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Herbicidal and Nitrogen Efficacy on Weed Management in Wheat Fields of Eastern Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NJ and SM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors NJ, SK, CKKB, JKS, Veershetty and KS managed the analyses of the study. Authors NJ, SM, VGR, SPK and YS managed the literature search. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Weeds can significantly affect crop yield and nutrient uptake, making effective management crucial in wheat fields. This study, conducted during the winter (Rabi) season of 2018-19 at the Agricultural Research Farm of Banaras Hindu University in Varanasi, aimed to assess the combined impact of different nitrogen levels and herbicide treatments on weed control and wheat production. The objective was to determine the best practices for reducing weed competition and improving crop performance. The experiment was set up using a split plot design with three replications. The treatments comprised of 3 nitrogen levels and 5 weed control methods. The study identified nine prevalent weed species in wheat fields, including *Phalaris minor, Anagallis arvensis, Cynodon dactylon, Chenopodium album, Melilotus indicus, Vicia sativa, Medicago denticulata, Solanum nigrum, and Cyperus rotundus*, with *Anagallis arvensis, Chenopodium album* and *Vicia sativa* being the most dominant. The application of Sulfosulfuron (25 g ha^{-1}) combined with 2, 4-D (750 ml ha^{-1}) resulted in the lowest weed density and biomass and the highest weed control efficiency. Additionally, performing hand weeding twice (30 and 60 days after sowing) in conjunction with 180 kg N ha^{-1}, followed by the application of Sulfosulfuron (25 g ha^{-1}) + 2, 4-D (750 ml ha^{-1}), significantly reduced *Anagallis arvensis, Chenopodium album* and *Vicia sativa* population and biomass and improved weed control effectiveness. Higher weed dry weight and population results in lower plant nutrient uptake and lower dry matter of crop plant and yield.

Keywords: Nitrogen levels; sulfosulfuron; 2, 4-DEE; weeds; wheat.

1. INTRODUCTION

Weeds represent a significant biotic challenge to achieving optimal wheat yields and are often the primary factor contributing to the high cost of production. This challenge exacerbates issues of poverty and food insecurity. Effective weed management, whether targeting grassy or broad-leaved species, necessitates a comprehensive approach that integrates both chemical and non-chemical control strategies [1]. Addressing complex weed populations requires the use of multiple herbicides in combination. This practice not only improves the control of resistant weed species but also helps in delaying the development of herbicide resistance [2]. Research indicates that broad-leaved and grassy weeds can reduce wheat grain yields by as much as 52.2% and 55.7%, respectively [3]. Additionally, [4] reported a 47.5% decrease in wheat grain production in plots with unmanaged weed infestations compared to other treatment options.

The management of diverse weed populations requires the application of several herbicides, as this approach enhances the effectiveness of weed control and postpones the onset of herbicide resistance [5]. Furthermore, [6] demonstrated that increasing nitrogen levels from 0 to 45 kg ha^{-1}, 45 to 90 kg ha^{-1}, and 90 to 135 kg ha^{-1} resulted in increased nitrogen uptake by 28.20%, 14.90%, and 7.70%, respectively, and phosphorus uptake by 26.20%, 13.60%, and 8.50% over previous levels. It was observed that both the quantity and timing of input applications significantly influenced weed presence and density in the field. Enhancing nitrogen fertilization from 120 to 150 kg N ha^{-1} improved grain and straw yields by promoting greater dry matter accumulation, increasing tiller numbers, and boosting nutrient uptake [7,8]. This research aims to clarify the interplay between nitrogen levels, herbicide application, and weed management to provide valuable insights for optimizing wheat production and mitigating the negative impacts of weed infestations.

2. MATERIALS AND METHODS

The fieldwork was carried out at the Agricultural Research Farm of Banaras Hindu University in Varanasi during the winter (rabi) season of 2018–19. The farm is situated in the subtropical

Indo-Gangetic Plains at a latitude of 25° 18' North and a longitude of 83° 03' East, on the left bank of the River Ganga, at an elevation of 75.70 meters above sea level. The soil at the site is sandy clay loam with a pH of 7. It has low organic carbon content (0.21%), available nitrogen (152 kg ha^{-1}), medium phosphorus (23.5 kg ha^{-1}), and readily available potassium (188 kg ha^{-1}). The experimental design employed was a split plot arrangement with three replications.

