

**IMPACT OF PLANTING PATTERNS, NITROGEN AND
FYM ON GROWTH AND DEVELOPMENT OF FENNEL
(*Foeniculum vulgare* Mill.) UNDER VARIABLE WEED
CONTROL METHODS**

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Agronomy

By

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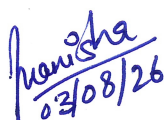
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2026

DECLARATION

I, hereby declared that the presented work in the thesis entitled, “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of **Dr. Ujagar Singh Walia**, working as **Professor**, in **Department of Agronomy, School of Agriculture, Lovely Professional University, Punjab, India**. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



(Signature of scholar)

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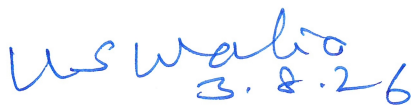
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This is to certify that the work reported in the Ph. D. thesis entitled, “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph. D.) in Agronomy** in the **School of Agriculture**, is a research work carried out by **Manisha Chaudhary** (Reg No: **12319913**), is bonafide record of her original work carried out under my supervision and that no part of thesis has been submitted for any degree, diploma or equivalent course.



(Signature of supervisor)

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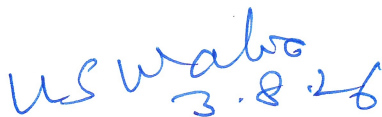
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ABSTRACT

The field experiment entitled “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” was carried out in two distinct experiments at the Agronomy Research Farm, Lovely Professional University, Phagwara, Punjab during *rabi* season of 2023-24 and 2024-25. Both the experiments were conducted in Split Plot Design with four replications each. In first experiments there were four planting patterns in main plots viz. two rows per bed, ridge sowing, flat sowing *fb* earthing up and flat sowing. Four weed control treatments in sub plots were black plastic mulch, white plastic mulch, one hand weeding *fb* straw mulch and unweeded (control). The results revealed that among planting patterns, significantly less weed count (m^{-2}) and weed dry matter ($q\ ha^{-1}$) were recorded in flat sowing *fb* earthing up as compared to all other planting patterns. Among weed control treatments, significantly lower weed count (m^{-2}) and weed dry matter ($q\ ha^{-1}$) were recorded in black plastic mulch as compared to all other weed control methods. The periodic growth parameters such as plant height (cm), plant dry matter ($plant^{-1}$), number of primary and secondary branches $plant^{-1}$ were significantly higher in flat sowing *fb* earthing up as compared to all other planting patterns. Among weed control treatments, application of black plastic mulch improved all these periodic growth parameters. The yield attributes like number of primary and secondary umbels $plant^{-1}$, diameter of main, primary and secondary umbels (cm), number of umbellets per umbel, number of seeds per umbellet, number of seeds per umbel, seed weight per umbel (g) and 1000 seed weight of umbels (g) were found to be significantly higher in flat sowing *fb* earthing up planting pattern. Among weed control treatments, all these yield parameters were significantly better in black plastic mulch treatment as compared to all other weed control treatments. On the basis of average of two years, the seed yield ($q\ ha^{-1}$) recorded in planting pattern of flat sowing *fb* earthing up ($13.6\ q\ ha^{-1}$) increased by 40.20% as compared to flat sowing ($9.7\ q\ ha^{-1}$). Among weed control treatments, the seed yield of fennel in black plastic mulch ($17.3\ q\ ha^{-1}$) was increased by 458.06% as compared to unweeded (control) ($3.1\ q\ ha^{-1}$). Total N uptake by crop was found to be significantly higher in flat sowing *fb* earthing up as compared to all other planting

patterns. Among weed control treatments, total N uptake by crop was found to be higher with the application of black plastic mulch than all other weed control treatments. N uptake by weeds was significantly more in flat sowing as compared to other planting patterns. Among the weed control treatments, N uptake by weeds was significantly higher in unweeded (control). The highest net returns were recorded in flat sowing *fb* earthing up with application of black mulch treatment. These findings were similar for 2023-24 and 2024-25.

In the second experiment, four weed control treatments i.e. black plastic mulch, hand weeding *fb* straw mulch, pendimethalin (0.45 kg ha^{-1}) *fb* one hand weeding, and unweeded (control) were kept in main plots and four nutrition levels viz. 25 kg N ha^{-1} , $25 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$, 50 kg N ha^{-1} and $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ were kept in sub plots. The results revealed that, among weed control treatments, significantly less weed count (m^{-2}) and weed dry matter (q ha^{-1}) was recorded in black plastic mulch. Among nutrition level treatments, lower weed count (m^{-2}) and weed dry matter (q ha^{-1}) were recorded with application of 25 kg N ha^{-1} . The growth parameters such as plant height (cm), plant dry matter (plant^{-1}), number of primary and secondary branches plant^{-1} were significantly higher in black plastic mulch, among weed control treatments and among nutrition level treatments, application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ significantly improved all these growth parameters. The yield attributes like number of primary and secondary umbels plant^{-1} , diameter of main, primary and secondary umbels (cm), number of umbellets per umbel, number of seeds per umbellet, number of seeds per umbel, seed weight per umbel (g) and 1000 seed weight (g) were significantly higher in black plastic mulch application. Among nutrition level treatments, all these yield parameters were significantly better with application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ as compared to all other nutrition level treatments. On the basis of average of two years, the seed yield (q ha^{-1}) recorded in black plastic mulch (18.8 q ha^{-1}) increased by 1005.88% as compared to unweeded (control) (1.7 q ha^{-1}). Among nutrition level treatments, the seed yield of fennel in integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ (14.9 q ha^{-1}) was increased by 39.25% as compared to 25 kg N ha^{-1} (10.7 q ha^{-1}). Among weed control treatments, total N uptake by crop was found to be significantly higher in black plastic mulch.

Among nutrition level treatments, total N uptake by crop was significantly higher with the application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹. N uptake by weeds was significantly more in unweeded (control) as compared to other weed control treatments. Among nutrition level treatments, N uptake by weeds was significantly better with application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15 t ha⁻¹. The highest net returns were recorded with application of black plastic mulch along with 50 kg N ha⁻¹ + FYM 15 t ha⁻¹. These findings were similar for 2023-24 and 2024-25.

Keywords: earthing up, fennel, nutrition levels, planting patterns, plastic mulch, straw mulch, weed control.

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LIST OF ABBREVIATION

Abbreviation	Full name
ANOVA	Analysis of variance
@	At the rate of
⁰ C	Degree Celsius
C.D.	Critical difference
cm	Centimetre
DAS	Days after sowing
dS	Deci siemens
EC	Electrical conductivity
<i>fb</i>	Followed by
FYM	Farmyard manure
g	Gram
ha	Hectare
hrs	Hours
<i>i. e.</i>	that is
K	Potassium
kg	Kilograms
mg	Milligram
mm	Millimetre
m ²	Meter square
N	Nitrogen
NS	Non-significant
OC	Organic carbon
%	Percent
P	Phosphorus
pH	Potential of hydrogen
q	Quintal
RDN	Recommended dose of nitrogen

SE(m)	Standard error of means
SSP	Single super phosphate
t	Ton
WCE	Weed control efficiency

CHAPTER 1

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) is one of the most prominent seed spice crop, grown on an extensive scale in India. It is cultivated in temperate or subtropical regions including Romania, Russia, Germany, France, Italy, Argentina, and the United States. Also, it is cultivated in Bulgaria, China, Denmark, Egypt, Syria, and Japan for aromatic seeds that are used as spices during food preparations. It is a robust and fragrant annual herb, locally known as "Saunf" which is native to Southern Europe and the Mediterranean region (Abd El-Wahab and Mehasen, 2009). India is currently the world's biggest producer, exporter, and consumer of spices and is also known as the "land of spices". Each edible portion of the plant, including the leaves, stalks, bulbs, and seeds, has a pleasant fragrance. According to Bhunia *et al.* (2005), the seeds have roughly 9.5% protein, 10.0% fat, 42.3% carbohydrates 18.5% fibre, and 13.4% minerals. Furthermore, depending on the genotypes or agronomic practices, the seeds' volatile oil content ranges from 0.7% to 6.0%.

Fennel ($2n=22$) is cultivated as a seed crop almost throughout the world. It is used to make a variety of foods, including soups, sauces, pastries, confections, pickles, and meat dishes, as well as for medicinal purposes. Additionally, the leaves, stalks and young shoots can be used for salad purposes. India is recognised as the "Home of Spices" due to its status as the largest producer, consumer, and exporter of spices globally (Meena *et al.*, 2016). Major fennel-producing States in India include Gujarat, Rajasthan, and Uttar Pradesh, while many other States, including Bihar, Madhya Pradesh, Punjab, and Haryana, cultivate it on a smaller scale (Anonymous, 2018). Fennel is currently grown on 105 thousand hectares in India, producing 180 thousand MT and overall productivity 16 quintal per hectare in the year 2024-25 (Anonymous, 2026). Total production of Punjab in the year 2021-2022 was below 0.20 tonnes (Anonymous, 2022). Rajasthan and Gujarat contribute more than 80% of the country's total seed spice production. This belt is also known as the "seed spice bowl" of India. With 47549 ha under cultivation and a production of 98272 tons, Gujarat accounts for 82% of fennel output in India (Anonymous, 2024). Although it can be raised effectively as a winter direct seeded crop, however, it can also be grown as a transplanted crop. The fennel crop had low productivity per unit area due to lack

of timely sowing, maintenance of optimum plant populations, weed management, irrigation management, fertilizer management practices etc.

Many Indians have a habit of eating dried fennel seeds as a mouth refresher (mukhwas) especially after meals, which is very healthy for the digestive system. One of the key ingredients in fennel oil is anethole. The seeds of best fennel types have 4 to 5 percent volatile oil, primarily composed of anethole (50 to 60%) and fenchone (18 to 22%). Anethole is a main component in anise oils as well. Fenchone has a strong camphoraceous fragrance and flavor which most likely makes a significant contribution to the oil's medical characteristics, and in the market for oil, the only form that can be used medicinally is fenchone. The volatile oil content in Indian fennel seed varies between 0.7% and 1.2%, while East European fennel seeds exhibited a range of 4% to 6%. The seeds are known for their substantial mineral content, including calcium, iron, magnesium, potassium, sodium, and zinc, along with Vitamin A, niacin, and phytate levels ranging from 11.35 to 13.10 mg/g (Lal *et al.*, 2023). The quality of the seed has a significant impact on the market price of fennel seed. Customers choose green seeds that are consistent in size, free of chemical residues, bioagents, or physical imperfections, have the highest fibre content, and are in high demand in the national and international market at a premium price. Good quality seeds are bright green in colour, has a pleasant aroma, and are consistent in shape and size, which mostly depends on the stage of umbel plucking. Although early umbel harvesting can result in high-quality seed, but it reduces seed output. To retain the quality of fennel, it is necessary to use correct harvest and post-harvest technological methods, such as selection of proper harvesting stage and drying procedures. For preserving quality and productivity, the right harvesting stage is crucial.

Fennel usually takes longer time to germinate and grows slowly at first, which frequently encourages severe weed infestations. These weeds negatively influence crop growth and results in significant yield losses if not controlled at the proper time. As much as 91% of the crop yield could be lost due to severe competition by weeds. Weeds compete with all crops for space, nutrients, soil moisture and sunlight, ultimately limiting plant growth and reducing yield and quality of seed spices also.

Initial slow growth of seed spices leads to a critical competition between crop and weeds, which inhibits growth and yield up to 91.40% (Mamatha *et al.*, 2021). Therefore, one of the most important variables in achieving optimal yields is timely weed management. Integrated weed management approach that combines chemical, cultural, mechanical or other methods are successful for managing weeds in fennel crop. To keep weeds under check, manual weeding is a traditional practice in fennel. Due to the shortage of workers and rising wages, manual weed management has become difficult, labour-intensive, time-consuming, and expensive.

