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RESEARCH ARTICLE

Sequential herbicidal application on weed community and yield of wheat

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ABSTRACT

Effect of time, dosage of herbicide and crop residue were evaluated in Dharwad (Karnataka) on weed flora in wheat during winter (*Rabi*) season of 2020-21 and 2021-22. The experiment used a factorial randomized block design with twelve treatments, including a randomized complete block design to compare controls with treatment combinations. Results revealed that pre-emergence of pendimethalin reduced the number of grasses (3.0/m^2), sedges (1.7/m^2), broad-leaved weeds (4.5/m^2) and total number of weeds (9.2/m^2) at 20 DAS. At 40 and 60 DAS, sequential application of pre-emergence followed by post-emergence reduced the grasses (2.9 and 5.9/m^2), sedges (1.1 and 1.5/m^2), broad-leaved weeds (3.1 and 3.5/m^2), total number of weeds (6.8 and 10.6/m^2) and dry weight of weeds (1.9 and 3.4 g/m^2). Among the dosage, 100% recommended dose of herbicide (RDH) recorded lower grasses, sedges, broad-leaved weeds and dry weight of weeds compared to 75% RDH. Weed population did not differ significantly with application of soybean residue and no residue treatment. Pre-emergence followed by post-emergence at 100% RDH with soybean residue recorded higher grain yield (4.17 t/ha), weed control efficiency (79.7, 92.1 and 84.5%) and lower weed index (4.5%) compared to rest of the treatments. Lower grain yield (2.98 t/ha) and weed control efficiency (65.9, 56.6 and 42.7%) were with pre-emergence at 75% RDH without soybean residue. The results suggested that pre-emergence followed by post-emergence with 100% RDH with soybean residue was the best broad spectrum effective herbicide in order to minimize the diverse weed flora in wheat.

Keywords: 100% RDH, Pre-emergence, Post-emergence, Sequential herbicide, Soybean residue

INTRODUCTION

Weeds compete intensely with wheat crops for resources such as nutrients, water, and light, resulting in decreased wheat yield and reduced produce quality. Research findings from different sources suggest that unmanaged weed proliferation in wheat fields could lead to a decline in grain yield, varying between 15% to 40%, based on the extent, type and duration of weed infestation (Jat *et al*. 2003). Until the late 1990s, farmers predominantly relied on manual and mechanical weeding methods. However, since the 1990s, there has been a notable rise in nominal farm wages, which subsequently led to a higher dependence on herbicides, either applied individually or as part of integrated weed management strategies. While manual weeding remains the safest and most reliable approach to weed control, the challenge lies in ensuring the timely availability of sufficient labour, particularly during critical stages when weeding is required. Additionally, manual weeding has become expensive and time-consuming. As a result, chemical weed control methods are gaining popularity nowadays.

Herbicides represent one of the most effective weed management technologies ever created due to their selectivity, affordability, ease of application, manageable persistence, and adaptable timing for application. These are also environmentally friendly when utilized with the correct dosage, approach, and timing, besides being notably safer compared to other pesticides. However, with the emergence of resistance in significant weeds such as *Phalaris minor* against isoproturon and other suggested herbicides for grassy weeds like fenoxaprop-p-ethyl, it becomes imperative to explore alternative herbicidal options (Kamboj *et al*. 2021). Certain herbicides, like 2,4-D, which are primarily used to manage broadleaved weeds, perform effectively to suppress weeds but frequently cause deformity in wheat leaves and earheads (Balyan *et al*. 1990). Recent compounds of broadleaf herbicides such as metsulfuron-methyl effectively manage broadleaf weeds (Sharma *et al*. 2018) but lack efficacy against grassy weeds. This suggests the necessity of utilizing herbicides with diverse modes of action either in rotation or through sequential application to

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effectively manage the diverse weed population in wheat fields. The combination of various herbicide formulations in tank mixes or pre-mixes, as well as the sequential application of pre- and post-emergence herbicides at different timings, demonstrated efficient weed management (Kaur *et al.* 2017). In present study, the efficiency of combination of pre- and post-emergence herbicides used in sequence against weed flora in wheat was evaluated.

