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# Phytotoxic Effect and the Efficiency of Different Herbicides and Nitrogen Levels on Weed Control in Wheat Crop

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

A field experiment was carried out during the winter (rabi) season of 2018–19 at the Agricultural Research Farm, Banaras Hindu University, Varanasi, to evaluate the impact of herbicides and nitrogen levels on phytotoxic effect and the efficiency of different herbicides and nitrogen levels in wheat. The wheat field was infested with nine weed species such as *Phalaris minor, Cynodon dactylon, Anagallis arvensis, Melilotus indicus, Chenopodium album, Vicia sativa, Medicago denticulata, Solanum nigrum,* and *Cyperus rotundus*. Among these, *Cyperus rotundus* and *Cynodon dactylon* were the major weeds. Visual phytotoxicity indicated that phytotoxicity was observed under pinoxaden (40 ml $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$). The data pertaining to available N, $P_2O_5$, $K_2O$ in soil after harvest of crop revealed that application of herbicides and nitrogen levels observed non-significant differences except higher available $K_2O$ in soil observed by application of pinoxaden 5.1%EC + 2,4- DEE 38%EC (40+750 ml $ha^{-1}$) significantly over weedy check and statistically at par with rest of the treatments. Further, higher weed management index (WMI) was recorded under HW twice plot (30&60 DAS) was 0.13 followed by under application of sulfosulfuron (25 g $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$) was 0.11. Weed density and biomass had strong negative correlation with grain yield ($r$ = -0.39 and $r$ = -0.40, respectively). The interaction effect of highest grain and straw yields were achieved with the application of Sulfosulfuron (25 g $ha^{-1}$) + 2,4-DEE (750 ml $ha^{-1}$) in combination with 180 kg N $ha^{-1}$.

*Keywords: Herbicides; weeds; efficiency; yield.*

## 1. INTRODUCTION

Wheat is a crucial cereal and staple food crop globally, cultivated across diverse regions. It plays a significant role in feeding a large portion of the world's population. Any reduction in wheat yields due to biotic or abiotic factors could negatively impact global food security. Weeds, in particular, are a major pest for wheat, leading to an estimated 24% reduction in grain yield [1].

Weeds represent a significant challenge in wheat production, often emerging as the most expensive factor impeding optimal yields. This challenge exacerbates issues related to poverty and food insecurity. Effective management of both grassy and broad-leaved weeds requires a comprehensive strategy that integrates chemical and non-chemical control methods" [2,3]. "Managing diverse and complex weed populations necessitates the use of multiple herbicides. Herbicide mixtures not only enhance the efficacy of weed control but also play a critical role in delaying the development of herbicide resistance" [4]. Grassy weeds can lead to a reduction of up to 52.2% in wheat grain yield, while broad-leaf weeds can cause a yield decrease of up to 55.7% [5,1]. "In untreated plots, weeds have been shown to decrease wheat grain yield by 47.5% compared to other treatments. To effectively manage complex weed populations, employing a combination of herbicides is essential, as it improves control efficiency against various weed species and helps in postponing resistance development" [6]. "Yield losses in wheat can reach up to 65%, influenced by factors such as weed type and density, the crop species, the level of weed infestation, and the management practices employed" [7]. "Research has identified several predominant weed species in wheat fields: broad-leaved weeds include *Parthenium hysterophorus* L., *Melilotus* spp., *Rumex dentatus*, and *Chenopodium album*, while grass species such as *Phalaris minor* and *Cynodon dactylon*, and the sedge *Cyperus rotundus* are also significant" [8,9]. "The effectiveness of clodinafop at 60 g $ha^{-1}$ is comparable to that of Pinoxaden for controlling *Phalaris minor* and *Avena ludoviciana"* [10,4]. "While sulfosulfuron and mesosulfuron-methyl are used to manage isoproturon-resistant *Phalaris minor* in wheat, they are not safe for barley" [11]. "Clodinafop-propargyl has been extensively used for post-emergence control of grassy weeds, particularly *Phalaris minor* and *Avena ludoviciana*, in Punjab and Haryana. However, after 8-10 years of continuous application, resistance issues have emerged, with *Phalaris minor* developing resistance to clodinafop in these regions" [5]. "Nitrogen supply in wheat is directly linked to weed competition and the crop's competitive ability" [12]. "Optimizing fertilizer application has garnered interest, as both the timing and amount of nitrogen significantly influence weed emergence and density" [13]. Increasing nitrogen application from 120 to 150 kg N per hectare enhances dry matter accumulation, increases tiller numbers, improves nutrient uptake, and subsequently boosts grain and straw yields [14,15]. Thus, integrating various herbicide combinations with optimal nitrogen levels can significantly improve wheat growth and yield.