To achieve optimal yields and reduce dependence on labour, integration of other weed control methods including the use of herbicides, are essential for achieving satisfactory weed management in fennel. As a result, it is vital to find an effective pre-emergence herbicide that can control weeds during their early growth stages. Herbicide applications, on the other hand, has revolutionised weed control and decreased production costs; however, most farmers are totally unaware of the right doses, time of application, and proper spraying technologies of herbicides (Meena *et al.*, 2022). Despite referring to seed production, Patel *et al.* (2017) revealed that this crop is extremely sensitive to weed competition. However, the crop growth in the plots covered with olive leaves was lower than the weed-free treatment and did not differ from the unmulched treatment. Mulches are generally applied after planting the crop or before the weed seeds begin to emerge. Fennel often requires a long time to germinate and grows slowly at first, which frequently results in intense crop weed competition. Weed infestations can reduce seed output by 50% if not kept under control (Gohil *et al.*, 2015). The application of plastic mulch has become a routine practice for most of the vegetable growers, which results in decreased evaporation, better weed control, reduced fertilizer leaching, and reduced soil compaction, as well as moderation of soil temperatures that encourage early plant maturity. According to Farag *et al.* (2020), mulching with the right materials enhanced soil temperature, preserved soil moisture, and reduced incidence of weeds, pests, and diseases.

Proper planting patterns are non-monetary inputs that prevent crop weed competition, collaborations, and competitive interaction; they are also vital for the plant canopy's ability to intercept sunlight (Singh and Amin, 2015). Maintaining the

ideal plant population is crucial for absorbing solar energy without creating a threat to water or nutrients and for reducing the weed intensity per unit area. The effectiveness of moisture and nutrient uptake by plants, as well as solar radiation absorption, are all influenced by planting geometries. Low plant population may not fully utilize supplied nutrients and may allow weeds to grow rapidly, resulting in low production of crop. On the other hand, a very high plant population may have negative effects on the yield due to competition among the crop plants for nutrients and moisture. To achieve optimum yield, it is essential to maintain an optimal plant population. Among various factors which can increase the yield are sowing date, planting patterns and crop management practices. Different planting geometries/sowing methods significantly affect the branches per plant and number of umbels per plant in fennel crop. Ridge sowing produced the maximum number of branches per plant which might be attributed to proper plant spacing and better agronomic practices resulting in better use of soil and environmental factors towards growth and development of crop in ridge sowing compared to rest of sowing methods (Mahmood, 2013). In comparison to flat irrigation, bed irrigation and ridge irrigation systems substantially decrease irrigation time. In comparison to flat sowing, bed and ridge sowing has a greater germination count (plants m⁻²) of crop. According to Asif *et al.* (2019), bed sowing produced 16.36% greater seed yield than flat sowing. It has been discovered that using a broad row planting technique, helps to boost the seeds produced by common fennel. During the main vegetative stages of the crop sown with a wide-row technique, the weight of common fennel increased during these phases especially during blooming time (Stotska, 2021).

Nitrogen fertilisation is one of the most crucial production aspects for the growth of the fennel crop because an imbalanced use of nitrogen can drastically lower seed yield and quality and severely compromise soil health (Angeli *et al.*, 2016). Applying the right amount of fertilizer enhances the yield of crop as well as quality of produce. Nitrogen is a typical nutrient that encourages vegetative growth of all field crops. Indian soils are often deficient in nitrogen, a critical element essential for plant growth and crop production and its deficiency is a significant agricultural challenge in sustaining productivity. Additionally, it is crucial for the yields of folium and herbs in

therapeutic crops. Fennel being a long-lasting crop, draws a lot of nutrients from the soil. The main cause of low yield as well as of poor quality is the improper and unbalanced application of nutrients. By limiting one or more elements, including micronutrients as well as the exclusive use of inorganic fertilizers, has a negative impact on crop productivity, soil fertility and soil health. No single nutrition source can provide plant nutrients in an amount that is sufficient for plant growth and in a ratio that is balanced. In addition to providing micronutrients and reducing dependence on chemical inputs, the combined (integrated) application of organic along with inorganic sources of nutrients also affects the physical behavior of the soil and improves the efficacy of applied nutrients (Pandey *et al.*, 2007). Animal and plant waste can be used as a source of nutrients to all field crops and are known as organic manures.

Organic manures are the source of nitrogen, phosphorus, potassium, organic carbon, enzymes, micronutrients etc. and contribute to increase output and quality. The most significant and often utilized bulky organic manures with NPK contents of 0.5-1.5 %, 0.2-0.4 %, 0.5-1.0 % and 1.5-3.0 %: 1.0-2.0 %: 1.5-2.25%, are well decomposed farmyard manure (FYM) and vermicompost, respectively. They also provide micronutrients for plants, enhance the physical characteristics of the soil, and promote nutrient availability. Organic manures apart from supplying nutrients, improves soil physical properties, water holding capacity, helps in moderation of soil temperature as well as provides better weed control. Manure and fertilizers are strategically combined to increase crop productivity, enhance the quality of agricultural products, and preserve soil fertility (Parihar *et al.*, 2016). An integrated approach to maintain supply of soil nutrients must be part of the overall strategy for boosting crop yields and maintaining them at a high level, together with other supportive measures.

Keeping these facts in view, the present study entitled “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” was conducted at the research farm of Lovely Professional University, Phagwara (Punjab) during *rabi* season of 2023-24 and 2024-25 with the following objectives.

- To determine the influence of planting patterns and weed control methods on growth and yield of fennel.
- To find out the interactive effects of planting patterns and nutrient levels with weed control methods on growth and development of fennel.
- To work out response of fennel to nitrogen and FYM as influenced by different weed control strategies.
- To work out uptake of N by crop and weeds as well as effect on quality of fennel by different treatments.

CHAPTER 2

REVIEW OF LITERATURE

The relevant literature pertaining to research project entitled, “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” have been reviewed under the following subheadings:

1. Losses due to weeds.
2. Role of planting pattern on growth and yield of fennel.
3. Role of weed management practices on fennel productivity.
4. Effect of FYM and nitrogen levels on growth & yield of fennel.
5. Effect of planting patterns and nitrogen levels on quality parameters of fennel.

2.1. Losses due to weeds.

An experiment was conducted by Singh (2023) at Bharatpur, Rajasthan, to find out the impact of pendimethalin on growth and yield of fennel. The results revealed that pre-emergence application of pendimethalin 30% EC @ 0.90 kg ha⁻¹ and one hand weeding (60 DAS) recorded higher grain yield as compared to farmers practice i.e. one hand weeding at 45 DAS. The seed yield was reduced by 11.91% in the farmers practice compared to integrated method. This might be due to vigorous growth of crop due to availability of sufficient nutrient, moisture, light and space owing to absence of weed because of higher weed control efficiency.

Paghadal *et al.* (2022) conducted an experiment at College of Agriculture, Junagadh Agricultural University, Junagadh and revealed that unweeded (control) treatment reduced the fennel seed yield by 44.6% due to unrestricted weed growth. The highest weed index was found to be 44.6% under this treatment.

Kaur *et al.* (2022) conducted an experiment at G.S.S.D.G.S. Khalsa College, Patiala and reported that the seed yield of fennel decreased by 32.57% under weedy check treatment as compared to weed free treatment due to the lesser crop weed competition in this treatment.

An experiment was conducted by Sharifi *et al.* (2022) at the Agricultural Sciences and Natural Resources University of Khuzestan, Iran. They reported that the yield loss in

fennel due to absence of straw mulch and herbicide was 77.5 % as compared to the application of Linuron herbicide at 3.0 kg/ha along with straw mulching (9 t ha⁻¹). Due to the poor control efficiency of Linuron herbicide alone, the combination of herbicide with mulch can provide better weed control.

Choudhary *et al.* (2021) conducted an experiment at Jobner, Rajasthan and reported that the initial slow growth of fennel crop leads to substantial competition by weeds, which reduces the seed yield up to 36.32% in weedy check as compared to treatment of two hand weedings (25 and 50 DAS). Therefore, it is crucial to keep the field weed free at the initial stage by using appropriate weed-control methods.

Mamatha *et al.* (2021) conducted an experiment at Kittur Rani Channamma College of Horticulture, Arabhavi to study the various weed management practices in fennel. The significant reduction in seed yield was recorded up to 56.40% in unweeded (control) treatment as compared to hand weeding treatment.

A field experiment was conducted by Kumar *et al.* (2019) at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana to study the efficient weed control method in fennel. The results revealed that seed yield was reduced up to 65.20 % in unweeded (control) treatment as compared to application of pendimethalin @ 1 kg/ha as pre-emergence.

Patel *et al.* (2019) conducted an experiment at Anand Agricultural University, Anand (Gujarat) and reported that there was a significant reduction in seed yield of fennel to the tune of 19.28% under weedy check plot as compared to treatment of paddy straw mulch 5 tha⁻¹ fb HW at 30, 60 days after transplanting.

Carrubba (2015) conducted an experiment at the experimental farm of Sparacia, Sicily, and reported that weeding had a more effect on crop growth than application of N fertilization, as weeds were found to lower seed yields (40–90 %) in coriander, fennel and psyllium crops.

Gohil *et al.* (2015) conducted an experiment at Junagadh Agricultural University, Junagadh, Gujarat and reported that if weeds are not controlled in fennel (weedy check), these can reduce the seed yield upto 50 per cent because crop generally takes

much time for germination and has initial slow growth which often leads to heavy crop weed competition.

A study was carried out by Amini and Yousefi (2014) at University of Zanjan, Iran. The results revealed that without adopting any weed control practices, i.e. unweeded (control) treatment, fennel yield was reduced up to 88.2%, in comparison to pre-emergence application of trifluralin herbicide combined with one hand weeding.

Gohil *et al.* (2014) conducted an experiment at Junagadh, Gujarat and revealed that in fennel crop, unweeded check recorded the highest weed seed bank due to production of large number of weed seeds under uncontrolled condition leading to 978 % increase in the initial weed seed bank as compared to treatment with pendimethalin at 0.90 kg ha⁻¹ pre-emergence + HW at 45 DAS.

According to Mubeen *et al.* (2009), as per study conducted at University of Agriculture, Faisalabad, a linear decrease in seed yield was observed by increasing duration of fennel-weed competition. There was 36.98 % yield reduction of fennel crop due to weed infestations. The maximum seed yield 2336 kg ha⁻¹ was obtained where there was no weed-crop competition, and it was statistically at par with the treatment of where weeds competed with crop upto 50 DAS. Minimum seed yield of 1472 kg ha⁻¹ was recorded in full season competition by weeds with the crop.

2.2.Role of planting pattern on growth and yield of fennel.

The study was conducted by Persiani *et al.* (2025) at the Council for Agricultural Research and Economics, Research Centre for Agriculture and Environment, Metaponto, Italy. They concluded that the organic fertilizer of vegetable origin + bur clover (as live mulch) + hydraulic arrangement of bed sowing treatment showed the higher seed yield (14.3 Mg ha⁻¹), as compared to mineral N fertilization with flat sowing (11.2 Mg ha⁻¹).

A study was carried out by Meena *et al.* (2024) at Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. The results revealed that paired row planting with 40 cm x 60 cm spacing produced significantly higher yield parameters, seed yield, and water use efficiency. Further, with the application of plastic mulch, all

yield parameters, yield, net return, and benefit: cost ratio were also improved as compared to no mulch treatment.

The findings of Singh (2024) from Lovely Professional University, Punjab, revealed that adopting appropriate planting methods like bed and ridge sowing along with weed control strategies like mulching in fennel resulted in improved growth characteristics and yield contributing parameters.

Choudhary *et al.* (2021) in their field experiment conducted at Sri Karan Narendra Agriculture University, Rajasthan, revealed that fennel grown with wider plant spacing (60 cm x 20 cm) enhanced the growth and yield attributes as compared to other treatments. They also observed higher seed yield (2.21 t ha^{-1}) in 60 cm x 20 cm among other planting geometries. This was ascribed to better initial control of weeds, rise in water and nutrient uptake.

According to Tamboli *et al.* (2020) from their study conducted at Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, reported that superior growth parameters, yield attributing characters, seed yield (1346 kg ha^{-1}) and stover yield (3914 kg ha^{-1}) of fennel were registered with 45 cm row spacing as compared to wider row spacing i.e., 60 cm.