MATERIAL AND METHODS

The study was conducted in the winter (*Rabi*) seasons of 2020–21 and 2021–22 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. The experiment was designed using a factorial randomized block design with 12 treatments. A randomized complete block design was employed to compare the control treatments with the treatment combinations. The treatment details of the experiment are time of application, *viz*., H_1: Pre-emergence herbicide (pendimethalin), H_2: Pre-emergence (pendimethalin) followed by post-emergence (sulfosulfuron + metsulfuron-methyl), H_3: Post-emergence (sulfosulfuron + metsulfuron-methyl) in factor A, dosage of herbicide, *viz*. D_1: 75% recommended dose of herbicide, D_2: 100% recommended dose of herbicide in factor B and Residue N_1: No residue, N_2: Soybean residue in factor C and the control treatments are W_1: Weed free check and W_2: Weedy check. The soil of the research field was loam in texture pH of 7.4, low in organic carbon (0.47%), available N (158.41 kg/ha), moderate in available P (32.15 kg/ha) and available K (291.52 kg/ha). Wheat (UAS 334) was sown on 27th November 2020 and 14th November in 2021 by using seed rate of 125 kg/ha at 5 cm depth with rows 20 cm apart. The recommended dose of fertilizer was applied at the rate of 120-60-40-20-20 kg N, P, K, $ZnSO_4$ and $FeSO_4$/ha in the form of urea, di-ammonium phosphate, muriate of potash, zinc sulphate and ferrous sulphate, respectively. At the time of sowing, half dose of nitrogen, full dose of phosphorous, potassium, zinc and sulphur were applied as basal dose. Basal application was done in lines 5 cm below the seed rows. The remaining 50 percent of nitrogen was top dressed onto the crop at 30 days after sowing. Pre-emergence herbicide pendimethalin 30% EC 1.0 kg/ha was sprayed uniformly as per the treatment one day after sowing of the crop. The post-emergence herbicide tank mixtures of sulfosulfuron 75% WG 25 g/ha and metsulfuron-methyl 20% WP 4 g/ha was sprayed uniformly as per the treatments at 29 DAS when the weeds attained 2-4 leaf stage. The determined quantity of herbicide was applied to each treatment using a knapsack sprayer, with a spray volume of 750 litres of water per hectare. Three t/ha of soybean residue was chopped and spread immediately after germination in between the plant rows of the wheat crop. In the weed free treatment, there was continuous control of weeds during the entire crop growth period with manual weeding frequently as and when weeds appear in the field. Total number of weeds per square meter was noted in each plot in quadrate of 1 × 1 m^2 at 20, 40 and 60 DAS. A square root transformation $(\sqrt{x+1})$ was used to normalize the distribution of the data in order to determine the number of weeds in the wheat crop. The weeds were uprooted from m^2 area randomly each time and oven dried of weeds at 70°C till a constant weight. These were weighed and expressed in g/m^2 of weed biomass. Weed index was calculated by the formula proposed by Gill and Kumar (1969). The grain yield was calculated and expressed as t/ha. The statistical analysis was carried out using Analysis of Variance (Gomez and Gomez 1984) and mean comparisons were based on the least significant difference (LSD) at 0.05 probability.

RESULTS AND DISCUSSION

Grasses

Significantly reduced number of grasses was registered with the application of pendimethalin (3.0/m^2) and pendimethalin followed by sulfosulfuron + metsulfuron-methyl (3.0/m^2) compared to sulfosulfuron + metsulfuron-methyl (12.3/m^2) at 20 DAS. At 40 and 60 DAS, pendimethalin followed by sulfosulfuron + metsulfuron-methyl (2.9 and 5.9/m^2) noted a substantial decrease in grass weed population. A substantially greater quantity of grass weeds was found in sulfosulfuron + metsulfuron-methyl (9.3 and 12.7/m^2) and was on par with pendimethalin (5.7 and 10.6/m^2). The results are in line with the observations made by Pisal and Sagarka (2013) indicated that pendimethalin effectively managed both monocot and dicot weeds, whereas post-emergence application of 2,4-D amine salt and metsulfuron-methyl efficiently controlled dicot weeds.

Among the dosage of herbicide, grass weed number was significantly lower in 100% RDH (4.5, 4.7 and 7.9/m^2) compared to 75% RDH (6.7, 6.8 and 11.9/m^2) at 20, 40 and 60 DAS. Number of grass weeds did not differ significantly with crop residue application. Weed free check (0.0/m^2) recorded notably lower grass weeds compared to all other interactions and weedy check. While, weedy check

(18.4, 25.0 and 28.8/m^2 at 20, 40, 60 DAS, respectively) registered significantly superior number of grass weeds compared to the remaining treatments.