## 2. MATERIALS AND METHODS

The field experiment was carried out during the winter (rabi) season of 2018–19 at the Agricultural Research Farm of Banaras Hindu University, Varanasi, Uttar Pradesh. This location, situated in the sub-tropical Indo-Gangetic plains at 25°18' N latitude and 83°03' E longitude, is located on the left bank of the River Ganga at an altitude of 75.70 meters above sea level. The soil at the site is classified as sandy clay loam, characterized by low organic carbon content (0.21%) and available nitrogen (152 kg $ha^{-1}$), with medium levels of phosphorus (23.5 kg $ha^{-1}$) and potassium (188 kg $ha^{-1}$), and a neutral pH of 7.28. The experimental design employed was a split plot design with three replications.

The treatments comprised of 3 nitrogen levels were (120 kg $ha^{-1}$ , 150 kg $ha^{-1}$ , 180 kg $ha^{-1}$) and 5 weed control methods were Includes (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 $ha^{-1}$ ) [Tank mixture at 29 DAS], Pendimethalin 30% EC at 1000 ml a.i $ha^{-1}$ (pre-emergence) *fb* 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 $ha^{-1}$ [Tank mixture at 29 DAS] Wheat variety 'HD-2967' with 100 kg $ha^{-1}$ seed rate was sown on 9th December, 2018 and the irrigation was provided at critical crop growth stages. A recommended dose of phosphorous and potassium was applied through single super phosphate (SSP), and muriate of potash (MOP), respectively at the rate of 60, 60 kg $ha^{-1}$. Nitrogen is applied through urea as per the treatment. Interaction effect of wheat yield was calculated. Correlation of different crop and weed parameters were carried out. Different physical, chemical and biological properties of soil shown in Table 1. The data were statistically analyzed by using statistical procedures and comparisons were made at 5% level of significance" [4].

### 2.1 Visual Phytotoxicity

Visual phytotoxicity was recorded at 1,3,5,7,10, 15, 20 and 30 days after spraying, which indicated based on 1-10 scale where: 1=0-10%, 2=11-20%, 3=21-30%, 4=31-40%, 5=41-50%, 6=51-60%, 7=61-70%, 8=71-80%, 9=81-90%, 10=91-100%.

**Herbicide efficiency index (HEI):** It indicates the weed killing potential of a herbicidal treatment and its phytotoxicity on the crop. Weed indices such as WMI, AMI, IWMI, HEI were calculated using formulae and given by [16] and [6].

$$HEI = [(Y_T - Y_C)/ Y_C] \div (W_T - W_C)$$

Where, $Y_T$ = Yield of treated plot
$Y_C$ = Yield of control (unweeded) plot
$W_T$ = Weed dry weight in treated plot
$W_C$ = Weed dry weight in control (unweeded) plot

**Weed management index (WMI)**

$$WMI = [(Y_T - Y_C)/ Y_C] \div [(W_T - W_C)/ W_C]$$

Where, $Y_T$ = Yield of treated plot
$Y_C$ = Yield of control (unweeded) plot
$W_T$ = Weed dry weight in treated plot
$W_C$ = Weed dry weight in control (unweeded) plot

**Agronomic management index (AMI)**

$$WMI = [\{(Y_T - Y_C)/ Y_C\} - \{(W_T - W_C)/ W_C\}/ (W_T - W_C)/ W_C)$$

Where, $Y_T$ = Yield of treated plot
$Y_C$ = Yield of control (unweeded) plot
$W_T$ = Weed dry weight in treated plot
$W_C$ = Weed dry weight in control (unweeded) plot

**Integrated weed management index (IWMI)**

$$IWMI = (AMI + WMI)/2$$
Where, WMI= Weed management index
AMI = Agronomic management index

