noted marginal improvements in spike length under effective weed control, though often not statistically significant.

Number of Grains per Spike

The number of grains per spike was significantly influenced by weed control treatments. The Weed Free plot recorded the highest grain count, followed closely by Pendimethalin + Hand Weeding at 30 DAS. This increase can be attributed to enhanced photosynthetic efficiency and reduced intra-species competition, resulting in better grain development. These findings are corroborated by Yadav et al. (2019) and Verma et al. (2021), who emphasized that better grain setting is closely linked to reduced weed pressure and better resource allocation.

Table10:- No. of spikes(m^{-2}), Length of spike (cm), No. of grains spike^{-1}and Test weight (g) as affected by different weed control methods in wheatcrop

Treatments	No. ofspike (m^{-2})	Lengthof spike(cm)	No. ofgrainspike^{-1}	Testweight(g)
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC)1-1.5kg/acrePE	253.00	10.55	45.01	41.75
T2- Clodinafop +Isoproturon(clodinafoppropargyl 15%WP	244.00	9.45	41.79	40.20
T3-24-D(200ml per acre)38%EC	232.00	9.55	39.59	40.49
T4-Handweeding(30&60DAS)	252.00	10.19	42.29	41.35
T5-Pendimethalin(30%EC)	250.00	10.08	42.19	41.29
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	237.00	9.69	40.39	40.07
T7-Weedycheck	222.00	9.33	38.60	40.34
T8-WeedFree	280.00	10.90	45.80	40.680
SE(m)	1.642	0.200	0.446	0.313
C.D.	5.029	0.614	1.365	0.959

Test Weight (g)

Test weight (1000-grain weight) showed non-significant differences among treatments. However, the highest test weight (41.75 g) was observed in the Pendimethalin + Hand Weeding treatment, while the lowest (40.34 g) was in the Weedy Check. Though statistically insignificant, slight variations in test weight may be attributed to the improved grain filling under effective weed control regimes. These results are supported by Kaur et al. (2018) and Singh et al. (2022), who reported that improved grain development and kernel weight are outcomes of enhanced nutrient uptake and source–sink efficiency under clean weed conditions. Yield attributes are the resultant expression of cumulative vegetative and reproductive development, both of which are enhanced by effective weed control through improved access to nutrients, moisture, space, and light. This is in line with the findings of Rathore et al. (2020) and Pandey et al. (2023).

Biological yield

Data pertaining to biological yield are presented in Table-11 result indicated that the weed control methods were significantly affected on biological yield**.**

The highest biological yield recorded with weed free and in cause of her bicide Pendimethalin +Hand weeding 30 DAS (Pendimethalin 30%EC)1-1.5kg/ acre PE over other treatments. This might be due to effective weed control by such as to treatment enhance ment more growth and development resulted more biological yield. Something Similar finding reported by**Malik et al (2013) and Tomar and Tomar(2014)**

Grainyield

The data pertaining to the grain yield presented inTable-11 that the weed control method swere significantly affected on grain yield.

The highest grain yield50.00 qha^{-1}recorded with weed free and in cause of herbicide Pendimethalin + Hand weeding 30DAS (Pendimethalin 30%EC) 1-1.5kg/acre PE over rest of treatments. Grain yield increase due to the effects of the respective weed management practices, which resulted check weed growth in more causes crop get more space,nutrient and inter caption of higher by canopy which ultimately increases translocation of food from source to sink, resulted more grain yield. Maximum grain yield(50.60qha^{-1})wasobtainedwithweedfree,itwasincreasedby12.05%,3.92%and 3.55% under treatments of T4, T6and T7respectively Almost similarfindingwas reported by **Tomar and Tomar (2014) and Malik *et al.* (2013).**Straw yield(qha^{-1}) Data pertaining to the straw yield as influenced by seed rate and weed management practices are presented in Table-11as per result that the weed control methods significantly affected on grain straw yield over weed ycheck.

The highest straw yield recorded (75.00) with weed free and in cause of herbicide Pendimethalin +Handweeding 30DAS (Pendimethalin30%EC)1-1.5kg/acre PE overrest of the treatments. The above findings may be due to effective control of weeds which contributed to better growth parameters and yield attributes, better vegetative growth coupled with higher yield attributes resulted in higher straw yield over restof the weed management practices something similar finding reported by **Malik *etal.*(2013),Tomar andTomar(2014).**

Table.11:- Biological yield (qha^{-1}),Grain yield(qha^{-1}),Straw yield(qha^{-1})and H.I.(%)as affected by control methods in wheat crop:

Treatments	Biological yield(qha^{-1})	Grainyield(qha^{-1})	Strawyield(qha^{-1})	H.I.
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC) 1-1.5 kg/acrePE	120.00	48.00	72.00	39.00
T2- Clodinafop +Isoproturon (clodinafoppropargyl 15%WP	104.00	41.00	63.00	41.00
T3-24-D(200ml per acre)38%EC	95.00	37.00	57.00	38.00
T4-Handweeding(30&60DAS)	111.00	44.00	67.00	39.00
T5-Pendimethalin(30%EC)	109.00	43.00	66.00	38.00
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	98.00	38.00	59.00	40.00
T7-Weedycheck	88.00	34.00	53.00	38.00
T8-WeedFree	125.00	50.00	75.00	40.00
SE(m)	0.354	0.354	0.791	0.463
C.D.	1.083	1.083	2.421	1.418

HarvestIndex:
The data pertaining to harvestind exhave been recorded and presentedin Table11 as per result in dicated that the weed control methods were nonsignificantly affected on harvestindex. Maximum harvestindex (40.20) is found intreatment weed free in cause of herbicide maximum harvest index Clod in a fop + Isoproturon(clodinafoppropargyl15%WP and minimum (38.00) in weedy check and cause of herbicide Pendimethalin (30%EC)(38.00).