Sedges

Weed management practices had a significant impact on the number of sedge weeds (**Table 1**). At 20 DAS, significantly lower number of sedge population with pendimethalin (1.7/m^2) and was on par with pendimethalin followed by sulfosulfuron + metsulfuron-methyl (1.9/m^2). Substantially higher number of sedges (4.1/m^2) was noticed in sulfosulfuron + metsulfuron-methyl. At 40 and 60 DAS, sedge population was markedly reduced in pendimethalin followed by sulfosulfuron + metsulfuron-methyl (1.1 and 1.5/m^2) compared to different treatments. Significantly higher sedge weeds were recorded in pendimethalin (3.2 and 4.2/m^2) and was on par with sulfosulfuron + metsulfuron-methyl (2.6 and 3.0/m^2) treatment.

Significantly lower number of sedge weeds was found in 100% RDH (2.1, 1.6 and 2.1/m^2) compared to 75% RDH (2.9, 2.8 and 3.6/m^2) at 20, 40 and 60 DAS. Sedge population did not differ significantly with application of soybean residue and no residue treatment. Among control treatments, weed free check (0.0/m^2) recorded lower sedge number than other treatment combinations. Significantly higher sedges population was observed in weedy check, with counts of 6.3, 8.0, 10.5/m^2 at 20, 40 and 60 DAS, respectively.

Broad-leaved weeds

The number of broad-leaved weeds at 20 DAS varied significantly with the time of herbicide application, the number of broad-leaved weeds was significantly lower in the pendimethalin treatment (4.5/m^2) and comparable to the pendimethalin followed by sulfosulfuron + metsulfuron-methyl treatment (4.6/m^2). Broad-leaved weeds were found in much higher numbers (7.7/m^2) in the sulfosulfuron + metsulfuron-methyl (**Table 2**). At 40 and 60 DAS, pendimethalin followed by sulfosulfuron + metsulfuron-methyl (3.1 and 3.5/m^2) recorded lowest broad-leaved weeds compared to pendimethalin (7.8

Table 1. Number of grasses and sedge weeds at 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Grasses (no./m^2)			Sedges (no./m^2)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Time of application						
H_1: Pre-emergence	2.0 (3.0)	2.6 (5.7)	3.4 (10.6)	1.6 (1.7)	2.1 (3.2)	2.3 (4.2)
H_2: Pre-emergence *fb* post emergence	2.0 (3.0)	1.9 (2.9)	2.6 (5.9)	1.7 (1.9)	1.5 (1.1)	1.6 (1.5)
H_3: Post-emergence	3.6(12.3)	3.2 (9.3)	3.7 (12.7)	2.3 (4.1)	1.9 (2.6)	2.0 (3.0)
LSD (p=0.05)	0.29	0.33	0.47	0.14	0.17	0.22
Dosage of herbicide						
D_1: 75% of herbicide	2.8 (6.7)	2.8 (6.8)	3.5 (11.2)	2.0 (2.9)	1.9 (2.8)	2.1 (3.6)
D_2:100% of herbicide	2.3 (4.5)	2.4 (4.7)	2.9 (7.9)	1.7 (2.1)	1.6 (1.6)	1.8 (2.1)
LSD (p=0.05)	0.24	0.27	0.38	0.12	0.14	0.18
Crop residue						
N_1 = No residue	2.7 (6.4)	2.7 (6.3)	3.4 (10.2)	1.9 (2.6)	1.9 (2.6)	2.0 (3.1)
N_2 = Residue	2.4 (4.8)	2.5 (5.2)	3.1 (8.8)	1.8 (2.3)	1.7(1.9)	1.9 (2.6)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction						
$H_1D_1N_1$	2.6 (5.8)	2.9 (7.7)	4.0 (15.7)	1.9 (2.5)	2.3 (4.3)	2.6 (5.6)
$H_1D_1N_2$	2.2 (3.9)	2.7 (6.3)	3.5 (11.7)	1.7 (1.8)	2.2 (3.8)	2.5 (5.1)
$H_1D_2N_1$	1.8 (2.2)	2.4 (5.0)	3.1 (9.0)	1.6 (1.5)	1.9 (2.6)	2.1 (3.5)
$H_1D_2N_2$	1.5 (1.3)	2.3 (4.5)	2.9 (8.0)	1.5 (1.2)	1.8 (2.3)	1.9 (2.6)
$H_2D_1N_1$	2.4 (5.2)	2.2 (4.0)	3.0 (8.3)	1.9 (2.8)	1.7 (1.8)	1.8 (2.2)
$H_2D_1N_2$	2.2 (3.9)	2.1 (3.5)	2.8 (7.0)	1.8 (2.3)	1.5 (1.3)	1.6 (1.7)
$H_2D_2N_1$	1.9 (2.7)	1.9 (2.8)	2.4 (5.2)	1.6 (1.7)	1.4 (1.0)	1.5 (1.2)
$H_2D_2N_2$	1.6 (1.7)	1.6 (1.7)	2.3 (4.2)	1.5 (1.2)	1.2 (0.5)	1.4 (0.9)
$H_3D_1N_1$	3.8 (13.5)	3.5 (11.0)	3.9 (14.3)	2.4 (4.7)	2.2 (3.8)	2.3 (4.3)
$H_3D_1N_2$	3.5 (11.6)	3.4 (10.7)	3.8 (13.3)	2.2 (3.8)	1.9 (2.6)	2.1 (3.5)
$H_3D_2N_1$	3.7 (12.7)	3.3 (9.7)	3.6 (12.0)	2.3 (4.3)	1.8 (2.3)	1.9 (2.7)
$H_3D_2N_2$	3.5 (11.6)	2.8 (6.7)	3.5 (11.7)	2.2 (3.8)	1.7 (1.8)	1.8 (2.2)
Control						
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
W_2: Weedy check	4.4(18.4)	5.1(25.0)	5.5 (28.8)	2.7 (6.3)	2.9 (8.0)	3.4 (10.5)
LSD (p=0.05)	0.54	0.62	0.89	0.29	0.37	0.46