Singh *et al.* (2019) conducted an experiment to study the effect of different planting methods and irrigation levels on the growth and yield of fenugreek at Guru Kashi University, Talwandi Sabo (Punjab). The results indicated that bed sowing (67 cm) proved to be better over all other planting patterns as it recorded maximum growth as well as yield parameters. Highest plant height (cm), number of branches, number of pods per plant, number of seeds per pod, seed yield, and biological yield were reported in bed planting (67 cm) as compared to flat sowing method.

Patel *et al.* (2018) conducted an experiment at AAU, Anand, Gujarat and concluded that significantly lower weed density and biomass of weeds were found in intercropping+ HW at 30 and 60 DAT *fb* earthing up at 75 DAT, which can be due to effective weed control throughout the growing season. The growth and yield were also recorded higher in this treatment as compared to weedy check.

The research carried out by Fahim *et al.* (2017) at the research field of Spices Research Centre, Shibganj, Bogra, to determine optimum seed rate and suitable sowing method for black cumin cultivation. The highest seed yield (1254 kg ha⁻¹) was recorded from treatment combination of 8 kg seed/ha + raised bed, and the lowest seed yield (254 kg ha⁻¹) was found in 4 kg seed/ha + broadcasting method.

A field experiment was conducted by Ghawade *et al.* (2017) at Chilli and Vegetable research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, on cumin as a seed spice. The results revealed that sowing of cumin with ridge and furrow method produced higher seed yield (5.99 q ha⁻¹) as compared to flat sowing method.

An experiment was conducted by Waskela *et al.* (2017) at the Horticulture Research Farm, College of Horticulture, Mandsaur, to study the effect of row spacing and nutrient levels on the growth and yield of fennel. Among the various spacing treatments, 45 cm spacing recorded significant higher growth and yield parameters and higher seed yield (11.06 q ha⁻¹) as compared to 30 cm row spacing.

Mahmood (2013) conducted a study at Agronomic Research Institute Faisalabad, Pakistan, and concluded that different geometries and sowing methods had a significant effect on the growth and yield components of fennel. The ridge sowing method gave significantly higher yield (1780 kg ha⁻¹) than the bed sowing and drill sowing methods mainly because of greater number of reproductive branches (7.90) and umbels per plant (39.67), seeds per umbel (200.30) and 1000 seeds weight (7.77g) in the former treatment. It was closely followed by bed sowing, whereas line sowing treatments (flat) produced the lowest seed yield (1549 kg ha⁻¹).

A study was conducted by Mehta *et al.* (2012) at Ajmer (Rajasthan). The results revealed that significantly higher yield attributes were found in crop geometry of 60 cm x 25 cm over crop geometry of 50 cm x 25 cm and 40 cm x 25 cm. Further, the application of 120 kg N/ha and 50 kg P₂O₅/ha at 60 cm x 25 cm spacing was found to be effective for getting higher yield and productivity of fennel.

Khorshdi *et al.* (2009), in a study conducted at college of agriculture Karaj, reported that umbels per plant in all the planting geometry/sowing methods increased

significantly in ridge sowing as compared to line sowing methods respectively. Sowing methods and plant spacing have significant effect on umbels per plant.

Ayub *et al.* (2008) conducted a field experiment at Agronomic Research Area, University of Agriculture, Faisalabad, to evaluate the effect of four sowing methods viz., broadcast, line sowing (45 cm), ridge sowing (45 cm) and bed sowing (45 cm) on growth and yield of fennel. The crop sown in lines, gave significantly higher seed yield (571.54 kg ha⁻¹) because of higher number of umbels per plant (12.98) and number of seeds per umbel (147.06) as compared to other methods.

Amin *et al.* (2005) conducted a study at Gujarat Agricultural University, Sardarkrushinagar, and reported that crops sown on 45 cm row spacing recorded significantly higher fennel seed yield, stover yield and yield attributes as compared to other spacings. Whereas growth attributes increased with an increase in row spacing from 30 cm to 60 cm.

2.3. Role of weed management practices on fennel productivity.

An experiment was conducted by Khalili *et al.* (2025) at the University of Kurdistan, Iran. They reported that the highest fennel seed yield was obtained in the weed-free treatment (3.95 t/ha), and it was followed by treatments of hand weeding and application of diuron 80% WP @ 2.5 kg/ha, which produced seed yield of 3.63 t/ha and 3.3 t/ha, respectively. These treatments were superior due to effective weed control which provided better growing conditions for the crop.

A study was carried out by Meena *et al.* (2024) at Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. The results revealed that with the application of plastic mulch, all yield parameters, yield, net return, and benefit: cost ratio was also improved as compared to no mulch treatment.

Kumar *et al.* (2023) conducted an experiment at the College of Agriculture, Jodhpur and reported that with the application of straw mulch, the mean seed yield of fennel increased significantly over plastic mulch (2131 kg ha⁻¹) and no mulch (1585 kg ha⁻¹) treatments. The increase in seed yield by straw mulch was higher by 4.79 and 40.88 percent than plastic mulch and no mulch treatments, respectively. However, plastic mulch increased seed yield by 34.45 % than no mulch treatment.

Sharifi *et al.* (2022) carried out an experiment at Agricultural Sciences and Natural Resources University of Khuzestan. They revealed that the application of different doses of linuron herbicides at different rates (0, 1.5, 3 and 4.5 L ha⁻¹) with variable quantities of mulch materials (0, 3, 6, 9 and 12 t/ha) had a significant effect on biomass of weeds and weed control efficiency. Linuron herbicide has poor weed control efficiency alone, but the combination of herbicide with suitable mulch material can provide better weed control.

A study was conducted by Amini *et al.* (2023) at East Azarbaijan, Iran and the results revealed that weed biomass in dill seed at reduced doses of trifluralin, one hand weeding and wheat straw mulch treatments were lower than those in live mulching with fenugreek and vetch. Therefore, there was a significant increase in seed yield and oil yield under these treatments.

The field experiment was conducted by Kaur (2022) at G.S.S.D.G.S. Khalsa College, Patiala. The results revealed that the maximum growth, yield attributes and yield was found with the application of pendimethalin @ 1.25 kg ha⁻¹ (P.E.) + one hand weeding at 45 DAS and it was statistically at par with the treatment of two hand weeding at 20 and 40 DAS. Whereas these parameters were found lower in weedy check as compared to all other weed control treatments.

Pagadhal *et al.* (2022) conducted an experiment on fennel crop at College of Agriculture, Junagadh Agricultural University, Junagadh, and the results revealed that there was a significant reduction in weed count and weed index (20 DAS) with the application of pendimethalin 900 g ha⁻¹ pre-emergence and black plastic mulch. Therefore, high seed production was found in these two treatments as compared to unweeded (control) treatment due to better growing conditions and efficient utilization of resources.

An experiment was conducted by Sharifi *et al.* (2022) at Agricultural Sciences and Natural Resources University of Khuzestan. The results revealed that the higher seed yield of fennel was found in linuron herbicide application at 3 L/ha with straw mulching @ 9 t ha⁻¹ (80 g m⁻²). Whereas lower seed yield of fennel (18 g m⁻²) was obtained in control treatment.

The study conducted at the Farm of Medicinal and Aromatic Plants Research Department, Qalyubia Governorate, Egypt by Abdallah *et al.* (2021) revealed that hand weeding had increased fennel yield and oil yield by 63% and 78%, respectively, as compared to unweeded control. In addition, the application of pendimethalin + fluazifop increased seed yield by 45% and oil yield by 83% as compared to unweeded (control).

A study conducted by Fracchiolla *et al.* (2021) in Southern Italy, revealed that the weed infestations in fennel was significantly reduced, both in the plots mulched with almond hull and in those with olive leaves compared to the unmulched treatment. These results confirm the effectiveness of organic mulch material in controlling weeds.

A field experiment was conducted by Meena *et al.* (2023) at Agronomy Farm, Jobner, Rajasthan. They concluded that among the weed management treatments, hand weeding at 25 and 50 DAS enhanced the growth and yield attributes significantly, and it was at par with the treatment of pendimethalin @ 0.75 kg/ha + 1 HW at 30 days. However, the growth and yield attributes remained lowest in the weedy check plot.

Farag and Abul-Soud (2020) conducted an experiment at Agriculture Research Center (ARC), Dokki - Giza governorate, Egypt and reported that mulching on soil minimized weed growth and offered better soil moisture and temperature conditions that encouraged more horizontal growth, while competition between the plant and weed encouraged more vertical growth and enhance the vegetative characteristics, yield parameters, dry weight (45.1 g/plant), number of leaves/plant (10.7) and plant height (91.5 cm) as well as N, P, K (%) contents of sweet fennel compared to bare soil. Mulching of soil led to an increase of 35 % in the yield of sweet fennel than bare soil.

A study conducted by Kumar *et al.* (2019) at Punjab Agricultural University, Ludhiana, Punjab revealed that there was significant increase in yield of fennel with the application of pendimethalin 1.0 kg ha⁻¹ (13.02 q ha⁻¹), as compared to unweeded (control) (4.53 q ha⁻¹) treatment due to less crop-weed competition for resources.

Patel *et al.* (2019) conducted a study at B.A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) and reported significantly higher crop growth parameters and lowest weeds density at harvest with the application of farmyard manure (FYM) 20 t ha⁻¹ and vermicompost 8.0 t ha⁻¹, respectively. However, highest fennel seed yield (2.09 t ha⁻¹) was recorded with vermicompost 8.0 t ha⁻¹. Significantly higher plant height (cm), number of umbels/plant and seed yield were recorded with paddy straw mulch 10 t ha⁻¹ *fb* hand weeding (HW) and it was at par with paddy straw mulch 5 t ha⁻¹ *fb* HW and twice inter cultivation (IC) + HW *fb* earthing up treatments.

Studies by Patel *et al.* (2017) have shown that application of appropriate herbicides can control the weeds effectively and can increase the seed yield of fennel by 43.2% to 86.9 % with the application of fluazifop-p-butyl and pendimethalin, respectively, as compared to control treatment.

A study conducted by Gohil *et al.* (2015) at Junagadh Agricultural University, Junagadh revealed that, significantly higher plant height (153.1 cm), number of branches/plant (7.1), number of umbels/plant (12.7), number of seeds/umbellate (25.5), test weight (7.30 g), seed weight/plant (31.10 g) and seed yield (1841 kg ha⁻¹) and stover yield (4512 kg ha⁻¹) of fennel were recorded with weed free treatments.

Meena *et al.* (2014) conducted a study at Agronomy farm, S.K.N. College of Agriculture, Jobner, revealed that application of straw mulch for weed management, significantly increased number of branches per plant, dry matter accumulation per metre row length, number of umbellets per umbel and yields of fennel crop (seed, stover and biological) over control, dust and plastic mulch treatment. Plant height (cm) and number of umbels per plant increased significantly with straw mulch as compared to control and dust mulch but remained at par with plastic mulch. The increase in seed yield due to straw mulch was 37.5%, 10.4% and 5.6% over control, dust and plastic mulch, respectively.

An experiment conducted by Yousefi and Rahimi (2014) at the Research Farm of the University of Zanjan, Zanjan, Iran, revealed that the application of 75% of recommended rate of herbicides (trifluralin and pendimethalin) followed by one hand-

weeding at 50 days after planting produced significantly high yield of fennel crop and less weed density, which reflects both crop safety and superior weed control.

Kolota and Sowinska (2013) reported that plastic and straw mulches reduced the rate of weed seed germination, as the mulches do not provide necessary conditions for weed seed germination and increases the overall growth and productivity of crops.

Kumar and Lal (2012) reported the positive effects of mulching cover by improving soil moisture, conservation of irrigation water, soil temperature improvement, less weed competition, better nutrient uptake and better root and vegetative growth, which can enhance the growth and productivity of fennel crop.

Hatami *et al.* (2012) conducted a study at the Kahriz Station (Urumia, Iran) and they reported that mulching treatments had significant effects on yield and yield attributes (weight of seed and number of seeds per plant) of fennel. Results also demonstrated that polyethylene mulch had a significant effect on suppression of weed density. Among the tried weed control methods, the best treatment for increasing seed yield and for obtaining better weed control was the mulch application on full ridges and half furrows.