The treatments comprised of 3 nitrogen levels and 5 weed control methods, *viz.*, nitrogen levels: 120 kg ha^{-1}, 150 kg ha^{-1}, 180 kg ha^{-1}, weed control treatments: Weedy check, Hand weeding at 30 DAS and 60 DAS, Pinoxaden 5.1% EC (40 ml a.i ha^{-1}) + 2,4-DEE 38% EC (750 ml a.i ha^{-1}), Pendimethalin 30% EC at 1000 ml a.i ha^{-1} and 2,4-DEE 38% EC (750 ml a.i ha^{-1} at 30-35 DAS), Sulfosulfuron 75% WG (25 g a.i ha^{-1})+ 2,4-DEE 38% EC at 750 ml a.i ha^{-1}. On December 9th, 2018, 100 kg ha^{-1} of the wheat variety "HD-2967" were sowed, and irrigation was given during crucial crop growth phases. At rates of 60 kg ha^{-1} for single super phosphate (SSP) and 60 kg ha^{-1} for muriate of potash (MOP), respectively, the necessary doses of phosphorous and potassium were applied. Urea is used to apply nitrogen in accordance with the therapy. The remaining half of the nitrogen was administered as a top-dressing in two equal portions after the first and second irrigations, along with the full doses of phosphorus, potassium, and the remaining half of the nitrogen at the time of sowing. In terms of weed population, weed dry matter buildup, nutritional content, depletion (N, P, and K), and efficiency of various treatments. Each plot had a 25 × 25 cm quadrant where weeds were gathered at random and sun-dried. Samples were dried in an electric oven at a temperature of 60 to 65°C for 48 hours after being exposed to the sun. The dry weight resulting from this process was given in g m^{-2}. At 15, 30, 60, and 90 days after treatment application (DAA), weed dry weight, weed control effectiveness, and weed population (pre-treatment) were all recorded. After 90 DAA, nutrient content and weed depletion of it were recorded. Data related to weed components were analyzed using various statistical methods and square root transformation ($\sqrt{x+0.5}$) was undergone for uniformity.

2.1 Weed Control Efficiency

Weed control efficiency (W.C.E.) can be calculated on the basis of dates of observation by using the formula suggested by Mani et al [9].

Weed control efficiency = [(DWC – DWT)÷DWC]×100

Where DWC = dry weight of weeds in control (unweeded) plot

DWT = Dry weight of weeds in the treated plot

2.2 Statistical Analysis

The distribution of the data on weeds was normalized using the square-root transformation and all data were statistically analyzed using ANOVA (Gomez and Gomez, 1984). A critical difference at $P < 0.05$ was used to differentiate treatment means.

3. RESULTS AND DISCUSSION

3.1 Weed Flora

During the field investigation, several common weed species were identified in the experimental field, including *Phalaris minor, Cynodon dactylon*, and various broad-leaved weeds such as *Medicago denticulata, Anagallis arvensis, Melilotus indicus, Vicia sativa, Chenopodium album, and Solanum nigrum*, with *Cyperus rotundus* being the only sedge present. The study explored the impact of nitrogen levels and pesticides on prominent weeds like *Anagallis arvensis*, *Chenopodium album* and *Vicia sativa* were examined how these factors influence its growth characteristics.

3.2 Herbicides and Nitrogen Levels on Weed Density and Weed Dry Weight

A detailed analysis of the data showed that both the population and dry weight of *Anagallis arvensis* were significantly affected by the various treatments, as outlined in Tables 2 and 5. At 15 days after application (DAA), the highest efficiency was achieved with the twice application of hand weeding (30 and 60 days after sowing) and the herbicide combination of Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), which resulted in the lowest weed density and dry weight. This treatment was significantly more effective than the weedy check and comparable to other herbicidal treatments. At 30 and 60 DAA, the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}) demonstrated a significant reduction in both the density and dry weight of

