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Effect of different weed management practices on the performance of cabbage (*Brassica oleracea* var. *capitata* L.) under North Western Himalayan regions

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Abstract
The present investigation was carried out at the Research farm of Abhilashi University, Mandi (H.P) during the *kharif* season of 2023. Seven different treatments were evaluated in a randomized block design with three replications. The main objectives of the investigation were to assess the impact of different weed management practices on growth and yield of cabbage crop. The results revealed that treatment T_7 (Weed-free) recorded the maximum values of all parameters *viz.*, plant height (32.23 cm), number of unwrapped leaves (15.49), dry weight of unwrapped leaves (26.59 g), dry weight of wrapped leaves (115.58 g), head weight (958.16 g), yield per plot (17.25 kg) and yield per hectare (344.94 q/ha) due to less presence of weeds and lower weed competition. Major weeds that were observed in the experimental field were *Eleusine indica* L., *Trifolium fragiferum* L., *Stachys arvensis* L., *Galinsoga quadriradiata* L., *Lysimachia arvensis* L., etc. Minimum values of weed parameters viz., weed count (0.00), weed fresh weight (0.00 g) and weed dry weight (0.00 g) were recorded in treatment T_7 (Weed-free) while highest weed control efficiency (100%) was recorded under the same treatment. In terms of economics, the maximum cost of cultivation (₹ 1,34,930) and gross income (₹ 5,20,106) was recorded under treatment T_7 (Weed-free) while the net income (₹ 3,84,986) and B: C ratio (3.89) was recorded highest under the treatment T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT) which is combined application of herbicides and manual weeding.

Keywords: Weed, cabbage, growth, yield and economics

Introduction
Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most important colecrops and belongs to the family Brassicaceae. Its chromosome number is 2n = 2x = 18. It is native to Western Europe and Mediterranean region. It was reported to have been grown during Mughal period and introduced by the Portuguese, though the crop became popular during British rule. Among all other cole crops, the first domesticated crops were cabbage and kale (Akshatha, 2018) [1]. India is the world's 3rd largest producer of cabbage and occupies an area of 423 thousand hectares with a production of 9.78 million MT (Anonymous, 2021).Reduction in cabbage yield is found due to the presence of weeds present in the field. Weeds are unwanted plants that grow in the field alongside crop and compete (directly and indirectly affects crop performance) for space, water and nutrients, therefore negatively impacting crop growth and yield (Chauhan *et al.* 2023) [5]. Cabbage requires frequent irrigations and heavy manuring which creates a favourable environment for the growth and germination of weeds. Weed competition during the early stages of the crop may result in diminished cabbage growth and production. The management of weeds is one of the most crucial issues facing the production of cabbage, since weeds have been shown to affect yield by 45-80 percent (Chadha, 2001) [4]. The critical period for crop weed competition in cabbage starts 30-40 days after transplanting. Common predominant weed species found in cabbage field are *Cynodon dactylon*, *Parthenium hysterophorus*, *Digitaria arvensis*, *Cyperus rotundus* and *Dactyloctenium aegyptium* (Kumar *et al*. 2014) [9].
Controlling weed growth poses a significant obstacle for all vegetable cultivators. Weed management involves different techniques. Mechanical techniques such as manual weeding, hand hoeing, or interculturing are effective in managing weed growth.

However, they come with the persistent issue of weed resurgence, necessitating frequent weeding. This can make these practices economically burdensome and labour-intensive (Chauhan *et al.* 2022) [6]. Furthermore, due to the crop's shallow root system, there exists a risk of damaging the roots when applying deep hoeing methods. So, chemical herbicides for weed control are considered more effective. Herbicides effectively manage weeds in the early season by limiting and reducing their growth. Pre- and post-emergent herbicides would increase farmer acceptance of herbicidal weed management, which wouldn't affect current agronomic practices but would enable complete weed control. It is more important to use pre-emergence herbicides because they are more effective right away. Pre-emergence herbicides like pendimethalin and oxyfluorfen are effective in controlling weed growth at the start by not allowing them to germinate. These herbicides permanently eliminate the growth of weeds at starting (Kaur *et al.* 2021) [8]. Integrated weed management helps to reduce weed competition at the right time. This is an affordable and efficient method that helps to produce higher yields. Herbicides when used alone do not provide effective results but when combined with mechanical weed management practices they provide better results. Therefore, it is crucial to use an integrated approach for efficient weed management to minimize the negative effects of chemical herbicides on human and animal health as well as on the environment.

