Original Research Article

Phytotoxic effect and the Efficiency of different herbicides on weed control in wheat crop

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evaluate the impact of different herbicides and nitrogen levels on weed control Accompanying of wheat crop (Triticum Aestivum L.)

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 weed control and wheat yield. 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) followed by under application of sulfosulfuron (25 g ha^{-1}) + 2, 4-DEE (750 ml ha^{-1}). 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}.

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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.

Keywords: Herbicides, Weeds, Efficiency, Yield

1. INTRODUCTION

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Weeds are a major challenge in wheat cultivation, often being the most costly factor that hinders achieving optimal yields. This issue contributes to rising poverty and food insecurity. To effectively manage both grassy and broad-leaved weeds, a comprehensive approach is essential, combining both chemical and nonchemical methods of weed control [2]. To effectively manage diverse and complex weed populations, using a combination of multiple herbicides is necessary. Herbicide mixtures enhance the effectiveness of weed control and also play a crucial role in delaying the development of herbicide resistance [20]. Grassy weeds can pose up to 52.2% reduction in grain yield of wheat and broad leaf weeds can reduce the yield by up to 55.7% revealed by [16] and [19], noticed that weeds in the weedy check reduced the grain yield of wheat by 47.5% in comparison with other treatments. To control complex weed populations effectively, using a combination of multiple herbicides is essential. Herbicide mixtures not only improve the efficiency of weed control against diverse weed species but also help in delaying the development of herbicide resistance [18]. Yield losses can reach up to 65%, depending on factors such as the type and intensity of weeds, the crop and its species, the degree of weed infestation, and the management practices used [17]. [10] and [12] revealed that broad leaved weeds *Parthenium hysterophorus L., Melilotus sp., Rumex dentatus* and *Chenopodium album* whereas among the grasses *Phalaris minor* and *Cynodon dactylon*, among sedges only one species *Cyperus rotundus* was predominant weed species found in the wheat field. The efficiency of clodinafop at 60 g ha^{-1} is more or less similar to that of Pinoxaden for controlling the population of *Phalaris minor* and *Avena ludoviciana* [3] . Sulfosulfuron and mesosulfuron-methyl used for control of isoproturon resistant *Phalaris minor* in wheat but it is not safe for barley (King, 2007) [7]. Clodinafop-propargyl has been widely used for post-emergence control of grassy weeds specially *Phalaris minor* and *Avena ludoviciana* in the region of Punjab and Haryana but after 8-10 years of continuous use of these herbicides, complaints regarding their efficacy also started to emerge. *Phalaris minor* populations have evolved resistance against clodinafop in wheat fields in this region [16]. In wheat, N supply directly correlates with weed competition and competitive ability [4]. Considerable benefits may accrue from the optimum application of fertilizers to crops and as a result, there has been much interest in the timing and amount of nitrogen being applied to crop reported by [6]. It has been observed that both the amount of inputs and their application timing significantly affect weed emergence and density in the field. Increasing nitrogen fertilization from 120 to 150 kg N per hectare enhances dry matter accumulation, increases the number of tillers, improves nutrient uptake, and consequently boosts both grain and straw yields (Singh et al., 2015) [11] . Therefore, using various herbicide combinations along with optimal nitrogen levels enhances both the growth and yield of wheat crops.

2. MATERIALS AND METHODS

The field experiment was conducted during the winter (rabi) 2018–19 at Agricultural Research farm at Banaras Hindu University, Varanasi, Uttar Pradesh under the sub-tropical zone of Indo-Gangetic plains on 25°18' N and 83°03' E, which lies in left bank of River Ganga at an altitude of 75.70 m above the mean sea level. The soil was sandy clay loam having low in organic carbon (0.21%) and available N (152 kg ha^{-1}), medium in P (23.5 kg ha^{-1}) and K (188 kg ha^{-1}) and neutral pH (7.28). The experiment was laid out in 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(~~, 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}) [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. Mani *et al.* (2016) [10] and Verma et al. (2013) [24] observed that broad leaved weeds *Parthenium hysterophorus* L., *Melilotus sp., Rumex dentatus, and Chenopodium*

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Trade name
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Commented [AA10]: What do you mean?

Commented [AA11]: Not mentioned in the reference list *album* whereas among the grasses *Phalaris minor* and *Cynodon dactylon*, among sedges only one species *Cyperus rotundus* was predominant weed species found in the wheat field. 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 were calculated. Correlation of different crop and weed parameters were carried out. Different physico-chemical properties of soil shown in table 1.

Table 1. Different physico-chemical 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□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)		

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English name
Scientific name
Family
Life cycle

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2.1. Visual phytotoxicity

Visual phytotoxicity was recorded at 1,3,5,7,10 and 15 days after spraying indicated ~~that there was no adverse effect of herbicidal treatments~~ , 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 [21].

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

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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

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*. The study examined the effects of herbicides and nitrogen levels on the two major weeds, *Cyperus rotundus* and *Cynodon dactylon*, and assessed their subsequent impact on growth parameters.

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} and lower under 150 kg N ha^{-1} (Table 2). These results were in close conformity with the findings of [4] and [5].

3.3. Physico-chemical and biological properties of soil after harvest of wheat

The data regarding the soil physico-chemical properties are presented in table 3 and 4. Soil-bulk density, soil pH, organic carbon content and electrical conductivity of soil did not influenced by nitrogen levels as well as herbicidal treatments. 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

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(40+750 ml ha^{-1}) over weedy check and statistically at par with rest of the treatments. Higher level of microbial count were recorded in weedy check followed by hand weeding. Lower microbial count were recorded in the application of pinoxaden 5.1%EC + 2,4- DEE 38%EC (40+750 ml ha^{-1}). These findings were similar to the findings of [12] and [13].

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 5. 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, lower agronomic management index (AMI) was recorded under application of Pinoxaden (40 ml ha^{-1}) + 2, 4-DEE (750 ml ha^{-1}) and higher value under HW twice plot (30&60 DAS) whereas higher value of integrated weed management index (IWMI) 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}). 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 [14] and [19].

3.5. Correlation matrix among weed density, biomass and yield components ~~and interaction effect~~

The data regarding correlation of weed density, biomass and yield components has been depicted in table 5. Weed density and weed biomass had registered significantly negative correlation with the yield attributes and yield of wheat crop. While the yield components (effective tillers m^{-2}, number of grains m^{-2}) and biological yield parameters (grain yield and straw yield) were significantly positively correlated among themselves. Weed density and biomass had strong negative correlation with grain yield (r = -0.39 and r = -0.40, respectively). Strong negative existed with weed parameters and crop growth parameters, which were in close conformation with the findings of [12] and [17].

3.6. Interaction effect of nitrogen levels and herbicides on grain yield and straw yield

Interaction effect of nitrogen levels and herbicides showed that application of 180 kg N ha^{-1} in combination with HW twice (30 & 60 DAS) plot followed by application of 180 kg N ha^{-1} in combination with sulfosulfuron (25 g ha^{-1})+2,4-DEE (750 ml ha^{-1}) significantly recorded highest grain yield whereas highest straw yield was obtained with application of 180 kg N ha^{-1} in combination with sulfosulfuron (25 g ha^{-1})+2,4-DEE (750 ml ha^{-1}) and this might be due to integrated effect on increase in number of effective tillers m^{-2} (Table 6). These were in close conformation with the findings of [8] and [16].

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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

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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 25^0C	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

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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	

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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