Anagallis arvensis compared to the weedy check, although it was statistically similar to other herbicide treatments. By 90 DAA, the sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}) combination, as well as Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), significantly reduced the density of *Anagallis arvensis* compared to the weedy check, but were statistically similar to other herbicidal treatments. Throughout all observation periods, variations in nitrogen application levels did not significantly affect weed density and dry weight. Additionally, the data analysis revealed that the population of *Chenopodium album* was also significantly influenced by the different treatments, as detailed in Tables 1 and 4. Application of sulfosulfuron (25 g ha^{-1}) + 2, 4-DEE (750 ml ha^{-1}) significantly exhibited lower density of *Chenopodium album* over the weedy check but it was statistically at par with the other herbicidal treatments except at 15 DAA where, HW twice (30&60 DAS) plot followed by pendimethalin (1000 ml ha^{-1}) *fb* 2, 4-DEE (750 ml ha^{-1}) significantly superior over the weedy check and statistically at par with rest of the herbicidal treatments. A thorough analysis of the data indicated that, at all observation dates, there were no significant differences in weed density and dry weight across the various nitrogen application levels, with the exception of 60 days after application (DAA). At this time, the application of 120 kg N ha^{-1} resulted in the highest density of *Chenopodium album*. These results were in close conformity with the findings reported by Meena et al [10], Katara et al [11] and Sandhu and Dhaliwal [12].

A critical analysis of the data showed that the population of *Vicia sativa* was significantly affected by the various treatments, as detailed in Tables 3 and 5. The lowest weed density was observed with the application of pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), compared to the weedy check. However, this treatment was statistically similar to other herbicidal treatments, except at 60 days after application (DAA), where the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}) significantly reduced both the density and dry weight of *Vicia sativa* compared to the weedy check, though it was still comparable to other herbicide treatments. The effectiveness of weed control, as indicated by these data, was positively correlated with crop yield. Detailed data on weed control efficiency for the various treatments are presented in Tables 7-9. These results are consistent with the findings reported by Jackson [13] and Singh et al [14].

3.3 Weed Control Efficiency of Different Herbicide Combinations and Nitrogen Levels on Weeds

A detailed analysis of the data, as shown in Table 8, revealed that the weed control efficiency (WCE) for *Anagallis arvensis* varied with different treatments. At 15 days after application (DAA), the highest WCE was achieved with the combination of Pendimethalin 30% EC (1000 ml ha^{-1}) followed by 2,4-D 38% EC (750 ml ha^{-1}). At 30 DAA, the highest WCE was again observed with Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), while the lowest WCE was recorded with the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}). By 60 and 90 DAA, the highest WCE was noted with the application of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}), whereas the lowest WCE was observed with Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}). These results align closely with the findings of Katara et al [11], Sandhu and Dhaliwal [12], and Ghosh et al [15].

A detailed examination of the data showed varying weed control efficiencies (WCE) across different nitrogen application levels. At 15 days after application (DAA), the highest WCE was observed with the application of 150 kg N ha^{-1}. During 30 and 90 DAA, the highest WCE was achieved with 120 kg N ha^{-1}, while at 60 DAA, the greatest WCE was noted with 180 kg N ha^{-1}. The WCE of *Chenopodium album* was significantly affected by different treatments, as detailed in Table 7. At 15 DAA, the highest WCE was recorded with Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), whereas the lowest WCE was observed with the twice hand weeding treatment (30 and 60 DAS). At 30, 60, and 90 DAA, the highest WCE was achieved with the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}), followed by Pendimethalin (1000 ml ha^{-1}) and 2,4-D (750 ml ha^{-1}). The lowest WCE during these periods was noted with the twice hand weeding treatment. For *Vicia sativa*, the WCE was also influenced by various treatments, as shown in Table 9. At both 15 and 30 DAA, the highest WCE was achieved with Pendimethalin (1000 ml ha^{-1}) followed by 2,4-D (750 ml ha^{-1}), with hand weeding twice (30 and 60 DAS) and the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}) also showing high WCE. The lowest WCE was recorded with Pinoxaden (40 ml ha^{-1}) combined with 2,4-D (750 ml ha^{-1}). These findings are consistent with those reported by Mani et al [9], Patel et al [16], and Shoeran et al [17].

Table 1. Effect of herbicides and nitrogen levels on density (No. m^{-2}) of *Chenopodium album* in wheat