A field experiment was conducted by Meena and Mehta (2009) at the research farm of NRCSS, Rajasthan, to find out most suitable method of weed control in fennel (*Foeniculum vulgare*). They found that significantly higher plant height (cm), number of branches, yield attributes like number of umbels/plant, number of umbellets/umbel, and seed yield of fennel were recorded with application of pre-emergence oxadiargyl @ 75 g /ha *fb* one hand weeding (HW) at 45 DAS as compared to unweeded (control) treatment.

2.4. Effect of FYM and nitrogen levels on growth & yield of fennel.

An experiment was carried out by Irfan *et al.* (2025) at the University of Agriculture, Peshawar, Pakistan to investigate the effect of nitrogen applications on the growth and production of fennel. The results revealed that nitrogen applied @ 60 kg ha⁻¹ recorded 25.22%, 29.54 % and 24.95% higher plant height (cm), more umbels per plant and seed yield (kg ha⁻¹), respectively as compared to control and it was statistically at par with the application of nitrogen at 40 kg ha⁻¹.

Fogawat *et al.* (2024) carried out a study at H.N.B. Garhwal University, Srinagar (Garhwal). The results indicated that application of FYM @ 25 tons ha⁻¹ enhanced the growth and yield of fennel significantly as compared to no application of FYM. The maximum seed yield (12.87 q ha⁻¹) was found in treatment of vermicompost @ 9 tons ha⁻¹.

Yadav *et al.* (2024) carried out a study at research area, Department of Vegetable Science, CCSHAU, Hisar with four levels of N (0, 25, 50 and 75 kg ha⁻¹) and three treatments of rows to row spacing (30 × 20, 45 × 20 and 60 × 20 cm). The results showed that the yield attributes and seed yield was higher in 75 kg ha⁻¹ nitrogen with a spacing of 45 × 20 cm. Higher dose of nutrient with less competition for space lead to increase in yield and yield attributes of fennel.

A field experiment was carried out by Rashid *et al.* (2023) at College of Agricultural Engineering Sciences, University of Sulaimani, Iraq. They concluded that the higher seed yield of fennel was obtained when high levels of nitrogen i.e. 30 kg N ha⁻¹ were applied as compared to 0 and 15 kg N ha⁻¹. It was due to positive effect of nitrogen fertilization on seed yield attributes, such as the number of umbels/plant, number of seeds/umbel, and 1000 seed weight. The average essential oil yield of (24.10 kg ha⁻¹) was significantly higher in the treatment of 30 Kg N ha⁻¹, and the lowest (17.44 kg ha⁻¹) was found in the control (no nitrogen) treatment.

Rajeshwari *et al.* (2022) in his study conducted at northern dry zone of Karnataka, reported highest plant height (165.97 cm), higher number of primary branches per plant (11.82), maximum fresh weight and dry weight of seed per plant (47.79 g and 30.68 g) and stover (155.61 g and 51.28 g per plant) in fennel crop at harvest with the application of higher levels of fertilizer i.e., 100:50:40 kg ha⁻¹ N, P₂O₅, K₂O which was at par with fertilizer level of 90:40:30 kg ha⁻¹ N, P₂O₅, K₂O.

Sharma and Kumar (2022) carried out a study at CCS Haryana Agriculture University, Hisar. The results of the study revealed that the growth parameters were significantly influenced by different fertilizer doses. The plant height (cm), number of primary branches and secondary branches of fennel were higher in treatment of 100% RDF + Azotobacter + PSB as compared to control (no fertilizer treatment).

A field experiment was conducted by Arolkar *et al.* (2021) at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola on fennel crop. The results revealed that plant height (189.49 cm), primary branches (11.53) and secondary branches (23.73) per plant were significantly higher with the application of higher doses of nitrogen (120 kg ha⁻¹) as compared to lower dose i.e. 60 kg N ha⁻¹.

The present research work was conducted by Siddika (2021) at the Horticulture Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The result revealed that the highest seed yield per plant of fennel (47.76 g) was found with the application of vermicompost (2.50 t ha⁻¹) + NPK (80:50:60 kg ha⁻¹) treatment as compared to no application of fertilizers treatment (control).

In the study, Barzegar *et al.* (2020) assessed the effect of different levels of nitrogen (N) and potassium (K) fertilizers on vegetative fresh bulb yield, quality and biochemical attributes of sweet fennel. Results showed that, the fresh bulb yield increased with application of N and K in both years. Macronutrient contents of bulb including magnesium (Mg), phosphorus (P), K, N, and calcium (Ca) were significantly enhanced with the application of NK fertilizers. Therefore, to improve fresh bulb yield, quality and antioxidant capacity in sweet fennel, 150 kg ha⁻¹ K and 100 kg ha⁻¹ N is recommended.

Dhillon *et al.* (2019) conducted research experiment on fennel at DAV College, Abohar, Punjab, and they reported that parameters such as plant height (cm), number of umbels per plant, fresh weight of plants (g), dry weight of plants (g) and seed yield were decreased with lowering the dose of Nitrogen whereas these parameters were minimum with the application of 50% Nitrogen dose. Maximum height (63cm), number of umbels per plant (11) and fresh weight per plant (32g) was reported in plots receiving 150% nitrogen.

Bajya *et al.* (2017) carried out an experiment on fennel crop at College of Horticulture Mandsaur, Madhya Pradesh. They reported that application of 50% recommended dose of nitrogen through vermicompost + 50% RDN through inorganic fertilizers recorded higher values of plant growth, viz. plant height (cm), dry weight, umbels plant⁻¹, seeds umbel⁻¹, 1000-seed weight (g), seed yield, stover yield and biological yield over 100% RDN through FYM only.

An experiment was conducted by Waskela *et al.* (2017) at the Horticulture Research Farm, College of Horticulture, Mandsaur, MP, to study the impact of row spacing and NPK levels on the growth and yield of fennel. They observed that higher level of nitrogen increased the vegetative growth of fennel and as a result there were more number of branches and number of umbels per plant, and hence it produced maximum seed yield as compared to lower nitrogen doses.

Pariari *et al.* (2015) conducted a study at Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, and concluded that the maximum seed yield (13.79 q ha^{-1}) of fennel was obtained with the application of 50% recommended dose of nitrogen through urea in addition to phosphorus and potassium, when the plants were spaced at $45 \text{ cm} \times 35 \text{ cm}$. The minimum yield (8.86 q ha^{-1}) was recorded with the application of 25% of recommended dose of nitrogen through urea at a spacing of $35 \text{ cm} \times 25 \text{ cm}$.

According to Shivran and Jat (2015), while working at Jobner, Rajasthan, the seed yield of fennel was found to be higher in integrated nutrient management of 50% RDN through FYM+ 50% RDN through inorganic fertilizers (1.68 t ha^{-1}), as compared to 100% RDN through FYM (1.56 t ha^{-1}).

Godara *et al.* (2014) conducted an experiment at Tabiji, Ajmer, Rajasthan and concluded that the fennel seed yield per plant was significantly higher (14.56 g) with the application of 50 % RDN through fertilizers + 50 % RDN through FYM as compared to no fertilizer (control) treatment (10.21 g/plant).

Vasoya (2014) conducted a study at College of Agriculture, Junagarh Agricultural University, Junagarh and reported that fennel attained maximum values of yield attributes viz., number of umbels/plant, umbellets/umbel, test weight and seed/umbel under the treatment of Vermicompost @ 1.5 t/ha and also this treatment increased the seed, stover and biological yield as compared to no organic manure treatment.

Ehsanipour *et al.* (2012) in a study conducted at Isfahan University of Technology Experimental Station, Isfahan, Iran, reported that nitrogen fertilization increased plant height (201.70 cm), number of umbel per plant (46.40), 1000 seed weight (3.62 g), number of seeds per umbel (35.97) and seed yield ($608.16 \text{ kg ha}^{-1}$). On an average,

the highest seed and foliage essential oil contents and seed yield was observed with the application of 160 kg N ha⁻¹.

Naruka *et al.* (2012) conducted an experiment at College of Horticulture, Mandsaur, Madhya Pradesh, and revealed that higher fertilizer levels i.e. 60 kg N ha⁻¹ in ajwain crop resulted in increased plant height, number of leaves, branching and fresh weight, which aided in achieving maximum dry weight as compared to lower doses of fertilizer (0, 20 and 40 kg N ha⁻¹). It is generally known that nitrogen supports vegetative growth which increases with higher nitrogen levels causing luxuriant plant growth, which is evident from higher fresh weight of seed and stover.

An experiment conducted by Ayub *et al.* (2011) at University of Agriculture, Faisalabad revealed that the application of 90 kg N/ha produced significantly higher fennel yield which was statistically at par with 105 and 120 kg N/ha. However, the lower seed yield was found in the treatment of zero nitrogen.

An experiment conducted by Bagari *et al.* (2010) at College of Horticulture, Mandsaur, Madhya Pradesh, revealed that with the application of 100 kg N per hectare, the growth parameters, yield attributes and yield of fennel were significantly increased as compared to lower nitrogen levels.

Amin *et al.* (2005) conducted a study at Gujarat Agricultural University, Sardarkrushinagar, and reported that growth and yield attributes like plant height (cm), number of primary, secondary and tertiary branches as well as seed yield (1438 kg ha⁻¹) of fennel increased with increase in nitrogen levels from 60 to 120 (kg ha⁻¹) but pronounced effect was observed up to 90 kg N ha⁻¹.

2.5. Effect of planting patterns and nitrogen levels on quality parameters of fennel.

The findings of Singh (2024) from Lovely Professional University, Punjab, revealed that adopting appropriate planting patterns like bed and ridge sowing along with weed control strategies like mulching significantly enhances the quality parameters and nutrient absorption of fennel crop.

An experiment was conducted by Gedik and Kus (2023) at Kahramanmaraş Sutcu Imam University, Turkey to find out the impact of nitrogen treatments on quality of fennel. They reported that increasing nitrogen doses lead to significant increase in fixed oil and essential oil components. These components were significantly higher in treatment of 150 kg N ha⁻¹ N dose. The higher anethole content (88.44%) was found in 90 kg N ha⁻¹.

Field studies by Delfieh *et al.* (2022) were conducted at the field research station of the Islamic Azad University, Shoushtar, South-West Iran. The results indicated that uniformly broadcasting 50% of urea at sowing time and spraying the other 50% of urea at stem elongation on fennel foliage could give 14.3% and 13.6% more essential oil yield than uniformly broadcasting 50% urea at sowing time and 50% at stem elongation time during first and second year of study, respectively.

Meena *et al.* (2022) conducted an experiment at Niche Area Excellence, S.K. Rajasthan Agricultural University, Bikaner. They reported that the highest oil content (1.31%), oil yield (19.55 kg ha⁻¹) and protein content (8.92%) was found in paired row sowing at 40 cm x 60 cm spacing as compared to normal line sowing (50 cm). However, there was no significant difference in protein content among different crop geometries.

An experiment was conducted by Nada *et al.* (2022) at the farm of El-Santa, Gharbia, Egypt. They reported that the increase in essential oil content (0.076-0.080 %) of fennel bulbs and bulb yield (11.76–11.99 ton/fed) were found with application of organic manure (rabbit manure at 60 m³ /fed) as compared to 150% of recommended NPK. Further, the most important constituents, α -pinene, β -pinene, limonene, were also increased in the treatment of rabbit manure and this treatment also resulted in the decrease of estragole, an undesirable compound.

Abdallah *et al.* (2021) conducted an experiment at the Farm of Medicinal and Aromatic Plants Research Department, Qalyubia Governorate, Egypt, and reported that oil percentage can be decreased up to 53.08% in control treatment as compared to hand weeding treatment and similarly, protein content in seeds decreased upto 13.09% under weedy check in comparison to hand weeding treatment.

Patel (2021) reported that application of 2.5 ton vermi-compost ha⁻¹ recorded significantly higher volatile oil content in fennel seed. In addition, the application of

nitrogen at 90 kg ha⁻¹ recorded higher volatile oil content in seed barring with application of N at 45 kg ha⁻¹ over control.

A field experiment was conducted by Kucha *et al.* (2019) at the College of Agriculture, Junagadh Agricultural University, Junagadh. The results revealed that fertilization of the crop with 120 kg N ha⁻¹ produced better quality of fennel and enhanced the protein content (17.42%) in seed as compared to lower doses of nitrogen.