Figures are ($\sqrt{x+1}$) transformed values and figures in the parentheses are original values; DAS- Days after sowing and 10.1/m²) and was on par with sulfosulfuron + metsulfuron-methyl (4.3 and 4.6/m²). Pendimethalin recorded significantly higher broad-leaved weeds compared to rest of the treatments.

Among the dosage, 100% RDH (4.3, 3.9 and 4.8 /m² at 20, 40 and 60 DAS, respectively) was substantially reduced broad-leaved weeds compared to 75% RDH. The treatment of 75% RDH (6.7, 5.9 and 6.9/m² at 20, 40 and 60 DAS, respectively) recorded highest broad-leaved weeds. Soybean residue (4.8/m²) recorded significantly lower broad-leaved weed population compared to no residue (6.2/m²) treatments at 20 DAS. At 40 and 60 DAS, Application of with and without soybean residue did not affect number of broad-leaved weeds statistically but lower broad-leaved weeds were noticed in soybean residue (4.7 and 5.2/m²) compared to no residue (5.7 and 6.3/m²). The weed free check (0.0/m²) found the lowest number of broad-leaved weeds compared to the other treatments. However, higher broad-leaved weeds population was observed in weedy check (11.5, 15.0 and 17.2/m² at 20, 40 and 60 DAS, respectively) compared to all other interactions.

Total number of weeds

Application of herbicides reduced the total number of weeds at 20, 40, 60 DAS compared to the weedy check (36.2, 48.0 and 56.8/m²). Pre-emergence application of pendimethalin is effective only during the initial days and its efficacy is lost after few days (**Table 2**). Combined application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl reduced the total number of weeds (9.9, 6.8 and 10.6/m²) compared with single application of pendimethalin (9.2, 16.6 and 25.0/m²) and sulfosulfuron + metsulfuron-methyl (24.0, 16.6 and 20.2/m²). Better performance of herbicide mixtures was known in controlling all types of weeds and this was due to synergistic effect of these herbicides when tank mixed. Kaur *et al*. (2019) indicated that the sequential application of pendimethalin 1.0 kg/ha followed by post-emergent herbicides enhanced weed control compared with pre-emergent or post-emergent herbicides alone. Individual herbicide effect was inferior when compared with pre-emergent *fb* post-emergent herbicides.