Treatments	**Weed Density (No. m^{-2})**				
	Pre-treatment	**15 DAA**	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})					
120	2.94 (8.67)	2.26 (4.67)	2.27 (4.67)	1.87 (3.00)	2.04 (3.67)
150	3.18 (9.67)	2.67 (6.67)	1.72 (3.00)	1.76 (2.67)	1.95 (3.33)
180	2.67 (6.67)	2.48 (5.67)	2.34 (5.00)	1.68 (2.33)	1.95 (3.33)
SEm ±	**0.262**	**0.212**	**0.08**	**0.042**	**0.065**
CD (P=0.05)	**NS**	**NS**	**NS**	**0.165**	**NS**
Herbicides					
Weedy check	3.37 (11.00)	3.53 (12.00)	3.80 (14.00)	2.76 (7.67)	2.80 (7.67)
HW twice (30&60 DAS)	2.97 (8.33)	1.72 (2.67)	1.87 (3.00)	1.50 (2.00)	2.05 (3.78)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	2.60 (6.33)	2.12 (4.00)	1.48 (1.67)	1.77 (3.00)	1.73 (2.89)
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	2.67 (6.67)	1.76 (2.67)	1.35 (1.67)	1.41 (1.67)	1.40 (1.78)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	3.18 (9.67)	2.57 (7.00)	1.22 (1.00)	1.10 (1.00)	1.22 (1.00)
SEm ±	**0.205**	**0.14**	**0.23**	**0.176**	**0.203**
CD (P=0.05)	**0.598**	**0.40**	**0.68**	**0.513**	**0.594**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*

Data subjected to square root ($\sqrt{x}$ + 0.5) transformation and original data presented in parenthesis

Table 2. Effect of herbicides and nitrogen levels on density (No. m^{-2}) of *Anagallis arvensis* in wheat

Treatments	Weed Density (No. m^{-2})				
	Pre- treatment	**15 DAA**	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})					
120	2.39 (5.67)	2.48 (5.67)	1.92 (3.67)	1.80 (3.33)	1.71 (2.67)
150	2.34 (5.33)	2.85 (7.67)	2.12 (4.00)	1.92 (3.67)	1.95 (3.33)
180	2.39 (5.67)	2.57 (6.00)	2.20 (4.33)	2.12 (4.00)	1.95 (3.33)
SEm ±	**0.73**	**0.07**	**0.43**	**0.08**	**0.15**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**
Herbicides					
Weedy check	2.19 (4.33)	3.48 (11.67)	3.53 (12.00)	3.08 (9.00)	3.01 (8.67)
HW twice (30&60 DAS)	2.12 (4.00)	1.63 (2.33)	1.78 (2.67)	1.71 (2.67)	2.04 (3.67)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	2.19 (4.33)	2.89 (8.33)	1.95 (3.33)	1.76 (2.67)	1.47 (1.67)
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	2.19 (4.33)	2.19 (4.33)	1.78 (2.67)	1.63 (2.33)	1.22 (1.00)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	1.95 (3.33)	2.48 (6.00)	1.68 (2.33)	1.22 (1.00)	1.08 (0.67)
SEm ±	**0.41**	**0.174**	**0.43**	**0.149**	**0.148**
CD (P=0.05)	**1.19**	**0.50**	**1.26**	**0.434**	**0.431**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*
Data subjected to square root ($\sqrt{x}$ + 0.5) transformation and original data presented in parenthesis

Table 3. Effect of herbicides and nitrogen levels on density (No. m^{-2}) of *Vicia sativa* in wheat

Treatments	Weed density (No. m^{-2})				
	Pre-treatment	**15 DAA**	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})					
120	1.79 (2.67)	1.64 (2.60)	1.76 (3.33)	1.63 (2.33)	1.76 (2.67)
150	1.69 (2.67)	1.54 (2.33)	1.63 (2.33)	1.63 (2.33)	1.50 (2.00)
180	2.04 (3.67)	1.81 (3.00)	2.04 (3.67)	2.04 (3.67)	1.85 (3.00)
SEm ±	**0.136**	**0.084**	**0.150**	**0.095**	**0.087**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**
Herbicides					
Weedy check	2.04 (3.67)	2.07 (4.00)	3.01 (8.67)	2.97 (8.33)	2.74 (4.00)
HW twice (30&60 DAS)	1.79 (2.67)	1.63 (2.33)	2.04 (3.67)	1.22 (1.00)	1.60 (2.33)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	1.45 (3.00)	1.87 (3.00)	1.48 (1.67)	1.60 (2.33)	1.95 (3.33)

Treatments	**Weed density (No. m^{-2})**				
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	1.50 (2.00)	1.00 (0.67)	1.08 (0.67)	1.35 (1.33)	1.53 (0.67)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	1.95 (3.33)	1.87 (3.00)	1.22 (1.00)	1.00 (0.67)	1.85 (3.00)
SEm ±	**0.119**	**0.128**	**0.148**	**0.166**	**0.182**
CD (P=0.05)	**0.346**	**0.373**	**0.431**	**0.484**	**0.532**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*
Data subjected to square root ($\sqrt{x}$ + 0.5) transformation and original data presented in parenthesis