**Weed persistence index (WPI)**

$$WPI = (W_T/W_C) \times (W_{PC}/W_{PT})$$

Where, $W_T$ = Weed dry weight of treated plot
$W_C$ = Weed dry weight of control (unweeded) plot
$W_{PT}$ = Weed population in treated plot
$W_{PC}$ = Weed population in control (unweeded) plot

**Table 1. Different physical, chemical and biological properties of soil**

| Particulars | Value | Rating | Method |
|---|---|---|---|
| ***1. Physical constants*** | | | |
| Bulk density (g $cm^{-3}$) | 1.43 | | Core sampler |
| Particle density (g $cm^{-3}$) | 2.64 | | Pycnometer |
| ***2. Chemical analysis*** | | | |
| Organic carbon (%) | 0.32 | Low | Wet digestion method |
| Available N (kg $ha^{-1}$) | 152 | Low | Alkaline potassium permanganate |
| Available $P_2O_5$ (kg $ha^{-1}$) | 23.5 | Medium | 0.5*M* $NaHCO_3$ extractable |
| Available $K_2O$ (kg $ha^{-1}$) | 188 | Medium | Flame photometer method |
| pH (1:2.5 soil:water suspension) | 7.28 | Neutral | Glass electrode digital pH meter |
| Electrical conductivity (1:2 soil: water suspension) dS $m^{-1}$ at $25^0$C | 0.35 | Normal | Systronics electrical conductivity meter |
| ***3. Biological properties (Population/g dry soil)*** | | | |
| Microbial properties | | | |
| Bacteria | 43.1 x $10^3$ (cfu/g) | | Plate Count Method |
| Fungi | 22.2 x $10^3$ (cfu/g) | | |
| Actinomycetes | 31.2 x $10^3$ (cfu/g) | | |

## 3. RESULTS AND DISCUSSION

### 3.1 Weed Flora

During the field investigation, the experimental field was found to be infested with dominant weed species, including grasses such as *Phalaris minor* and *Cynodon dactylon*, as well as broad-leaved weeds like *Anagallis arvensis, Melilotus indicus, Vicia sativa, Chenopodium album, Medicago denticulata,* and *Solanum nigrum*. The only sedge identified was *Cyperus rotundus*.

### 3.2 Crop Phytotoxicity

Visual phytotoxicity recorded at 7, 10, 15, 20 and 30 days after spraying based on 1-10 scale where 1=0-10%, 2=11-20%, 3=21-30%, 4=31-40%, 5=41-50%, 6=51-60%, 7=61-70%, 8=71-80%, 9=81-90%, 10=91-100% indicated that phytotoxicity was observed under pinoxaden (40 ml $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$). However, injury on tips or surface of leaf was observed after the spray of pinoxaden (40 ml $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$), that recorded below 20% which disappeared within 1-2 weeks and had no effect on crop, where there was no phytotoxicity in any other treatments. Close examination of data revealed that under application of different nitrogen levels, phytotoxicity observed higher under 180 kg N $ha^{-1}$ were 0.47, while the lower values under 150 kg N $ha^{-1}$ were 0.33 (Table 2). These results were in close conformity with the findings of [12] and [17].

### 3.3 Physical, Chemical and Biological Properties of Soil after Harvest of Wheat

The data on soil physical, chemical, and biological properties are detailed in Tables 3 and 4. Neither nitrogen levels nor herbicidal treatments significantly affected soil bulk density, pH, organic carbon content, or electrical conductivity. Analysis of available nutrients (N, $P_2O_5$, $K_2O$) in the soil post-harvest showed no significant differences due to herbicide or nitrogen applications, except for a notable increase in available $K_2O$ in soils treated with pinoxaden 5.1% EC + 2,4-D EE 38% EC (40+750 ml $ha^{-1}$) compared to the weedy check. This treatment was statistically comparable to other treatments. The highest microbial counts were observed in the weedy check plots, followed by those with hand weeding, while the lowest microbial counts were found in plots treated with pinoxaden 5.1% EC + 2,4-D EE 38% EC (40+750 ml $ha^{-1}$). These results align with the findings of [9] and [18].