Materials and Methods

Experimental site

The present investigation was conducted during the *kharif* season of 2023 at the Research Farm, School of Agriculture, Abhilashi University, Mandi (H.P.). The experimental farm is situated at 31^0 33'35" N latitude and 77^0 00'46" E longitude with an elevation of 1,413 m above mean sea level.

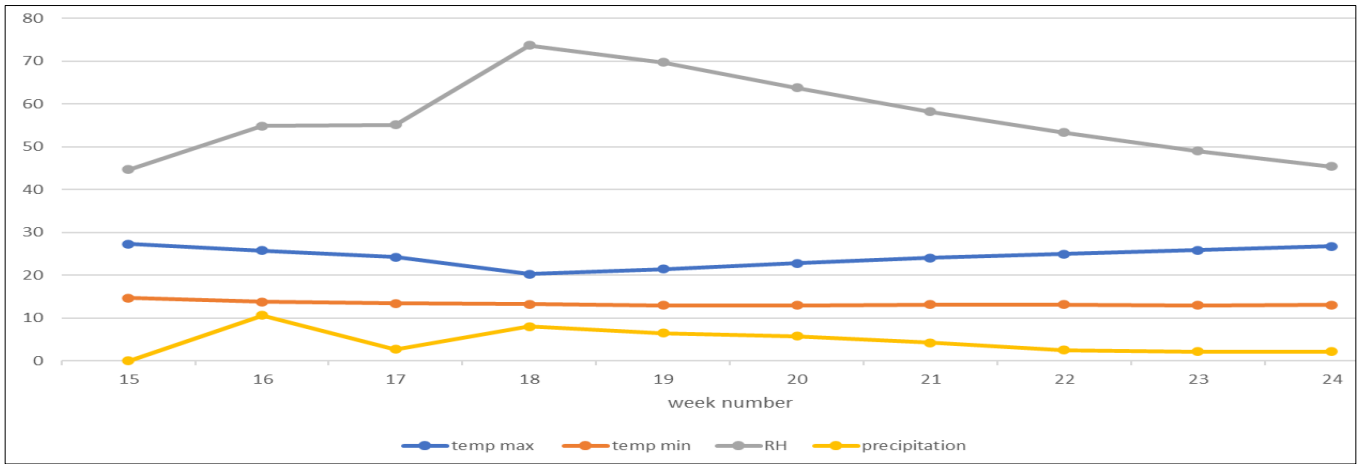

Fig 1: Meteorological data of experimental farm recorded during April to June, 2023.

Table 1: Treatment details

Notations	Treatments
T_1	Pendimethalin 1 kg a.i./ha
T_2	Oxyfluorfen 1 kg a.i./ha
T_3	Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting
T_4	Two hand weeding respectively at 30 and 45 days after transplanting
T_5	Pendimethalin 0.7 kg a.i./ha + hand weeding at 30 days after transplanting
T_6	Weedy check (Control)
T_7	Weed-free (Hand-weeding)

Design of experiment

The experiment was laid out in Randomized Block Design with three replications comprising of seven treatment combinations of inorganic fertilizer with organic manures. The layout plan is provided below:

Variety : Green Voyager
Design : Randomized Block Design
Number of replications : 3
Number of treatments : 7
Total number of plots : 21
Plot size : 2.5 m × 1.8 m
Spacing : 45 cm × 45 cm

Growth parameters

Plant height (cm): The height of five randomly selected plants was measured at the harvesting stage from the ground level to the tip of each leaf and after that their average height per plant was calculated.