Table 2. Broad-leaved weeds and total number of weedsat 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Broad-leaved weeds (no./m²)			Total number of weeds (no./m²)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Time of application						
H_1: Pre-emergence	2.3 (4.5)	2.9 (7.8)	3.3 (10.1)	3.2 (9.2)	4.2 (16.6)	5.1 (25.0)
H_2: Pre-emergence *fb* post-emergence	2.4 (4.6)	2.0 (3.1)	2.1 (3.5)	3.3 (9.9)	2.8 (6.8)	3.4 (10.6)
H_3: Post-emergence	2.9 (7.7)	2.3 (4.3)	2.4 (4.6)	5.0 (24.0)	4.2 (16.6)	4.6 (20.2)
LSD (p=0.05)	0.29	0.33	0.28	0.31	0.36	0.45
Dosage of herbicide						
D_1: 75% of herbicide	2.8 (6.7)	2.6 (5.9)	2.8 (6.9)	4.2 (16.6)	4.1 (15.8)	4.8 (22.0)
D_2: 100% of herbicide	2.3 (4.3)	2.2 (3.9)	2.4 (4.8)	3.5 (11.2)	3.4 (10.5)	4.0 (15.0)
LSD (p=0.05)	0.24	0.27	0.23	0.25	0.29	0.37
Crop residue						
N_1 = No residue	2.7 (6.2)	2.5 (5.7)	2.7 (6.3)	4.0 (15.0)	3.9 (14.2)	4.6 (20.2)
N_2 = Residue	2.4 (4.8)	2.3 (4.7)	2.5 (5.2)	3.6 (11.9)	3.5 (11.2)	4.2 (16.6)
LSD (p=0.05)	0.24	NS	NS	NS	NS	NS
Interaction						
$H_1D_1N_1$	2.8 (7.0)	3.3 (10.0)	3.7 (12.5)	4.0 (15.0)	4.8 (22.0)	5.8 (32.6)
$H_1D_1N_2$	2.6 (5.7)	3.1 (8.5)	3.5 (11.2)	3.5 (11.2)	4.4 (18.3)	5.3 (27.1)
$H_1D_2N_1$	2.2 (3.8)	2.8 (7.0)	3.2 (9.0)	2.9 (7.4)	3.9 (14.2)	4.7 (21.1)
$H_1D_2N_2$	1.8 (2.3)	2.6 (5.8)	3.1 (8.5)	2.4 (4.7)	3.7 (12.7)	4.5 (19.2)
$H_2D_1N_1$	2.8 (6.7)	2.4 (4.7)	2.4 (5.0)	3.9 (14.2)	3.3 (9.9)	4.0 (15.0)
$H_2D_1N_2$	2.5 (5.3)	2.2 (3.8)	2.2 (4.0)	3.5 (11.2)	3.1 (8.6)	3.7 (12.7)
$H_2D_2N_1$	2.2 (4.2)	1.9 (2.8)	2.1 (3.5)	3.0 (8.0)	2.7 (6.3)	3.3 (9.9)
$H_2D_2N_2$	1.9 (2.8)	1.7 (1.8)	1.7 (1.8)	2.6 (5.7)	2.2 (3.8)	2.8 (6.8)
$H_3D_1N_1$	3.1 (8.8)	2.5 (5.5)	2.6 (5.8)	5.3 (27.1)	4.6 (20.2)	5.0 (24.0)
$H_3D_1N_2$	2.9 (7.3)	2.4 (4.7)	2.4 (5.0)	4.8 (22.0)	4.3 (17.5)	4.7 (21.1)
$H_3D_2N_1$	3.0 (8.2)	2.3 (4.2)	2.3 (4.3)	5.2 (26.0)	4.1 (15.8)	4.5 (19.2)
$H_3D_2N_2$	2.8 (6.7)	2.1 (3.5)	2.1 (3.5)	4.7 (21.1)	3.6 (11.9)	4.2 (16.6)
Control						
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
W_2: Weedy check	3.5 (11.5)	3.9 (15.0)	4.3 (17.2)	6.1 (36.2)	7.0 (48.0)	7.6 (56.8)
LSD (p=0.05)	0.59	0.61	0.53	0.58	0.67	0.85

Figures are ($\sqrt{x+1}$) transformed values and figures in the parentheses are original values; DAS- Days after sowing

Recommended dosage of herbicide (11.2, 10.5 and 15.0/m^2 at 20, 40 and 60 DAS, respectively) reduced the total number of weed population due to efficient weed control compared with 75% RDH (16.6, 15.8 and 22.0/m^2 at 20, 40 and 60 DAS, respectively) in wheat at all the stages of crop growth. Duary *et al*. (2021) noticed that sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha recorded significantly the lower density of grasses, broad-leaved and total weeds compared with sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha. Total number of weeds showed no notable variance with the utilization of soybean residue practices in wheat crop. Soybean residue appears to be more effective in the absence of herbicide may rather than with the combinations. Abbas *et al.* (2017) found that application of mulches of sunflower, maize, rice and sorghum failed to achieve adequate weed control in wheat under clay-loam soil.