Table 4. Effect of herbicides and nitrogen levels on drymatter (g m^{-2}) of *Chenopodium album* in wheat

Treatments	**Weed Drymatter (g m^{-2})**			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	0.83 (0.21)	0.90 (0.37)	0.92 (0.40)	1.13 (0.89)
150	0.96 (0.51)	0.96 (0.54)	1.06 (0.74)	1.15 (0.94)
180	1.00 (0.58)	1.01 (0.73)	1.05 (0.75)	1.21 (1.14)
SEm ±	**0.010**	**0.024**	**0.020**	**0.031**
CD (P=0.05)	**0.038**	**NS**	**0.078**	**NS**
Herbicides				
Weedy check	1.36 (1.43)	1.61 (2.20)	1.60 (2.12)	1.79 (2.74)
HW twice (30&60 DAS)	0.89 (0.31)	0.85 (0.23)	0.89 (0.31)	1.26 (1.10)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	0.80 (0.14)	0.80 (0.15)	0.90 (0.33)	1.01 (0.53)
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	0.77 (0.10)	0.78 (0.11)	0.85 (0.24)	0.91 (0.36)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	0.83 (0.20)	0.73 (0.04)	0.81 (0.17)	0.84 (0.23)
SEm ±	**0.019**	**0.060**	**0.041**	**0.056**
CD (P=0.05)	**0.055**	**0.174**	**0.120**	**0.162**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*
Data subjected to square root ($\sqrt{x}$ + 0.5) transformation and original data presented in parenthesis

Table 5. Effect of herbicides and nitrogen levels on drymatter (g m^{-2}) of *Anagallis arvensis* in wheat

Treatments	**Weed Drymatter (g m^{-2})**			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	0.89 (0.30)	0.88 (0.29)	1.09 (0.8)	1.19 (1.21)
150	0.91 (0.33)	0.94 (0.40)	1.12 (0.88)	1.19 (1.15)
180	0.91 (0.32)	0.96 (0.46)	1.10 (0.89)	1.23 (1.28)
SEm ±	**0.013**	**0.010**	**0.018**	**0.069**
CD (P=0.05)	**NS**	**0.054**	**NS**	**NS**
Herbicides				
Weedy check	0.98 (0.47)	1.21 (0.97)	1.82 (2.82)	2.16 (4.19)
HW twice (30&60 DAS)	0.84 (0.21)	0.85 (0.22)	0.92 (0.35)	1.15 (0.83)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	0.88 (0.28)	0.90 (0.32)	0.96 (0.42)	0.97 (0.48)
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	0.89 (0.30)	0.85 (0.23)	0.95 (0.40)	0.89 (0.33)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	0.91 (0.33)	0.82 (0.18)	0.88 (0.28)	0.85 (0.25)
SEm ±	**0.013**	**0.020**	**0.025**	**0.050**
CD (P=0.05)	**0.037**	**0.070**	**0.072**	**0.145**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*
Data subjected to square root ($\sqrt{x}$ + 0.5) transformation and original data presented in parenthesis

Table 6. Effect of herbicides and nitrogen levels on drymatter (g m^{-2}) of *Vicia sativa* in wheat

Treatments	Weed Drymatter (g m^{-2})			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	0.85 (0.23)	0.87 (0.27)	0.90 (0.36)	0.97 (0.51)
150	0.90 (0.18)	0.91 (0.33)	0.86 (0.30)	0.98 (0.51)
180	0.91 (0.32)	0.93 (0.39)	0.89 (0.34)	1.05 (0.67)
SEm ±	**0.032**	**0.028**	**0.018**	**0.016**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**
Herbicides				
Weedy check	1.04 (0.58)	1.05 (0.61)	1.27 (1.13)	1.41 (1.49)
HW twice (30&60 DAS)	0.82 (0.18)	0.88 (0.28)	0.83 (0.20)	1.05 (0.62)
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	0.90 (0.32)	0.90 (0.32)	0.80 (0.15)	0.86 (0.25)
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	0.80 (0.14)	0.80 (0.14)	0.79 (0.13)	0.87 (0.26)
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	0.88 (0.29)	0.88 (0.29)	0.73 (0.04)	0.83 (0.20)
SEm ±	**0.030**	**0.028**	**0.039**	**0.042**
CD (P=0.05)	**0.087**	**0.083**	**0.113**	**0.123**