Number of unwrapped leaves

At the harvest stage, the number of unwrapped leaves of five randomly selected plants were counted and their average was calculated.

Quality parameters

Dry weight of unwrapped leaves per plant (g)

After calculating the fresh weight of the unwrapped leaves, they were chopped into small pieces followed by sun, air and oven drying. They were oven-dried at the temperature of 72 °C until the constant dry weight was achieved. The final dry weight of unwrapped leaves was noted and expressed in grams.

Dry weight of wrapped leaves per plant (g)

After calculating the fresh weight of the wrapped leaves (cabbage heads) they were chopped into small pieces and samples were taken for sun drying followed by air and oven

drying. The samples were oven-dried at the temperature of 72 °C until they attained a constant dry weight. After oven drying the final values were noted in grams.

Yield parameters

Weight of head (g)

Weight of head was calculated from five randomly selected and labelled plants from each treatment.

Yield per plot (kg)

To determine the yield from each plot, the average head weight from each plot was recorded.

Yield per hectare (q)

The total yield per hectare was recorded from each plot per replication per treatment and expressed in quintals. The yield per plot (kg) was transformed into yield per hectare (q) by multiplying the suitable factor.

Soil analysis

After the experiment, soil samples from 0-15 cm depth were collected from all the plots separately. Those samples were air dried, crushed, passed through 2 mm sieve and stored in bags for chemical analysis.

Table 2: Initial properties of soil

S. No.	Parameters	Values obtained	Methods used
1.	Soil pH (1:2.5, soil water suspension)	5.75	Glass electrode method (Jackson, 1973) [7]
2.	Available N (kg/ha)	212	Alkaline potassium permanganate (Subbiah and Asija, 1956) [16]
3.	Available P (kg/ha)	12.9	Olsen's method of extraction with 0.5 $NaHCO_3$ at pH 8.5 (Olsen et al. 1954) [12]
4.	Available K (kg/ha)	190	Neutral ammonium acetate extraction method (Merwin and Peech 1950) [10]

Available N (kg ha^{-1})

Available nitrogen in the soil (kg ha^{-1}) was determined through alkaline potassium permanganate method (Subbiah and Asija, 1956) [16] by digestion, distillation and collection of NH_3 in 2% boric acid and titrating it against standard sulphuric acid.

Available P (kg ha^{-1})

Available phosphorus content was determined by Olsen's method of extraction with 0.5 1$NaHCO_3$ at pH 8.5 (1954) as described by Jackson (1973) [7].

Available K (kg ha^{-1})

Available potassium in soil (kg ha-1) was extracted by neutral 1 N ammonium acetate and determined by flame photometric method as described by Jackson (1973) [7].

Soil pH

Soil pH was determined in 1: 2.5 soil to water suspension after stirring the contents intermittently for half an hour. The pH value was recorded using glass electrode method (Jackson, 1973) [7].

Weed parameters

Weed flora

Each replication's control plot was examined visually for the presence of weed species, and the growing weed species were noted.

Weed count

From each plot the weed count was taken at harvesting stage using a 50 × 50 cm (0.25 m^2) quadrant. The 50 cm × 50 cm quadrant was randomly placed on the plots and the weeds within the quadrant were counted.

Fresh weight of weeds (g)

Weeds within the 0.25 m^2 area of each plot were uprooted and cleaned and fresh weight was recorded at the time of harvesting and the values were noted in grams.

Dry weight of weeds (g)

Dry weight of weeds was recorded after recording the fresh weight of weeds. The weeds were cleaned and sun dried for 3 days until they recorded a constant weight. The final weight was expressed in grams.

Weed Control Efficiency (%)

It indicates the extent of weed control as a result of weed control treatments. The following method is used to compute it; the result is reported in percentage form. This formula was suggested by Jackson et al. (1973) [7].

$$WCE\ \% = \frac{DWC\text{-}DWT}{DWC} \times 100$$

Where,

WCE = Weed control efficiency (%)

DWC = Dry weight of weeds in the control plot (g)

DWT = Dry weight of weeds in the treated plot (g)

Results and Discussion

The results of the field experiment entitled "Effect of different weed management practices on the performance of cabbage (*Brassica oleracea* var. *capitata* L.) under North Western Himalayan regions" was carried out at the Research Farm, School of Agriculture, Abhilashi University, Mandi, (H.P.) during the summer season of 2023. Data on several parameters was statistically examined and the significance and non significance of results was verified.