### 3.4 Effect of Different Herbicidal Treatments on Weed Indices in Wheat Crop

The data related to weed indices of different herbicidal treatments has been depicted in the Table 6. Among various herbicidal treatments, highest herbicide efficiency index (HEI) was recorded under application of sulfosulfuron (25 g $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$) followed by pendimethalin (1000 ml $ha^{-1}$) *fb* 2, 4-DEE (750 ml $ha^{-1}$). Further, higher weed management index (WMI) was recorded under HW twice plot (30&60 DAS) followed by under application of sulfosulfuron (25 g $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$). While, higher agronomic management index (AMI) was recorded under application of Pinoxaden (40 ml $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$) and lower value under HW twice plot (30&60 DAS) whereas higher value of integrated weed management index (IWMI) was recorded under

**Table 2. Phytotoxicity evaluation of herbicides and nitrogen levels on wheat crop**

| Treatments | Phytotoxicity parameters observed (Mean observations recorded at 7, 10, 15, 20 and 30 days after treatment application) | | | | | |
|---|---|---|---|---|---|---|
| | Leaf injury on tips/ surface | Wilting | Vein clearing | Necrosis | Epinasty | Hyponasty |
| **Nitrogen levels** | | | | | | |
| 120 kg $ha^{-1}$ | 0.40 | Nil | Nil | Nil | Nil | Nil |
| 150 kg $ha^{-1}$ | 0.33 | Nil | Nil | Nil | Nil | Nil |
| 180 kg $ha^{-1}$ | 0.47 | Nil | Nil | Nil | Nil | Nil |
| **Herbicides** | | | | | | |
| Weedy check | Nil | Nil | Nil | Nil | Nil | Nil |
| HW twice (30&60 DAS) | Nil | Nil | Nil | Nil | Nil | Nil |
| Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 2.00 | Nil | Nil | Nil | Nil | Nil |
| Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | Nil | Nil | Nil | Nil | Nil | Nil |
| Sulfosulfuron 75% WG (25 g) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | Nil | Nil | Nil | Nil | Nil | Nil |

**Table 3. Effect of herbicides and nitrogen levels on physico-chemical properties of soil at harvest of crop**

| Treatments | BD (Mg $m^{-3}$) | pH | Organic Carbon (%) | EC (dS/ m) at 25$^0$C | Available N (kg $ha^{-1}$) | $P_2O_5$ (kg $ha^{-1}$) | $K_2O$ (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| **Nitrogen levels** | | | | | | | |
| 120 kg $ha^{-1}$ | 1.42 | 7.71 | 0.33 | 0.34 | 118.13 | 32.54 | 193.98 |
| 150 kg $ha^{-1}$ | 1.42 | 7.73 | 0.32 | 0.33 | 124.67 | 30.31 | 198.61 |
| 180 kg $ha^{-1}$ | 1.43 | 7.71 | 0.33 | 0.32 | 141.11 | 34.20 | 212.35 |
| SEm ± | 0.002 | 0.026 | 0.004 | 0.011 | 5.16 | 1.21 | 3.93 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS |
| **Herbicides** | | | | | | | |
| Weedy check | 1.42 | 7.70 | 0.33 | 0.34 | 107.32 | 28.86 | 181.18 |
| HW twice (30&60 DAS) | 1.42 | 7.69 | 0.33 | 0.34 | 142.17 | 35.83 | 203.10 |
| Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 1.44 | 7.72 | 0.33 | 0.33 | 129.44 | 29.61 | 210.56 |
| Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 1.41 | 7.74 | 0.32 | 0.34 | 127.06 | 36.34 | 208.82 |
| Sulfosulfuron 75% WG (25 g) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 1.43 | 7.73 | 0.34 | 0.30 | 133.85 | 31.11 | 204.59 |
| SEm ± | 0.006 | 0.022 | 0.006 | 0.017 | 10.07 | 2.66 | 5.40 |
| CD (P=0.05) | 0.017 | NS | NS | NS | NS | NS | 15.75 |