Better initial weed management was achieved with the pre-emergence of pendimethalin at 100% RDH combined with soybean residue (4.7/m^2) resulting in lower total number of weeds at 20 DAS. One of the reasons could be the implementation of the treatment. At 40 and 60 DAS of wheat, maximum control weeds were observed under pre-emergence followed by post-emergence at 100% RDH with soybean residue (3.8 and 6.8/m^2). Combining mulches and herbicides increased *Phalaris minor* mortality up to 98% in wheat crop (Abbas *et al.* 2017). Weed free check showed lower weed number due to continuous hand weeding to keep the field weed free. Weed management was achieved.

Dry weight of weeds

The herbicide application resulted in a notable reduction in the dry weight of weeds compared with weedy check (10.6, 13.2 at 14.8 g/m^2 at 20, 40 and 60 DAS, respectively). At 20 DAS, pendimethalin was efficient in reducing weed dry weight (2.8 g/m^2) compared with sulfosulfuron + metsulfuron-methyl (6.9 g/m^2) and it was on par with pre-emergence followed by post-emergence (3.2 g/m^2) and later dry weight of weeds was increases up to harvest (**Table 3**). This occurred because of the effective

Table 3. Total dry weight of weeds and weed control efficiency at 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Total dry weight of weeds (g/m^2)			Weed control efficiency (%)	
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS
Time of application					
H_1: Pre-emergence	1.9 (2.8)	2.4 (4.7)	2.9 (7.6)	75.2	64.1
H_2: Pre-emergence *fb* post-emergence	2.1 (3.2)	1.7 (1.9)	2.1 (3.4)	68.9	84.6
H_3: Post-emergence	2.8 (6.9)	2.2 (3.8)	2.6 (5.5)	34.4	69.1
LSD (p=0.05)	0.14	0.07	0.12	-	-
Dosage of herbicide					
D_1: 75% of herbicide	2.4 (4.7)	2.2 (3.8)	2.7 (6.3)	54.5	67.4
D_2:100% of herbicide	2.1 (3.2)	1.9 (2.8)	2.4 (4.7)	64.6	77.8
LSD (p=0.05)	0.12	0.05	0.10	-	-
Crop residue					
N_1 = No residue	2.3 (4.2)	2.2 (3.8)	2.6 (5.8)	56.1	70.2
N_2 = Residue	2.1 (3.6)	2.0 (3.2)	2.5 (5.1)	63.0	75.0
LSD (p=0.05)	0.12	0.05	0.10	-	-
Interaction					
$H_1D_1N_1$	2.1 (3.4)	2.6 (5.8)	3.0 (8.5)	65.9	56.6
$H_1D_1N_2$	2.0 (3.1)	2.4 (4.8)	2.9 (7.9)	71.1	61.8
$H_1D_2N_1$	1.8 (2.3)	2.3 (4.1)	2.8 (7.2)	79.6	67.1
$H_1D_2N_2$	1.6 (1.7)	2.2 (4.0)	2.7 (6.6)	84.3	71.1
$H_2D_1N_1$	2.3 (4.3)	1.9 (3.0)	2.4 (5.1)	58.5	78.0
$H_2D_1N_2$	2.2 (3.8)	1.8 (2.4)	2.3 (4.4)	63.9	81.4
$H_2D_2N_1$	1.9 (2.9)	1.7 (1.9)	2.0 (3.3)	73.6	86.7
$H_2D_2N_2$	1.8 (2.1)	1.5 (1.3)	1.8 (2.4)	79.7	92.1
$H_3D_1N_1$	2.9 (7.9)	2.5 (5.1)	2.8 (7.1)	28.4	60.7
$H_3D_1N_2$	2.7 (6.8)	2.3 (4.1)	2.7 (6.5)	39.0	65.9
$H_3D_2N_1$	2.9 (7.5)	2.2 (3.8)	2.5 (5.7)	30.4	71.9
$H_3D_2N_2$	2.6 (6.2)	1.9 (2.8)	2.4 (5.1)	39.9	77.7
Control					
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100.0	100.0
W_2: Weedy check	3.3(10.6)	3.72 (13.2)	3.9 (14.8)	-	-
LSD (p=0.05)	0.35	0.28	0.42	-	-