Bajya *et al.* (2017) carried out an experiment on fennel crop at College of Horticulture Mandsaur, Madhya Pradesh. They reported that application of 50% recommended dose of nitrogen through vermicompost + 50% RDN through inorganic fertilizers recorded higher values of plant growth seed yield, stover yield and biological yield over 100% RDN through FYM only. They also reported that seed quality also improves with integration of organic and inorganic fertilizers.

Waskela *et al.* (2017) carried out an experiment at the Horticulture Research Farm, College of Horticulture, Mandsaur, to study the effect of row spacing and NPK levels on growth of crop, yield and quality of fennel. The result revealed that higher value of chlorophyll content was recorded under 60:40:40 kg NPK ha⁻¹.

An experiment was conducted by Bhardwaj and Kumar (2016) at district Sirohi, Rajasthan, to study the impact of varied levels of nitrogen (60, 90, 120 and 150 kg N ha⁻¹) on production, quality and profitability of transplanted fennel. They found that volatile and total oil content, soluble sugar, total carbohydrate, and overall quality of seeds were higher with application of 120 kg N ha⁻¹ but higher protein and nitrogen content in seed was observed with the application of 150 kg N ha⁻¹.

Ayub *et al.* (2015) conducted an experiment to study the effects of nitrogen (0, 30, 60 and 90 kg N ha⁻¹) on growth, seed yield and quality of fennel. They found that maximum protein and oil content from fennel seed was recorded under the application of nitrogen 90 kg ha⁻¹ compared to rest of the treatments, as higher nitrogen supported the increase in protein content in the crop.

A study conducted by Moosavi *et al.* (2014) at Islamic Azad University of Birjand Branch, revealed that the highest yield and essential oil production was found with the

application of 60 kg N ha⁻¹. Therefore, 60 kg N ha⁻¹ with optimum irrigation can be beneficial for achieving higher essential oil yield of fennel.

An experiment conducted by Ehsanipour *et al.* (2012) at Isfahan University of Technology Experimental Station, Isfahan, Iran, reported that fennel seeds are a good source of protein and minerals. Nitrogen application increased protein (17.72 %) and fiber content (31.71%) and seed essential oil (1.93%) which was maximum in application of 160 kg ha⁻¹ Nitrogen. On the other hand, nitrogen application reduced the ash content of seeds.

In an experiment conducted by Mohamed and Abdu (2012) at Department of Horticulture, Minia University, Egypt, the results revealed that organic fertilizers increased the oil yield of fennel by increasing both seed yield and volatile oil percentage of the crop. The highest oil yield was obtained with the application of chicken manure, which was followed by cattle manure and plant compost.

A field experiment entitled “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” was carried out at Research Farm of Lovely Professional University, School of Agriculture, Phagwara (Punjab) during *Rabi* season 2023-24 and 2024-25. The details of various treatments, cultural practices and procedures adopted are discussed below.

3.1 Experimental site and location

The experiment was carried out at the research farm of the School of Agriculture, Lovely Professional University, Phagwara (Punjab) which comes under Trans Gangetic Plains. It is located geographically at 31.2432 °N and 75.696 °E longitude having an elevation of 240 meters above mean sea level.

3.2 Climate and weather conditions

Phagwara comes under semi-arid and subtropical climate with hot summers and cold winters. The highest temperature of the region was 46°C and the lowest was 6°C, with average annual rainfall of 816 mm.

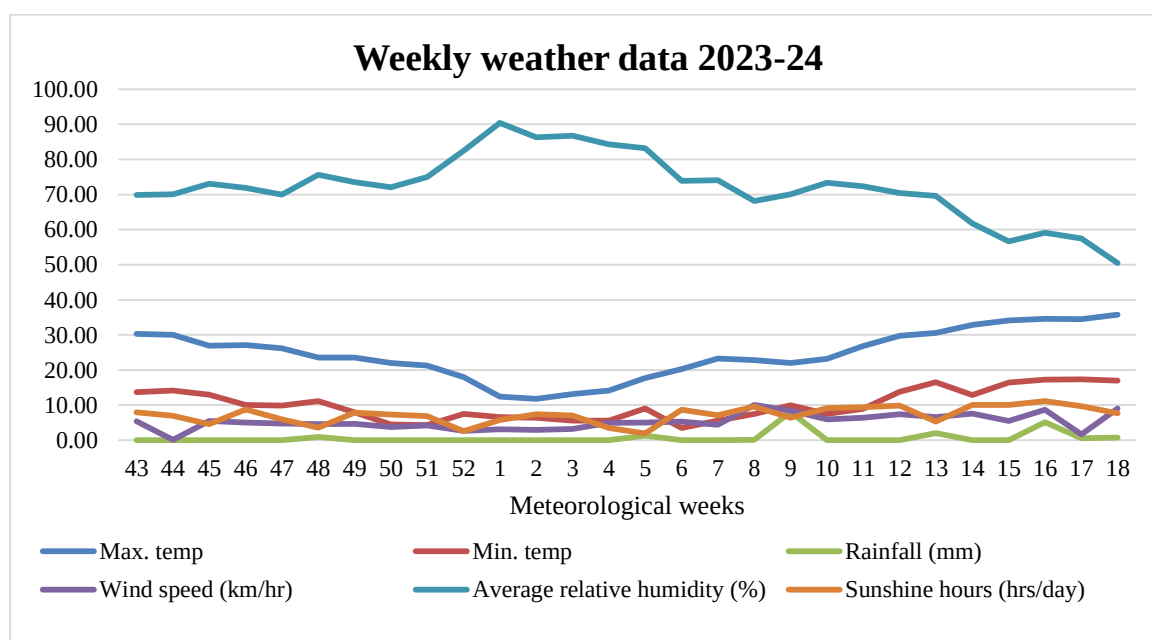


Figure 3.1 Weekly weather data during crop season of 2023-24

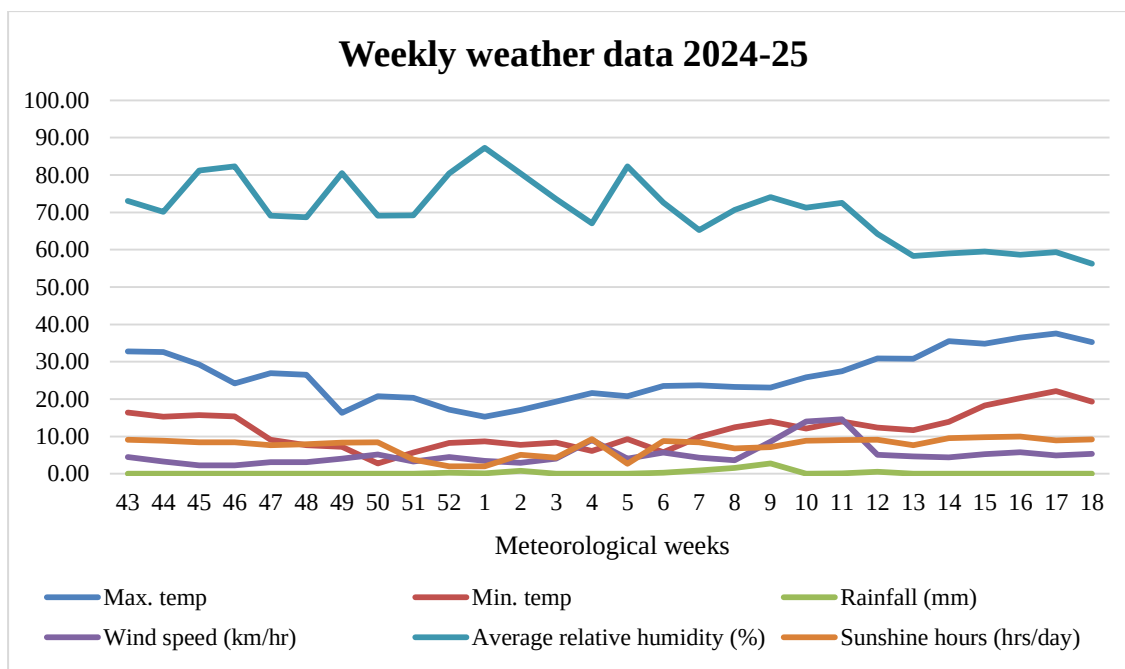


Figure 3.2 Weekly weather data during crop season of 2024-25

3.3 Soil of the experimental field

To check the physiochemical properties and fertility status, soil samples were collected from five random spots of the experimental field at a depth of 0- 15 cm. The collected soil samples were mixed to form a composite sample and tested in the laboratory for mechanical analysis (Table 3.2) as well as to work out chemical properties of experimental field (Table 3.3).

Table 3.1 Mechanical analysis of soil

S. no	Soil separates	Percentage (%)	Method
1	Sand	44.2 %	Bouyoucos hydrometer method (Bouyoucos, 1927)
2	Silt	25.7 %	
3	Clay	30.1 %	
	Texture of soil	Clay loam	

Table 3.2 Chemical properties of the experimental soil

S.no.	Particulars	Result	Method
1	Soil pH	7.4	Glass electrode pH meter (Jackson, 1973)
2	Soil EC	0.31 dS m ⁻¹	Jackson (1973)
3	Organic carbon	0.43% (low)	Walkley and Black's method (Jackson, 1973)
4	Available N	224.3 kg ha ⁻¹ (low)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P	25.8 kg ha ⁻¹ (medium)	Olsen's calorimetric method (Olsen <i>et al.</i> , 1954)
6	Available K	218.9 kg ha ⁻¹ (medium)	Flame photometer method (Jackson, 1973)

3.4 Technical programme of study

Experiment 1. Role of planting patterns and weed control methods on growth and development of Fennel (*Foeniculum vulgare* Mill.)

Main plots (Planting patterns)

P₁- Two rows per bed (90 cm- 60 cm bed top and 30 cm furrow)

P₂- Ridge sowing (45 cm)

P₃- Flat sowing (45 cm) *fb* earthing up

P₄- Flat sowing (45 cm)

Sub-plots (Weed control treatments)

T₁- Black plastic mulch

T₂- White plastic mulch

T₃- Hand weeding *fb* straw mulch (5tha⁻¹)

T₄- Unweeded (control)

Note–I Plant population remained the same in all the planting patterns.

II Row to row spacing in bed planted crop was kept as 45cm.

III Plant to plant spacing was 20 cm.