Growth parameters and quality parameters

The result recorded for plant height was significantly affected by different weed management practices. The maximum plant height (32.23 cm) was obtained under treatment T_7 (regular hand weeding) which was statistically at par with the treatments T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT) and T_5 (Pendimethalin 0.75 kg/ha + HW at 30 DAT) and the minimum (20.74 cm) was observed under treatment T_6 (weedy check). The similar results were observed by Atal *et al*. (2021) [3] and Patil *et al*. (2022) [13].

Among all the treatments the maximum number of unwrapped leaves (15.49) were recorded in treatment T_7 (weed free) which was statistically at par with the treatments T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT) and T_5 (Pendimethalin 0.75 kg/ha + HW at 30 DAT) while the minimum number of unwrapped leaves (8.45) were recorded

in treatment T_6 (weedy check). Similar results were found in Atal *et al*. (2021) [3] and Thakur *et al*. (2023) [17].

The experiment's dry weight of unwrapped leaves was relatively affected by different weed management practices. The treatment T_7 (weed free) recorded the maximum dry weight of unwrapped leaves (26.59 g) which was statistically at par with the treatment T_3 (Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting). The minimum dry weight of unwrapped leaves (16.39 g) was obtained in treatment T_6 (weedy check). It might be due to the absence of weeds which didn't interfere with the plant growth. This improved the plant's ability to spread and grow, which in turn increased the amount of dry matter they produced. Similar results were observed by Sen *et al.* (2018) [15].

The dry weight of wrapped leaves was found maximum (115.58 g) in T_7 (weed free) treatment whereas the minimum (53.25 g) was found under T_6 (weedy check) treatment. The total amount of dry matter generated indicates increased utilization of resources and light absorption. Plants in weed free treatment were able to maximize the use of these resources for growth as there were no weeds present. This could be the cause of the higher total dry matter recorded in this treatment as compared to other treatments by the harvesting time. Results are in concordance with Patil *et al*. (2022) [13] and Thakur *et al*. (2023) [17].

Yield parameters

The weight of heads was significantly affected by the treatments used in the experiment. The maximum weight of heads (958.16 g) was observed in treatment T_7 (weed free) which was statistically at par with the treatment T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT). While the minimum head weight (411.89 g) was observed in treatment T_6 (weedy check). The maximum head weight was achieved in weed free treatment as there were no weeds present and allowed plants to utilize all available resources exclusively for their growth and development. Similar results were found by Atal *et al*. (2021) [3], Patil *et al*. (2022) [13] and Thakur*et al*. (2023) [17].

The yield per plot was relatively affected by different weed management practices. The treatment T_7(weed free)recorded the highest yield per plot (17.25 kg) which was statistically at par with the treatment T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT) and the lowest yield per plot (6.03 kg) was measured in T_6 (weedy check). This might be due to less weed competition which may result in increased plant development, growth and at last yield. Similar results for maximum yield per plot have been reported by Patil *et al*. (2022) [13] and Thakur *et al*. (2023) [17].

The yield per hectare was relatively affected by different treatment combinations in the experiment. The maximum yield per hectare (344.94 q/ha) was observed intreatment T_7 (weed free) which was statistically at par with the treatment T_3 (Oxyfluorfen 0.25 kg/ha + HW at 30 DAT). The least (120.54 q/ha) was recorded in treatment T_6 (weedy check). This might be due to absence of weeds in the beginning of the crop growth period which helped plants in the proper utilization of light, moisture, space and water for their better growth. Similar results for yield per hectare were found by Atal *et al*. (2021) [3], Patil *et al*. (2022) [13] and Thakur *et al*. (2023) [17].