Figures are $(\sqrt{x+1})$ transformed values and figures in the parentheses are original values; DAS- Days after sowing management of weeds during the initial stage through the application of pendimethalin (Kumar *et al.* 2024). At 40 and 60 DAS, combined application of pre-emergence followed by post-emergence recorded lower dry weight of weeds (1.9 and 3.4 g/m^2) over single application of pre-emergence (4.7 and 7.6 g/m^2) and post-emergence (3.8 and 5.5 g/m^2). This may be due to higher efficacy of sulfosulfuron + metsulfuron in controlling both narrow and broad-leaved weeds at later stages (Meena *et al.* 2020). Recommended dosage of herbicide (100% RDH) (3.2, 2.8 and 5.1 g/m^2) was superior at all the stages over 75% RDH (4.7, 3.8 and 6.3 g/m^2) in terms of lowering the weed dry weight at 20, 40 and 60 DAS, respectively. Mekonnen (2022) noticed that rate of herbicides increased, the weeds density decreased in all herbicide treatments resulting in observable reduction in dry biomass. On the contrary, the practice of soybean residue mulching consistently resulted in reduced dry weight of weeds during every growth phase of the crop when compared to the absence of residue application (Meena *et al.* 2022). Combination of pre-emergence followed by post-emergence at 100% RDH with soybean residue reduced weed dry weight (2.1, 1.3 and 2.4 g/m^2 at 20, 40 and 60 DAS, respectively). Higher weed dry weight was observed under pre-emergence at 75% RDH without residue (3.4, 5.8 and 8.5 g/m^2 at 20, 40 and 60 DAS, respectively). This could result from the fact that herbicides were very efficient in suppressing weed biomass. The findings are confirmatory with Abbas *et al.* (2009) who observed significant reduction in weeds dry weight due to decrease in their population under herbicide treatments.

Weed control efficiency

At various phases of crop growth higher weed control efficiency was recorded with pre-emergence followed by post-emergence (68.9, 84.6 and 75.2 % at 20, 40, 60 DAS, respectively). It is due to the fact that pendimethalin and metsulfuron-methyl control both monocot and dicot weeds. Sulfosulfuron ready mixture with metsulfuron-methyl control grasses and broad-leaved weeds and enhance the efficacy of this combination and achieved highest value of WCE (84.6 %) at 40 DAS (**Table 3** and **4**).

The improvement in weed control efficiency with soybean crop residue application was to an extent of 12.29, 6.83 and 7.69 per cent over no mulching at 20, 40 and 60 DAS. This might be due to effective suppression of weeds. Similarly, in the initial stage at 20 DAS, pre-emergence at 100% RDH with soybean residue (84.3%) was better in weed control efficiency compared to the other treatment due to low weed dry weight obtained. At 40 to 60 DAS, pre-emergence followed by post-emergence at 100% RDH with soybean residue had higher weed control efficiency (92.1 and 84.5%). Combined effect indicated that effective management of emerged weeds and reduced carryover of weed seed bank in subsequent seasons. Pre-emergence at 75% RDH without residue recorded lower weed control efficiency. In studies conducted by Chopra *et al.* (2008) more than 80 per cent control of broad-leaved weeds with mixed application of metsulfuron and carfentrazone in wheat. Removing the weeds whenever they appear in the weed free treatment resulted in total control of weeds only by manual weeding. However, this is not feasible due to labour scarcity and un-economical. The lower weed control efficiency was noticed under weedy check treatment, because of higher weed competition stress.

Weed index

Weed index is a measure of crop yield loss due to treatments in comparison to weed free treatment (**Table 4**). Notably, the weedy check exhibited a significantly high weed index, reaching 40.7%. This can be primarily attributed to the intense competition posed by uncontrolled weed growth, which results in a competition for vital resources such as nutrients, moisture and light. This, in turn, leads to diminished growth and suboptimal yield components. Significantly lower weed index (4.5%) was obtained in the pre-emergence followed by post-emergence at 100% RDH with soybean residue. Deshmukh *et al.* (2020) observed that weed index was lower in all the herbicide treatments as compared with weedy check which created favourable conditions for crop growth which ultimately enhanced the grain yield of wheat crop as compared with weedy check treatment.