IV Earthing up and hand weeding *fb* straw mulching was done at 45 DAS

Experiment 2. Response of Fennel (*Foeniculum vulgare* Mill.) to nitrogen and FYM in relation to weed control strategies

Main plots (Weed control treatments)

T₁- Plastic mulch (Black)

T₂- One hand weeding *fb* straw mulch (5 t ha⁻¹)

T₃-Pendimethalin (pre-emergence) 0.45 kg ha⁻¹ *fb* hand weeding

T₄- Unweeded (control)

Sub-plots (Nitrogen levels)

N₁- 25 kg N ha⁻¹

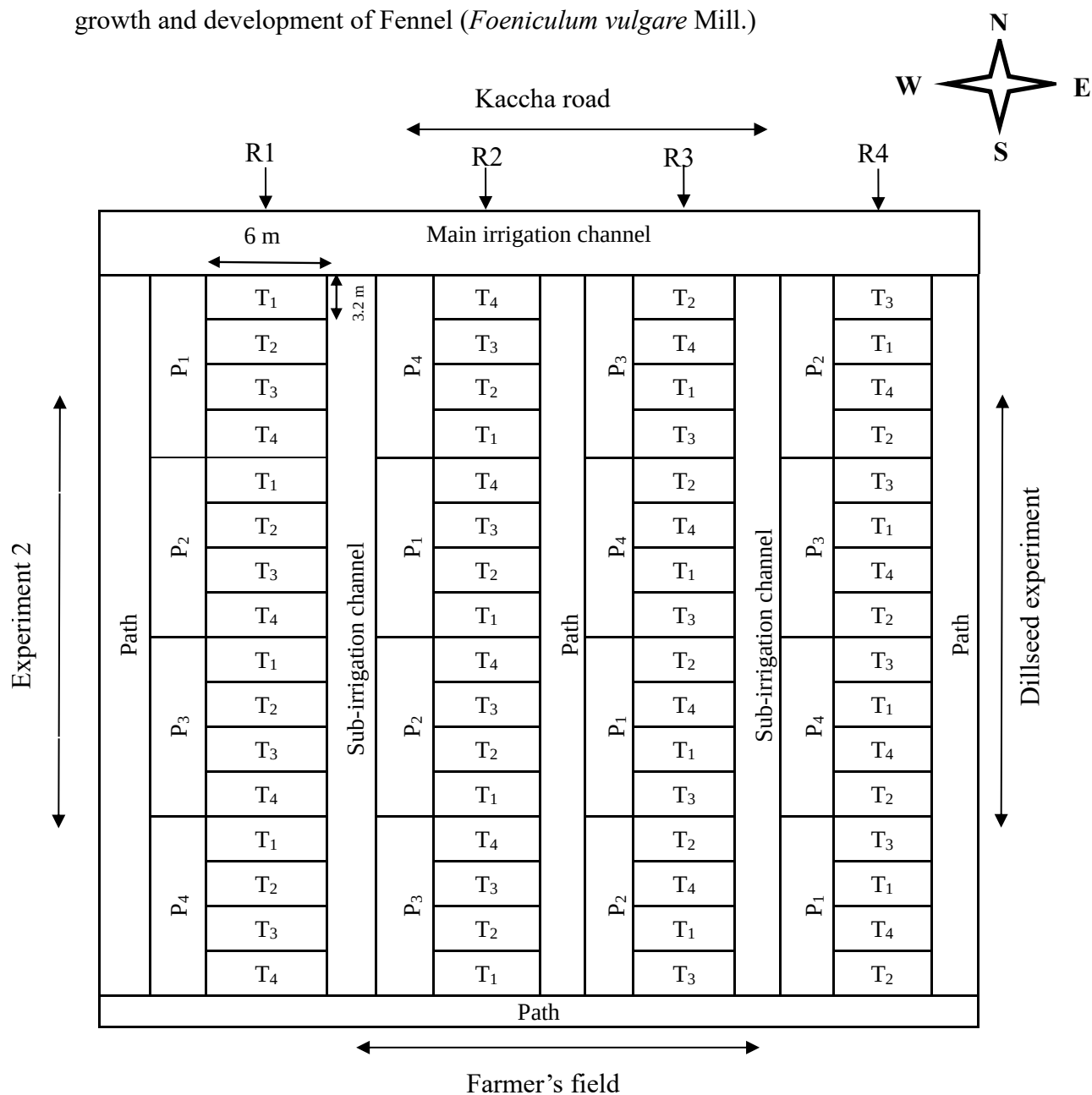
N₂- 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹

N₃- 50 kg N ha⁻¹

N₄- 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹

Note – Hand weeding and straw mulching was done at 45 DAS

Layout of Experiment 1- Role of planting patterns and weed control methods on growth and development of Fennel (*Foeniculum vulgare* Mill.)



Design: Split Plot Design

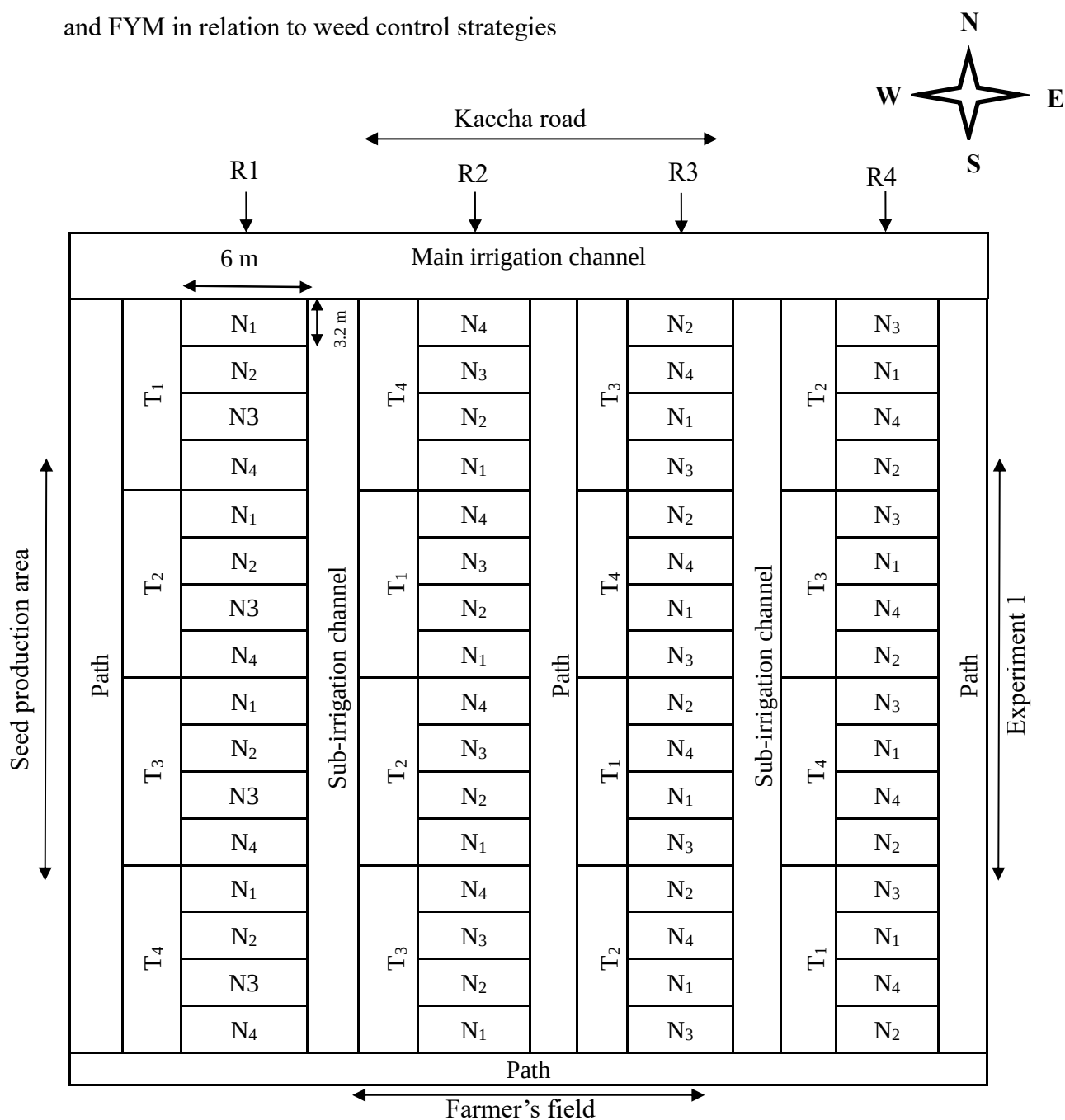
Main plots: Four

Sub plots: Four

Main plot size: 6 mx 12.8 m

Sub plot size: 6 m x 3.2 m

Layout of Experiment 2- Response of Fennel (*Foeniculum vulgare* Mill.) to nitrogen and FYM in relation to weed control strategies



Design: Split Plot Design

Main plots: Four

Sub plots: Four

Main plot size: 6 m x 12.8 m

Sub plot size: 6 m x 3.2 m

3.5 Experiment details (Experiment 1 and 2):

Year	2023-2024 and 2024-25
Season	<i>Rabi</i>
Crop	Fennel (<i>Foeniculum vulgare</i> Mill.)
Variety	Ajmer Fennel 2
Seed rate	10 kg ha ⁻¹
Spacing	45 cm × 20 cm
Date of sowing	27 October 2023 and 22 October 2024
Design of each experiment	Split Plot Design
Main plots in each experiment	4
Sub plots in each experiment	4
Total no. of treatments in each experiment	16
No. of replications in each experiment	4
Total no. of plots in each experiment	64
Gross plot size	6 m × 3.2 m
Net plot harvested	3.6 m ² during 2023-24 and 4.95 m ² during 2024-25
Fertilizers	N- 50 kg ha ⁻¹ in Experiment 1 and as per treatments in Experiment 2 P ₂ O ₅ - 25 kg ha ⁻¹ in each experiment FYM (0.5 % N) - 15 t ha ⁻¹ as per treatments in Experiment 2

3.5.1 Cropping history of field

S. no.	Year	<i>Kharif</i>	<i>Rabi</i>
1	2021-22	Maize	Gobhi sarson
2	2022-23	Maize	Gobhi sarson
3	2023-24	Maize	Experimental crop
4	2024-25	Maize	Experimental crop

3.6 Agronomic practices:

3.6.1 For Experiment 1 and 2

Name of the operation	Dates of operations	
	2023-2024	2024-2025
Land preparation	24 October 2023	15 October 2024
Layout of experiment	25 October 2023	17 October 2024
Organic manure (FYM) application as per treatment	25 October 2023	18 October 2024
Plastic mulch application	26 October 2023	21 October 2024
Sowing	27 October 2023	22 October 2024
Pre-emergence herbicide application as per treatment	27 October 2023	22 October 2024
Irrigation after dry sowing	28 October 2023	24 October 2024
Gap filling and thinning	15 November 2023	18 November 2024
Hand weeding as per treatment	10 December 2023	11 December 2024
Straw mulching as per treatment	12 December 2023	15 December 2024
Earthing-up as per treatment	28 December 2023	23 December 2024

3.6.2 Calendar of operations (For both experiments)

Name of the operation	Dates of operations	
	2023-2024	2024-2025
First irrigation	8 November 2023	10 November 2024
First dose of N (urea)	12 December 2023	8 December 2024
Second irrigation	15 December 2023	17 December 2024
Second dose of N (urea)	27 December 2023	24 December 2024
Data collection at 60 DAS	29 December 2023	25 December 2024
Third irrigation	13 January 2024	15 January 2025
Data collection at 90 DAS	27 January 2024	22 January 2025
Fourth irrigation	15 February 2024	18 February 2025
Data collection at 120 DAS	26 February 2024	22 February 2025
Fifth irrigation	18 March 2024	22 March 2025
Sixth irrigation	16 April 2024	15 April 2025

Data at harvest	2 May 2024	29 April 2025
Harvesting	4 May 2024	30 April 2025
Plant sample for lab study	5 May 2024	1 May 2025
Soil sampling	5 May 2024	2 May 2025
Threshing	9 May 2024	6 May 2025
Winnowing	9 May 2024	6 May 2025

3.6.3 Irrigation for field preparation:

The field was irrigated after harvest of *khariif* season maize crop during both years, in order to prepare a fine seed bed.

3.6.4 Field preparation:

The field was prepared using a disc harrow twice and then rotavator for land preparation and finally planking was done. So, the crop was sown on well pulverized field during both years.

3.6.5 Layout of field experiments:

After seed bed preparation, the layout of both the experiments was made manually by dividing the field into main plots and sub plots. The irrigation channels and experimental plots were prepared manually by the labour. Finally, the levelling of sub plots was done with the help of an implement called Zindra. Ridges at 45 cm apart and beds of 90 cm (60 cm bed top and 30 cm furrow) were made as per treatment with spade.

3.6.6 Fertilizer application:

Nitrogen at the rate of 50 kg/ha was applied uniformly in Experiment 1 and as per treatments in Experiment 2. The application of nitrogen was done in two split doses in both experiments at 45 and 60 days after sowing the crop. Phosphorus @ 25 kg ha⁻¹ was applied uniformly in the form of SSP (single super phosphate) in all the plots as an initial dose.

3.6.7 Application of straw and plastic mulches:

Rice straw mulch (sun dried) at 5 t ha⁻¹ was used as per treatment in both experiments. Black and white plastic mulch of thickness 25 microns (0.025 mm) were spread on the experimental plots as per treatments before sowing. After spreading plastic sheets, holes were made using a plastic pipe with diameter of 5 cm. The holes were made by keeping 20 cm plant to plant spacing irrespective of planting pattern.