**Table 4. Effect of herbicides and nitrogen levels on soil biological properties at harvest of wheat crop**

| Treatments | Mean population | | |
|---|---|---|---|
| | **Bacteria (1 ×10$^3$ cfu/ g)** | **Fungi (1 ×10$^3$ cfu/ g)** | **Actinomycetes (1 ×10$^3$ cfu/ g)** |
| **Nitrogen levels** | | | |
| 120 kg ha$^{-1}$ | 67.1 | 28.7 | 37.7 |
| 150 kg ha$^{-1}$ | 68.6 | 27.7 | 37.1 |
| 180 kg ha$^{-1}$ | 68.3 | 28.6 | 37.9 |
| SEm ± | 1.34 | 1.07 | 0.551 |
| CD (P=0.05) | NS | NS | NS |
| **Herbicides** | | | |
| Weedy check | 69.2 | 28.9 | 39.1 |
| HW twice (30 & 60 DAS) | 70.2 | 30.1 | 37.6 |
| Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml ha$^{-1}$) | 69.1 | 26.7 | 36.3 |
| Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE* 38% EC (750 ml ha$^{-1}$) | 65.1 | 27.9 | 37.4 |
| Sulfosulfuron 75% WG (25 g) + 2,4-DEE* 38% EC (750 ml ha$^{-1}$) | 66.3 | 28.2 | 37.3 |
| SEm ± | 1.38 | 0.79 | 0.78 |
| CD (P=0.05) | NS | NS | NS |

**Table 5. Correlation matrix among weed density, weed biomass and yield components of wheat crop**

| | **Weed density (no. m$^{-2}$)** | **Weed biomass (g m$^{-2}$)** | **Effective tillers m$^{-2}$** | **Number of grains spike$^{-1}$** | **Grain yield (kg ha$^{-1}$)** | **Straw yield (kg ha$^{-1}$)** |
|---|---|---|---|---|---|---|
| Weed density (no. m$^{-2}$) | 1.00 | | | | | |
| Weed biomass (g m$^{-2}$) | 0.99** | 1.00 | | | | |
| Effective tillers m$^{-2}$ | -0.78** | -0.78** | 1.00 | | | |
| Number of grains spike$^{-1}$ | -0.47** | -0.46** | 0.76** | 1.00 | | |
| Grain yield (kg ha$^{-1}$) | -0.39** | -0.40** | 0.78** | 0.80** | 1.00 | |
| Straw yield (kg ha$^{-1}$) | -0.41** | -0.41** | 0.78** | 0.75** | 0.95** | 1.00 |

**Table 6. Bio-efficiency of different herbicidal treatments in wheat crop**

| Treatments | Herbicide efficiency index | Weed management index | Agronomic management index | Integrated weed management index | Weed persistence index |
|---|---|---|---|---|---|
| Weedy check | - | - | - | - | - |
| HW twice (30 & 60 DAS) | 0.69 | 0.13 | 0.87 | 0.13 | 0.90 |
| Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 0.71 | 0.05 | 0.95 | 0.05 | 1.07 |
| Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 0.72 | 0.08 | 0.91 | 0.09 | 1.01 |
| Sulfosulfuron 75% WG (25 g) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 0.76 | 0.11 | 0.89 | 0.11 | 0.85 |

**Table 7. Interaction effect of nitrogen levels and herbicides on grain yield and straw yield**

| Treatments | Grain yield (kg $ha^{-1}$) | | | Straw yield (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Nitrogen levels (kg $ha^{-1}$)** | | | | | | |
| | **120** | **150** | **180** | **120** | **150** | **180** |
| **Herbicides** | | | | | | |
| Weedy check | 4094 | 4619 | 4454 | 6362 | 6600 | 7273 |
| HW twice (30&60 DAS) | 4617 | 4881 | 4896 | 7116 | 7290 | 7806 |
| Pinoxaden 5.1% EC (40 ml) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 4412 | 4631 | 4615 | 6635 | 7098 | 7224 |
| Pendimethalin 30% EC (1000 ml) *fb* 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 4371 | 4848 | 4733 | 6603 | 7412 | 7498 |
| Sulfosulfuron 75% WG (25 g) + 2,4-DEE* 38% EC (750 ml $ha^{-1}$) | 4674 | 4786 | 4863 | 7093 | 7197 | 7714 |
| | **SEm ±** | **CD (P=0.05)** | | **SEm ±** | **CD (P=0.05)** | |
| For comparison between herbicides at same level of nitrogen levels | 62.43 | 182.21 | | 99.54 | 290.53 | |
| For comparison between nitrogen levels at same or different level of herbicides | 61.70 | 191.34 | | 110.98 | 363.80 | |

HW twice plot (30 & 60 DAS) followed by application of sulfosulfuron (25 g $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$). Further, highest value of weed persistence index (WPI) was recorded under HW twice plot (30&60 DAS) followed by application of sulfosulfuron (25 g $ha^{-1}$) + 2, 4-DEE (750 ml $ha^{-1}$). These findings were in close conformity with the findings of [19] and [1].