**Ethyl ester, DAA= Days After Treatment Application, NS= Non-Significant*
Data subjected to square root ($\sqrt{x}+0.5$) transformation and original data presented in parenthesis

Table 7. Effect of herbicides and nitrogen levels weed control efficiency of *Chenopodium album* in wheat

Treatments	Weed control efficiency (%)			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	52.58	72.87	64.47	59.39
150	72.26	71.35	69.79	63.96
180	70.97	74.88	72.59	64.58
Herbicides				
Weedy check	0.00	0.00	0.00	0.00
HW twice (30&60 DAS)	66.66	85.47	82.42	56.86
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	85.65	89.37	83.78	78.77
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	91.18	94.49	87.55	85.90
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	82.86	95.83	90.99	91.67

**Ethyl ester, DAA= Days After Treatment Application*

Table 8. Effect of herbicides and nitrogen levels on weed control efficiency (%) of *Anagallis arvensis* in wheat

Treatments	Weed control efficiency (%)			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	31.78	63.62	68.21	72.59
150	37.00	55.01	68.46	70.20
180	24.50	61.53	71.88	70.66
Herbicides				
Weedy check	0.00	0.00	0.00	0.00
HW twice (30&60 DAS)	52.75	76.16	87.61	79.96
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	38.35	64.91	84.71	88.55
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	36.73	77.35	85.39	92.55
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	27.63	81.85	89.87	94.69

Table 9. Effect of herbicides and nitrogen levels on weed control efficiency (%) of *Vicia sativa* in wheat

Treatments	Weed Control Efficiency (%)			
	15 DAA	**30 DAA**	**60 DAA**	**90 DAA**
Nitrogen levels (kg ha^{-1})				
120	51.11	49.78	67.25	64.88
150	48.52	42.83	73.19	60.99
180	43.40	43.73	68.88	60.25
Herbicides				
Weedy check	0.00	0.00	0.00	0.00
HW twice (30&60 DAS)	70.78	52.10	81.39	58.39
Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha^{-1})	42.27	46.92	85.82	82.87
Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE 38% EC (750 ml ha^{-1})	73.33	76.30	84.90	81.95
Sulfosulfuron 75% WG (25 g) + 2,4-DEE 38% EC (750 ml ha^{-1})	52.00	51.92	96.75	86.98

The highest weed control efficiency was observed with the combination of sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}), followed by Pinoxaden (40 ml ha^{-1}) combined with 2,4-D (750 ml ha^{-1}). The lowest weed control efficiency was noted with the twice hand weeding treatment (30 and 60 DAS). Analysis of the data showed that the application of 120 kg N ha^{-1} resulted in higher weed control efficiency at 15, 30, and 90 days after application (DAA), while the highest weed control efficiency at 60 DAA was achieved with 150 kg N ha^{-1}. These results align with the findings of Meena et al [10], Borowczak et al [18], and Gomez and Gomez [19]. Additionally, [6] found that increasing nitrogen levels from 0 to 45 kg ha^{-1}, from 45 to 90 kg ha^{-1}, and from 90 to 135 kg ha^{-1} resulted in increases in nitrogen uptake by 28.20%, 14.90%, and 7.70%, respectively, and phosphorus uptake by 26.20%, 13.60%, and 8.50% over the previous levels. The study also highlighted that both the quantity and timing of inputs significantly influenced weed presence and density. Enhanced nitrogen fertilization from 120 to 150 kg N ha^{-1} improved grain production and straw yield by increasing dry matter accumulation, the number of tillers, and nutrient uptake.

4. CONCLUSION

Based on the summarized results, the following conclusions can be made: The combination of sulfosulfuron (25 g ha^-1) and 2,4-D (750 ml ha^{-1}) demonstrated superior weed control effectiveness, leading to reduced weed density and lower dry matter of *Chenopodium album*, *Anagallis arvensis*, and *Vicia sativa*. The highest weed control efficiency, along with reduced weed dry weight and density, was achieved with the application of 180 kg N ha^{-1} in conjunction with sulfosulfuron (25 g ha^{-1}) and 2,4-D (750 ml ha^{-1}). This integrated approach not only enhanced weed management but also alleviated the negative impacts of increased weed dry weight and population on nutrient uptake and crop yield. Consequently, the findings highlight the benefits of combining herbicide treatments with strategic hand weeding to improve crop performance and resource use efficiency in wheat cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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