3.6.8 Variety and seed rate:

Ajmer Fennel 2 variety of fennel was sown by using seed rate of 10 kg ha⁻¹. This variety was developed by ICAR- NRCSS, Ajmer (Rajasthan) in the year 2017 for early sowing during *rabi* season. It is tall, erect growing, has large size umbels and is tolerant to *Ramularia* and *Alternaria* blight. The average yield of AF-2 (Ajmer Fennel 2) during *rabi* season is 17.90 q ha⁻¹. The duration of this variety is 175-180 days after sowing.

3.6.9 Date of sowing and sowing methods

The sowing was done on October 27th and October 23rd during the year 2023 and 2024, respectively for both experiments. The sowing of the seeds was done using dibbling method. Beds (90 cm) with 60 cm bed top and 30 cm furrow, and ridges (45 cm apart) were prepared. The plastic mulches (black and white) were spread on the surface of field and holes of 5.0 cm diameter were made in the sheets with the help of plastic pipe by keeping plant to plant spacing of 20 cm and sowing was done with row to row spacing of 45 cm irrespective of planting patterns (flat, bed or ridge). Two rows per bed were sown at 45 cm apart on the bed top of 60 cm. Two to three seeds of fennel were put per hole at a depth of 1 cm and were covered with soil. Dry sowing of both experiments was made. The plant population was kept constant in all the planting patterns.

3.6.10 Pre-emergence application of herbicide:

Pre emergence application of Stomp 30 EC (pendimethalin) 0.45 kg a.i. / ha was done after sowing but before applying irrigation. The herbicide was dissolved in 500 lit/ ha of water. The spraying was done with knap sack sprayer using flat fan nozzle.

3.6.11 Irrigation:

After dry sowing, irrigation was applied to facilitate crop germination, and additional irrigations were applied as required based on the weather conditions. At any stage of growth, the crop was not permitted to wilt. In general, six irrigations were applied during both years for successful raising the crop.

3.6.12 Thinning and gap filling:

Gap filling was done 10-15 days of sowing the crop in the plots where the plant population was not satisfactory. Then thinning of the crop was carried out after 30 days of sowing by keeping one healthy plant per hill. All the densely spaced plants were removed, and gaps were filled through transplanting healthy seedlings to maintain the proper spacing.

3.6.13 Hand weeding

One hand weeding as per treatment in both experiments was done after 45 days of sowing during both the years.

3.6.14 Earthing up and straw mulching

Earthing up was done in experiment 1 as per treatments after 60 days of sowing with the help of a spade. Straw mulch was applied @ 5 t ha⁻¹ as per treatment between the rows of the crop by covering entire soil surface. Rice straw mulch was used.

3.6.15 Pest management:

To control termites and ants, chloropyrifos 20% EC was sprayed @500-1200 ml per hectare at 30 DAS in both experiments.

3.6.16 Harvesting:

Harvesting of the crop was done when majority of umbels turned brown with a sickle on 3rd May 2024 and 30th April 2025 during the first and second year, respectively. The crop was harvested when the seeds of the umbels were fully matured and became hard. The net plot harvested was 3.6 m² during the first year and 4.95 m² during the second year.

3.6.17 Threshing:

The harvested plants were kept in shade for 3-4 days for uniform drying of all the umbels. Once the samples were dried, threshing was done for each plot separately by beating the bundles with a wooden stick. Later, the seeds were cleaned thoroughly, dried in sun and were put in brown bags for weighing and yield estimation. These samples were weighed on electronic balance plot wise.

3.6.18 Biological yield (q ha⁻¹):

The bundles of net plot harvested were kept in shade for 3-4 days for drying. Then, weighing the plants along with umbels was done with digital weighing balance. The values recorded were converted into q ha⁻¹.

3.6.19 Seed yield (q ha⁻¹):

After threshing the crop, seeds of each plots, after proper cleaning were collected in separate brown bags and then weighing was done by using digital weighing balance after proper cleaning. The values were then converted into q ha⁻¹ for presentation.

3.6.20 Stover yield (q ha⁻¹):

Stover yield (q ha⁻¹) was obtained by subtracting seed yield of each experimental plots from the biological yield of respective plots and expressed in q ha⁻¹.

3.7 Soil sampling:

The soil samples were collected before sowing and after harvesting the crop. The tool used for soil sampling was soil auger which was used to collect the soil

samples from the depth of 0-15 cm below the ground level. After that, the samples were dried in shade followed by sieving with a 2 mm sieve and prepared for further lab analysis.

3.8 Observations recorded (Experiment 1 and 2):

3.8.1 Weed parameters:

3.8.1.1 Weed count (m^{-2})

Periodic weed count (m^{-2}) was taken at 60, 90, 120 DAS and at harvest for both the experiments. The quadrat of 30 cm x 30 cm was thrown randomly in each plot twice, and the number of weeds coming in each quadrat were counted to find out the average number of weeds per quadrat in each experimental plot. Later on, weed count data was converted to number of weeds per square meter for final presentations. Due to wide variation in data, square root transformation ($\sqrt{x+1}$) was used for analysis of weed count data after adding one to original values.

3.8.1.2 Weed dry matter (q ha^{-1})

Periodic weed dry matter (q ha^{-1}) was recorded 60, 90, 120 DAS and at harvest. A quadrat of 30 cm x 30 cm was randomly thrown at two places in each plot. The weeds coming inside the quadrat were cut above ground level with the help of a sickle and were collected in brown paper bags. After sun drying, the samples were kept in hot air oven at temperature of 60 °C up to their complete dryness. Electronic weighing balance was used to measure the dry weight of the weeds per quadrat which was converted to q ha^{-1} for final presentation. Due to wide variation in data, square root transformation ($\sqrt{x+1}$) was used for weed dry matter analysis also by adding one to the original values.

3.8.1.3 Weed control efficiency (%) at harvest

The weed control efficiency was calculated at harvest and expressed in percentage by using the given formula.

$$\text{WCE (\%)} = \frac{X-Y}{X} \times 100$$

X= Weed dry weight (q ha⁻¹) in weedy check (control) plot

Y= Weed dry weight (q ha⁻¹) in treatment for which WCE is to be calculated.

3.8.2 Crop parameters:

3.8.2.1 Plant height (cm)

The plant height (cm) was measured from five randomly selected plants from each plot with the help of a measuring rod. The height in cm was measured from ground level to the last fully opened leaf at 60, 90, 120 DAS and at harvest and average plant height was calculated for presentation in cm.

3.8.2.2 Number of plants per meter row length

The number of plants were counted from one central row from each plot and average value was noted for obtaining the final value of number of plants per meter row length at 60, 90, 120 DAS and at harvest.

3.8.2.3 Dry weight per plant (g)

Dry matter was recorded at 60, 90, 120 DAS and at harvest. For this, five random plants were selected and were cut with sickle above the ground surface and their fresh weight was recorded with the help of digital weighing balance from each experimental plot. The samples were put into brown bags. After air drying for some days, the samples were dried in an electric hot air oven at 60 °C till constant weight was obtained. The data was represented as an average value of single plant weight in grams (g plant⁻¹).

3.8.2.4 Number of primary branches per plant

Five randomly selected plants were used for recording the number of primary branches from each plot at 90, 120 DAS and at harvest. Average number of primary branches/plant were worked out for presentation.

3.8.2.5 Number of secondary branches per plant

Five randomly selected plants were used for recording the number of secondary branches from each plot at 90, 120 DAS and at harvest and their average was worked out for presentation.

3.8.3 Yield parameters

3.8.3.1 Number of umbels per plant (primary and secondary)

The randomly selected five plants which were taken for recording dry matter accumulation, were used for counting the number of primary and secondary umbels at harvest and their average was done to get number of respective umbels per plant.

3.8.3.2 Number of umbellets per umbel (main, primary and secondary)

Total number of umbellets of five randomly selected umbels were counted for main, primary and secondary umbels from each plot at harvest and their average was calculated for getting number of umbellets per main, primary and secondary umbel, respectively.

3.8.3.3 Number of seeds per umbellet (main, primary and secondary)

Total number of seeds from five randomly selected umbellets of main, primary and secondary umbel from each plot at harvest were recorded, and their average was worked out to get number of seeds per main, primary and secondary umbellet respectively.

3.8.3.4 Number of seeds per umbel (main, primary and secondary)

At harvest, three umbels were randomly selected from each main, primary and secondary umbels in each plot and the total seeds were counted to record the average number of seeds per main, primary and secondary umbel, respectively.

3.8.3.5 Diameter of main, primary and secondary umbels (cm)

The diameter of main, primary and secondary umbels was measured at harvest with the help of a measuring scale, from five randomly selected umbels and their average was done to get diameter of main, primary and secondary umbel in cm respectively.

3.8.3.6 Seed weight per umbel (g) (main, primary and secondary)

Five randomly selected umbels of different categories were taken at harvest from each plot and the seeds per umbel were weighted on a digital weighing balance and the values were noted. Seed weight of main, primary and secondary umbels was taken separately. The seed weight/umbel was worked out in g/umbel, respectively.

3.8.3.7 Test weight (g)

Representative samples of seeds were taken from each plot at harvest, then 1000 seeds were counted, and weighing was done on a digital weighing balance, and the value was recorded in grams for reporting test weight.

3.8.3.8 Biological yield (q ha^{-1})

The net plot harvested was 3.6 m^2 during 2023-24 and 4.95 m^2 during 2024-25 and biomass per plot was dried in shade for 3-4 days till uniform drying was obtained. Then, weighing of net plot harvested biomass was done with weighing balance and the values were recorded in kg/ plot and later converted to q ha^{-1} to calculate biological yield.

3.8.3.9 Seed yield (q ha^{-1})

After complete shade drying, the produce of each net plot harvested was threshed followed by proper cleaning. The seeds were collected from each harvested plot in brown bags with proper tagging. Later, it was weighed separately on digital weighing balance and converted to q ha^{-1} for presentation.

3.8.3.10 Stover yield (q ha^{-1})

The stover yield was calculated by subtracting the seed yield (kg/plot) from the biological yield (kg/plot) and then converted to q ha^{-1} .

3.8.4 Quality parameters at harvest

3.8.4.1 Nitrogen content in seed, stover and weeds (%)

The dried samples of seed, stover or weeds at harvest were grinded by a grinder and 0.1 g of powdered sample was kept into Kjeldahl digestion tubes with crystals of CuSO_4 and 20 ml of 98% H_2SO_4 . It was kept for digestion for 2-3 hours at auto set temperature. After that, 40% NaOH, 4% boric acid and mixed indicator were prepared for distillation process. After completion of the distillation process by Kel-Plus, the samples extracted were titrated with 0.1 N H_2SO_4 . The reading was noted and calculated in percentage for nitrogen content. Also at 90 DAS, nitrogen content in crop for experiment 2 only, was also calculated. The formula used for calculating N% was given below.

$$\text{N\%} = \frac{14.01 \times 0.1\text{N} \times (\text{T.V.} - \text{B.V.})}{1000 \times \text{Weight of sample}} \times 100$$

T.V. = Titrated value

B.V. = Blank value

3.8.4.2 Protein content in seeds (%)

Protein content in seeds was calculated by multiplying N % in seeds with 6.25.

$$\text{Protein \%} = \text{N content in seed (\%)} \times 6.25$$

3.8.4.3 Seed essential oil content (%)

To extract the essential oil, air-dried seeds of fennel was finely crushed into a grinder to obtain a fine powder and subjected to hydro distillation for 3-4 hours using a Clevenger-type apparatus. Distillates of essential oils were subsequently dried over anhydrous sodium sulfate to remove water, then, it was filtered and stored at 4°C until analyzed (Anwar and Hussain, 2009). The essential oil yield was calculated as the ratio between the volume of oil obtained and the weight of seeds used.