Soil analysis

The higher content of available nitrogen (281.00 kg/ha) and available phosphorus (22.23 kg/ha) was recorded in treatment T_7(regular hand weeding). The higher content of available potassium (260.02 kg/ha) was exhibited in treatment T_7(regular hand weeding) which was statistically at par with treatment T_4. However, the lower content of available nitrogen (235.42 kg/ha), available phosphorus (15.94 kg/ha) and available potassium (245.67 kg/ha) was recorded in T_6 (weedy check). Similar results of this investigation were also in concordance with the findings reported by Sekhar (2017) [14] and Akshatha V. (2018) [1].

Soil pH was found maximum (5.7) in treatment T_6 (weedy check) whereas minimum pH (5.1) was recorded in T_2 (Oxyfluorfen 1kg a.i/ha).The effect of different weed management practices had no significant effect on soil pH.

Table 3: Effect of different treatments on plant height (cm), number of unwrapped leaves, dry weight of unwrapped leaves (g) and dry weight of wrapped leaves (g).

Treatments	Plant height (cm)	Number of unwrapped leaves	Dry weight of unwrapped leaves (g)	Dry weight of wrapped leaves (g)
Pendimethalin 1 kg a.i./ha	25.40	10.69	20.27	71.60
Oxyfluorfen 1 kg. a.i./ha	27.31	11.26	20.73	80.63
Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting	30.30	13.71	24.99	105.18
Two hand weeding respectively at 30 and 45 days after transplanting	27.89	12.35	23.07	88.26
Pendimethalin 0.7 kg a.i./ha + hand weeding at 30 days after transplanting	29.08	13.03	24.44	100.20
Weedy check (Control)	20.74	8.45	16.39	53.25
Weed-free (Hand weeding)	32.23	15.49	26.59	115.58
SE(m) (±)	1.17	0.98	0.68	3.08
$CD_{(0.05)}$	3.64	3.06	2.13	9.59

Table 4: Effect of different treatments on weight of head (g), yield per plot (kg) and yield per hectare (q)

Treatments	Weight of head (g)	Yield per plot (kg)	Yield per hectare (q)
Pendimethalin 1 kg a.i./ha	768.87	11.77	235.47
Oxyfluorfen 1 kg. a.i./ha	827.33	13.04	260.77
Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting	913.34	16.13	322.61
Two hand weeding respectively at 30 and 45 days after transplanting	833.07	13.79	275.80

Pendimethalin 0.7 kg a.i./ha + hand weeding at 30 days after transplanting	884.65	15.05	300.98
Weedy check (Control)	411.89	6.03	120.54
Weed-free (Hand weeding)	958.16	17.25	344.94
SE(m) (±)	22.83	0.38	7.67
$CD_{(0.05)}$	71.11	1.20	23.95

Table 5: Effect of different treatments on soil properties

Treatments	Available N, P and K (kg/ha)			Soil pH
	N	P	K	
Pendimethalin 1 kg a.i./ha	245.12	17.17	249.51	5.3
Oxyfluorfen 1 kg. a.i./ha	247.64	17.98	250.51	5.1
Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting	262.78	19.76	256.76	5.3
Two hand weeding respectively at 30 and 45 days after transplanting	265.39	20.16	258.07	5.5
Pendimethalin 0.7 kg a.i./ha + hand weeding at 30 days after transplanting	259.08	19.04	253.16	5.5
Weedy check (Control)	235.42	15.94	245.67	5.7
Weed-free (Hand weeding)	281.00	22.23	260.02	5.7
SE(m) (±)	4.54	0.55	0.96	0.17
$CD_{(0.05)}$	13.88	1.72	3.00	NS

Table 6: Effect of different treatments on weed count/0.25 m^2,fresh weight of weeds (g), dry weight of weeds (g) and weed control efficiency (%)