### 3.5 Correlation Matrix among Weed Density, Biomass and Yield Components

The weed indices associated with various herbicidal treatments are detailed in Table 6. Among the treatments evaluated, the highest Herbicide Efficiency Index (HEI) was achieved with the application of sulfosulfuron (25 g $ha^{-1}$) combined with 2,4-D EE (750 ml $ha^{-1}$), followed by pendimethalin (1000 ml $ha^{-1}$) followed by 2,4-D EE (750 ml $ha^{-1}$). The highest Weed Management Index (WMI) was observed with two hand weeding operations (30 and 60 days after sowing), followed by the sulfosulfuron (25 g $ha^{-1}$) + 2,4-D EE (750 ml $ha^{-1}$) treatment. The highest Agronomic Management Index (AMI) was recorded with Pinoxaden (40 ml $ha^{-1}$) + 2,4-D EE (750 ml $ha^{-1}$), while the lowest was observed with the two hand weeding treatment. For the Integrated Weed Management Index (IWMI), the highest value was seen with two hand weeding (30 and 60 DAS), followed by the sulfosulfuron (25 g $ha^{-1}$) + 2,4-D EE (750 ml $ha^{-1}$) treatment. The Weed Persistence Index (WPI) was also highest in the two hand weeding plots (30 and 60 DAS), followed by the sulfosulfuron (25 g $ha^{-1}$) + 2,4-D EE (750 ml $ha^{-1}$) treatment. These results are consistent with the findings reported by [19] and [1].

### 3.6 Interaction Effect of Nitrogen Levels and Herbicides on Grain Yield and Straw Yield

The interaction between nitrogen levels and herbicide applications revealed that the combination of 180 kg N $ha^{-1}$ with two hand weedings (30 and 60 DAS) resulted in the highest grain yield. Additionally, the highest straw yield was achieved with the same nitrogen level combined with sulfosulfuron (25 g $ha^{-1}$) and 2,4-D EE (750 ml $ha^{-1}$). and this might be due to integrated effect on increase in number of effective tillers $m^{-2}$ (Table 7). These were in close conformation with the findings of [20] and [5].

## 4. CONCLUSION

The data pertaining to available N, $P_2O_5$, $K_2O$ in soil after harvest of crop revealed that application of herbicides and nitrogen levels observed non-significant differences except higher available $K_2O$ in soil observed significantly by application of pinoxaden 5.1%EC + 2,4- DEE 38%EC (40+750 ml $ha^{-1}$) over weedy check and statistically at par with rest of the treatments. The most effective herbicidal treatment was sulfosulfuron (25 g $ha^{-1}$) combined with 2,4-DEE (750 ml ha-1), which had the highest Herbicide Efficiency Index (HEI). This was followed by pendimethalin (1000 ml $ha^{-1}$) plus 2,4-DEE (750 ml $ha^{-1}$). The highest Weed Management Index (WMI) was achieved with two hand weeding sessions at 30 and 60 days after sowing (DAS), followed by sulfosulfuron and 2,4-DEE. The highest Agronomic Management Index (AMI) was also observed with two hand weeding sessions, while the lowest was with Pinoxaden (40 ml $ha^{-1}$) and 2,4-DEE. The Integrated Weed Management Index (IWMI) was highest with two hand weeding sessions, followed by sulfosulfuron and 2,4-DEE. The highest Weed Persistence Index (WPI) was recorded with two hand weeding sessions, followed by sulfosulfuron and 2,4-DEE. Weed density and biomass had a strong negative correlation with grain yield (r = -0.39 and r = -0.40, respectively), and similarly, there was a strong negative relationship between weed parameters and crop growth parameters.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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