Grain yield

The application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl resulted in a notably increased grain yield (3.85 t/ha) compared to other treatments (**Table 4**). Pendimethalin (3.21 t/ha) recorded lower grain yield compared to pendimethalin followed by sulfosulfuron + metsulfuron-methyl and sulfosulfuron + metsulfuron-methyl (3.47 t/ha) treatments. Bagri *et al.* (2023) found similar superior wheat grain yields with herbicide combinations compared with herbicides alone. Among the herbicide dosage, 100% RDH (3.69 t/ha) higher grain yield compared to 75% RDH (3.33 t/ha) treatment. The grain yield was higher in soybean residue (3.56 t/ha) compared to no residue (3.46 t/ha) treatment. The mulching effect created favourable conditions,

Table 4. Weed control efficiency at 60 DAS, grain yield and weed index as influenced by weed management practices in wheat (pooled data of 2 years)

Treatment	Weed control efficiency (%) at 60 DAS	Weed index (%)	Grain yield (t/ha)		
			2020-21	2021-22	Pooled
Time of application					
H_1: Pre-emergence	49.5	26.7	3.16	3.26	3.21
H_2: Pre-emergence *fb* post-emergence	75.2	11.9	3.79	3.91	3.85
H_3: Post-emergence	57.6	20.6	3.39	3.55	3.47
LSD (p=0.05)	-	-	0.07	0.08	0.07
Dosage of herbicide					
D_1: 75% of herbicide	55.3	23.9	3.26	3.39	3.33
D_2:100% of herbicide	66.2	15.6	3.64	3.75	3.69
LSD (p=0.05)	-	-	0.06	0.06	0.06
Crop residue					
N_1 = No residue	58.5	21.0	3.39	3.53	3.46
N_2 = Residue	63.0	18.5	3.51	3.62	3.56
LSD (p=0.05)	-	-	0.06	0.06	0.06
Interaction					
$H_1D_1N_1$	42.7	31.9	2.94	3.02	2.98
$H_1D_1N_2$	46.4	29.4	3.05	3.13	3.09
$H_1D_2N_1$	52.2	23.8	3.27	3.41	3.34
$H_1D_2N_2$	56.5	21.6	3.39	3.49	3.44
$H_2D_1N_1$	66.0	18.0	3.52	3.66	3.59
$H_2D_1N_2$	71.4	16.2	3.60	3.73	3.66
$H_2D_2N_1$	78.8	9.1	3.92	4.03	3.97
$H_2D_2N_2$	84.5	4.5	4.14	4.21	4.17
$H_3D_1N_1$	50.4	25.2	3.17	3.37	3.27
$H_3D_1N_2$	54.6	22.9	3.29	3.44	3.37
$H_3D_2N_1$	60.8	17.9	3.51	3.66	3.59
$H_3D_2N_2$	64.7	16.4	3.59	3.72	3.65
Control					
W_1: Weed free check	100.0	-	4.32	4.42	4.37
W_2: Weedy check	-	40.7	2.62	2.58	2.60
LSD (p=0.05)	-	-	0.14	0.15	0.13

DAS- Days after sowing

including reduced evaporation, enhanced soil moisture content due to soil cover, improved water infiltration and retention, reduced weed growth, and the decomposition of added mulch materials (Zhang and Wu 2011). These factors likely contributed to an increase in the supply of nutrients and moisture, leading to an overall enhancement in crop yields. Among the treatment combination, application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl at 100% RDH with soybean residue (4.17 t/ha) was significantly higher grain yield compared to rest of the interactions. This increase in grain yield can be attributed to the enhancement of yield-related characteristics and the total production of dry matter, with subsequent distribution into various parts of the plant. Lower grain yield was recorded in pendimethalin at 75% RDH without residue (2.98 t/ha) compared to other interactions. This decrease in yield can be attributed to the inferior performance of growth and yield-related parameters. Weed free check (4.37 t/ha) recorded significantly superior grain yield. While, statistically inferior grain yield was noticed in weedy check (2.60 t/ha) compared to all other treatment combinations. Lower yield in weedy check was due to poor plant growth and higher weed density, which could have competed with wheat crop for space, water and nutrients, there by adversely affecting grain yield.

It was concluded that weeds associated with irrigated wheat can be effectively managed through sequence application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl at 100% recommended dose of herbicide with soybean residue and resulted higher grain yield.

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