Economics:
Costofcultivation (Rs.ha^{-1}):
In all weed control methods maximum cost of cultivation (Rs.38828.00ha^{-1}) Hand weeding (30&60DAS) was higher than rest of the treatments.

Table12: - Cost of cultivation (Rs. ha^{-1}), Gross return (Rs. ha^{-1}), Netreturn (Rs.ha^{-1})andB:Cratio(Rs.Re^{-1}invested)as affected by different weed control methods in wheat crop:

Treatments	Cost ofCultivation(Rs.ha^{-1})	Grossreturn(Rs.h a^{-1})	Netreturn(Rs.ha^{-1})	B:C ratio
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC)1-1.5kg/acrePE	38728	117303	78574	2.04
T2- Clodinafop +Isoproturon(clodinafoppropargyl15%WP	38604	101679	63075	1.64
T3-24-D(200mlperacre)38%EC	38478	91775	53791	1.41
T4-Handweeding (30& 60 DAS)	38828	108871	70042	1.79
T5-Pendimethalin(30%EC)	38480	106737	68258	1.77
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	38178	95163	56984	1.49
T7-Weedycheck	37704	85068	47364	1.26
T8-WeedFree	38404	123216	84812	2.20

Gross return(Rs.ha^{-1}):
Inall weed control methods higher gross return gross return(Rs.123216.00ha^{-1}) found in treatment weed free.
Net return(Rs.ha^{-1}):
Inall weed control methods maximum net return ofRs.84812.00received with the treatment of weed free.
Benefit: cost ratio:
Weed free was not found to be economical in comparison too ther herbicidal treatments because of its high expenditure involved in keeping the plots free ofweeds. In the herbicides the better net return and net return per rupee investment wa smain lyduetoless increase in cost of cultivation with these treatments compare to(T8)weed free. All some similar result reported by**Saha & Rao(2010).**

Table13:- Physio-chemical property of soil after harvesting of crop as affected by different weed control methods in wheat crop:

Treatments	Soil pH	EC (dsm^{-1})	OC (%)	Avail. N (kg ha^{-1})	Avail. P (kgha^{-1})	Avail. K (kgha^{-1})
T1-Pendimethalin+Handweeding30DAS(Pendimethalin30%EC)1-1.5kg/acrePE	7.8	0.29	0.30	149.0	14.00	287.0

T2- Clodinafoppropargyl 15% WP +Isoproturon	7.9	0.30	0.29	147.6	13.0	273.0
T3-24-D(200ml per acre)38%EC	8.1	0.28	0.29	145.0	13.00	282.0
T4-Handweeding(30&60DAS)	8.0	0.29	0.30	147.0	13.00	279.0
T5-Pendimethalin(30%EC)	7.9	0.28	0.33	145.0	13.00	282.0
T6-Isoproturon(75%WP)200-400gm/acre(PoE)	7.8	0.29	0.32	145.0	13.0	275.0
T7-Weedycheck	8.0	0.30	0.29	142.0	13.00	271.0
T8-WeedFree	7.9	0.27	0.32	152.0	14.00	290.0
SE(m)	0.004	0.004	0.006	0.624	0.177	0.463
C.D.	0.012	0.013	0.009	1.910	0.541	1.418

Physio-chemical property of soil after harvesting of crop

The data pertaining to physio-chemical property of soil after harvesting of crop as affected by weed control methods are presented in Table 13. clearly revealed that the soil pH ,organic carbon (%) available nitrogen (kg ha^{-1}), available phosphorus (kg ha^{-1}) and available potassium(kg ha^{-1}) recorded non-significant except electrical conductivity (E.C.). The result exhibited that the integrated application through in organic fertilizer and organic manure used in a suitable combination improved the soil fertility.

Summary

The study investigated the effectiveness of weed management practices in enhancing the growth and yield performance of late-sown wheat. Among the treatments, weed-free plots and Pendimethalin followed by hand weeding at 30 DAS consistently showed superior plant height, tiller density, dry matter accumulation, and leaf area index. These treatments also significantly improved yield attributes such as number of spikes per m^2 and grains per spike, compared to the weedy check. Although spike length and test weight showed non-significant variation, they were numerically higher in effective treatments. The research highlights the crucial role of timely weed control in ensuring optimal wheat growth and maximizing yield potential under delayed sowing conditions.

CONCLUSION

The findings demonstrate that effective weed management, particularly the integration of Pendimethalin with hand weeding at 30 DAS, or maintaining a weed-free environment, significantly enhances the growth parameters, yield attributes, and final productivity of late-sown wheat. These treatments ensured better resource utilization by minimizing weed competition, leading to improved crop establishment and grain development. The study underscores the importance of integrated weed management strategies for sustainable wheat cultivation, especially under delayed sowing scenarios, and supports the adoption of such practices for optimizing both crop yield and soil health.

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