Treatments	Weed count/0.25 m^2	Fresh weight of weeds (g)	Dry weight of weeds (g)	WCE (%)
Pendimethalin 1 kg a.i./ha	4.52 (20.00)*	15.18 (230.14)*	6.99 (48.42)*	57.17
Oxyfluorfen 1 kg. a.i./ha	3.93 (15.00)*	13.99 (195.31)*	6.34 (39.77)*	64.81
Oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting	3.41 (11.33)*	10.96 (120.10)*	5.06 (25.34)*	77.49
Two hand weeding respectively at 30 and 45 days after transplanting	3.76 (13.67)*	13.49 (181.61)*	6.02 (35.70)*	68.38
Pendimethalin 0.7 kg a.i./ha + hand weeding at 30 days after transplanting	3.56 (12.33)*	11.75 (137.66)*	5.50 (29.81)*	73.58
Weedy check (Control)	6.26 (38.67)*	23.63 (558.12)*	10.65 (112.90)*	0.00
Weed-free (Hand weeding)	1.00 (0.00)*	1.00 (0.00)*	1.00 (0.00)*	100.00
SE(m) (±)	0.18	0.31	2.22	1.86
$CD_{(0.05)}$	0.57	0.96	0.58	5.80

Table 7: Economic analysis of different weed management practices

Treatments	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B: C ratio
Pendimethalin 1 kg a.i./ha	88,831	3,53,20	2,64,377	2.98
Oxyfluorfen 1 kg a.i./ha	1,01,200	3,91,154	2,89,954	2.87
Oxyfluorfen 0.25 kg a.i./ha + HW at 30 DAT	98,604	4,83,920	3,85,316	3.91
Two hand weeding respectively at 30 and 45 days after transplanting	1,01,930	4,13,693	3,11,763	3.06
Pendimethalin 0.7 kg a.i./ha + HW at 30 DAT	96,563	4,51,472	3,54,909	3.68
Weedy check (Control)	85,430	1,80,809	95,379	1.12
Weed-free (Hand-weeding)	1,34,930	5,17,406	3,82,476	2.83

Weed parameters

Major weed species found in the experimental field were *Eleusine indica* L., *Amaranthus viridis* L., *Chenopodium album* L., *Stachys arvensis* L., *Lepidium didymium* L., *Persicaria capitata* L., *Melilotus indicus* L., *Poa annua* L., etc.

The maximum weed population (38.67 weed/0.25 m^2) was recorded in treatmentT_6 (weedy check) as there was no treatment effect in weedy check treatment and the weeds were left to grow unchecked that's why a higher population of weeds was observed in weedy check treatment which contributed to maximum fresh weight and dry weight of weeds in T_6 treatment. The minimum values of weed population, fresh weight and dry weight of weeds were observed in treatment T_7 (weed free). Similar results were also observed by Nandal *et al.* (2005) [11] and Patil *et al.* (2022) [13].

Maximum weed control efficiency (100%) was recorded under T_7 (weed free) treatment because no weeds were present. The lowest weed control efficiency was obtained in treatment T_6 (weedy check). Similar are the findings of Sen *et al.* (2018) [15] and Thakur *et al.* (2023) [17].

Economics

The combined use of manual weeding and herbicides substantially affects economics. The highest cost of cultivation ₹ 1,34,930 was found in treatment T_7 (weed free) which was followed by T_4i.e. ₹ 1,01,930 whereas least cost of cultivation was found in T_6 (weedy check) i.e. ₹ 85,430. The economics in terms of net returns (₹3,85,316) and B: C ratio (3.91) were maximum in T_3 (oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting) and the minimum was incurred in T_6 (weedy check) i.e. ₹ 95,379 and 1.12 respectively.

Conclusion

This experiment concluded that preventing weeds in the field helped reduce weed growth and increase yield but this approach could not be taken into consideration due to the labor requirements and increased costs. As the net returns and benefit: cost ratio were recorded higher under T_3 (oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting) treatment. Therefore, it may be concluded that treatment T_3 (oxyfluorfen 0.25 kg a.i./ha + hand weeding at 30 days after transplanting) may be recommended for the commercialization after verification of results by the way of conducting on farm trials across the cabbage growing areas of Himachal Pradesh, India.

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