3.8.4.4 N uptake by grain (kg ha^{-1})

$$\text{N uptake by grain (kg ha}^{-1}\text{)} = \text{nitrogen content \% (seed)} \times \text{seed yield (kg ha}^{-1}\text{)}$$

3.8.4.5 N uptake by stover (kg ha⁻¹)

N uptake by stover (kg ha⁻¹) = nitrogen content % in stover × stover yield (kg ha⁻¹)

3.8.4.6 Total N uptake by crop (kg ha⁻¹)

Total N uptake by crop (kg ha⁻¹) = N uptake by seed (kg ha⁻¹) + N uptake by stover (kg ha⁻¹)

3.8.4.7 N uptake by weeds (kg ha⁻¹)

N uptake by weeds (kg ha⁻¹) = Nitrogen content (%) in weeds × weed dry matter (kg ha⁻¹)

3.8.5 Economics of treatments

To evaluate the profitability and effectiveness of the treatments, the economics was worked out in terms of net return (Rs/ha) and gross return (Rs/ha) based on prevailing market prices so that the most beneficial treatment could be evaluated. Further, to ascertain profitability on per Rupee investment basis for each treatment, benefit: cost ratio (B: C) was also calculated.

3.8.6 Soil parameters

3.8.6.1 Before sowing

3.8.6.1.1 Soil texture

Fifty grams of oven dried soil sample which was sieved through 2 mm sieve was taken. Dispersing reagent, sodium hexametaphosphate was added to the soil sample. The dispersed soil suspension was transferred to a 1000 ml graduated cylinder and agitation of the mixture was done. Then a hydrometer was inserted gradually, and the reading was noted at different intervals. A blank solution was also worked out in the same way. Then the percentages of sand, silt, and clay using specific formulas were calculated and plotted on a soil texture triangle to classify the soil type.

3.8.6.1.2 Available P (kg ha⁻¹)

Two and a half gram soil sample was taken into 150 ml conical flask. Then, a pinch of activated charcoal along with 50 ml of 0.5 M NaHCO₃ was added to it. Sample was then kept on a mechanical shaker for at least 30 minutes. The solution was filtered with Whatman filter paper no. 1, then 5 ml of extractant was poured out into 25 ml volumetric flask and 5 ml (NH₄)₆Mo₇O₂₄ was added. Then, 10 ml distilled water was added with 1 ml stannous chloride solution, and the volume was made up to 25 ml. The reading was taken with spectrophotometer at a wavelength of 660 nm by making a standard curve for phosphorus.

3.8.6.1.3 Available K (kg ha⁻¹)

One g of soil sample was weighed into a conical flask. Then, 25 ml of 1 N C₂H₇NO₂ was added, and shaken manually or with mechanical shaker for 5-7 minutes, the solution was filtered through Whatman filter paper no. 1. The final reading was taken on flame photometer by making a standard curve having one sample as blank by using KCl.

3.8.6.2 Before and after sowing

3.8.6.2.1 Soil pH

A soil sample of 10 g was weighed and put into a 100 ml glass beaker. Then, 25 ml of water was added to it. After continuous stirring of the sample for a few minutes, the sand particles were allowed to settle at bottom. The electrode was dipped in the solution, and the reading was noted. The calibration of the pH was done with the buffer solutions of pH 4, 7 and 9.2.

3.8.6.2.2 Soil EC

Ten grams of soil sample was taken in a 100 ml conical flask and 25 ml of water was added to it. The sample was kept on a mechanical shaker for 8-10 minutes. After shaking, the sample was left for few minutes to settle down. Then, the reading was taken with electrical conductivity meter (dS/m).

3.8.6.2.3 Soil organic carbon (%)

One gram soil was weighed and kept into a 500 ml conical flask. Twenty ml of $K_2Cr_2O_7$ and H_2SO_4 were added into the flask. The sample was stirred and left for 30 minutes. Afterwards, 200 ml of distilled water was added along with 10 ml of ortho-phosphoric acid. Also 4-5 drops of diphenylamine indicator was added and then titrated with FAS, the value at which solution turns green was recorded.

3.8.6.2.4 Available N ($kg\ ha^{-1}$)

Ten grams of soil was added in Kjeldahl flasks and kept in the distillation unit and along with this, 4-5 drops of mixed indicator was taken in a conical flask. Then, the distillation unit was set to add 20 ml of boric acid (4%) in the conical flask and 25 ml of 0.32% $KMnO_4$, 25 ml of 2.5% of NaOH and 10ml of distilled water in kjeldahl flask. The distillation process was done for 7 minutes. The conical flask solution was taken and titrated with 0.02 N H_2SO_4 . When the colour of solution changed, the reading was noted.

3.9 Statistical Analysis: All the above research data of different parameters of crop (growth, dry matter, yield attributes) and weeds (weed count and weed dry matter) were analyzed by OPSTAT software. The analysis of variance (ANOVA) was formulated, and CD values were worked at 5% level of significance, and the non-significant data was denoted as NS. SE (m) $\pm$ was also given in Table 3.9.1.

3.9.1 ANOVA Table (Experiment 1 and 2)

Sources of Variation	Degree of freedom	Sum of Squares	Mean Sum of squares	F_{cal} (F – calculated)
Replication	$r-1 = 3$	RSS	RMS	RMS/EMS(a)
A (main plots)	$m-1 = 3$	ASS	AMS	AMS/EMS(a)
Error (a)	$(r-1)(m-1) = 9$	ESS(a)	EMS(a)	
B (sub plots)	$s-1 = 3$	BSS	BMS	BMS/EMS(b)
A x B (interaction)	$(m-1)(s-1) = 9$	ABSS	ABMS	ABMS/EMS(b)
Error (b)	$m(r-1)(s-1) = 36$	ESS(b)	EMS(b)	
Total	$rms-1 = 63$	TSS		

Photo gallery

Layout preparation and sowing



Layout



Sowing in white mulch



Sowing in black mulch



Pendimethalin spray



Irrigation



Germination

Experiment 1

Main plots (Planting patterns) – 45 DAS



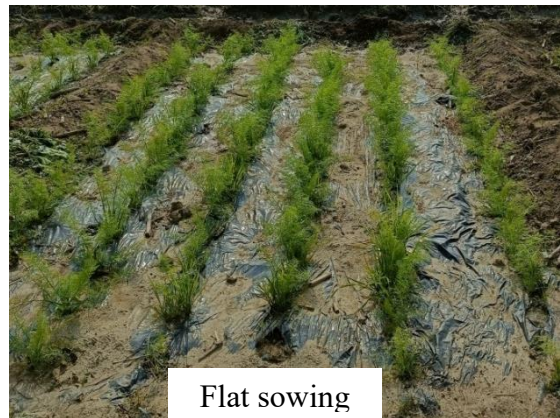
Bed sowing



Ridge sowing

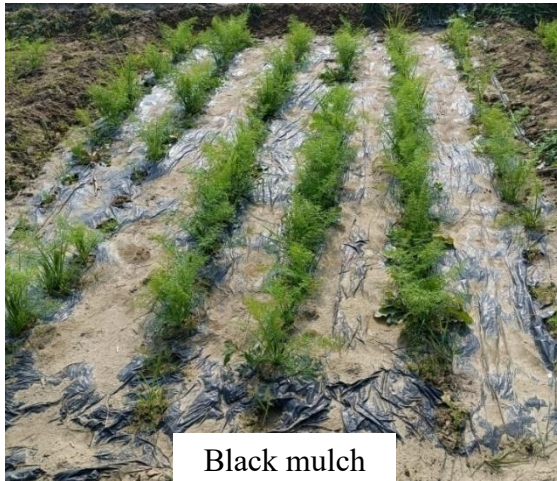


Flat sowing *fb* earthing up

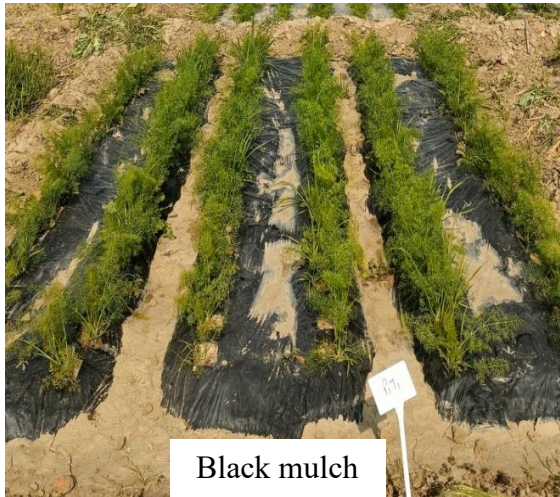


Flat sowing

Sub plots (Weed control treatments) - 45 DAS in flat sowing



Sub plots - 45 DAS in bed sowing



Sub plots (Weed control treatments) - 90 DAS



Experiment 2

Main plots (Weed control treatments) - 45 DAS



Black plastic mulch



One hand weeding *fb* straw mulch

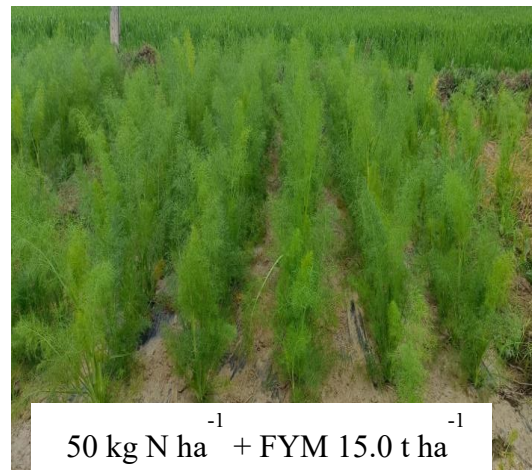
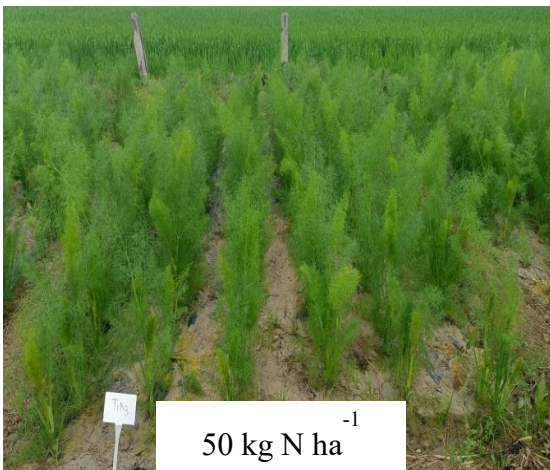
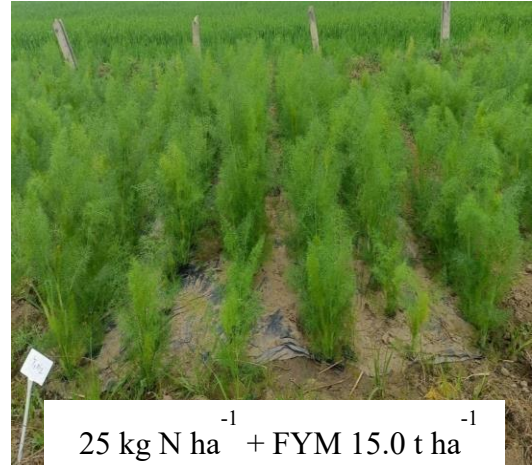
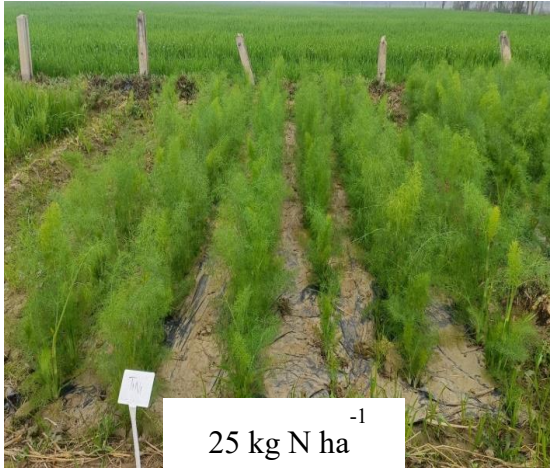


Pendimethalin *fb* one hand weeding



Unweeded (control)

Sub plots (Nutrition levels) - 60 DAS



Sub plots (Nutrition levels) - 90 DAS



Experiment 1- General view of the crop at 90 DAS



Experiment 2- General view of crop at 90 DAS



Lab analysis

Soil testing-



Soil pH



Soil EC

Soil organic carbon-



Soil organic carbon (%)



Before titration



After titration

Oil extraction by soxlet apparatus-



Oil content

Nitrogen content estimation by kjeldahl apparatus-



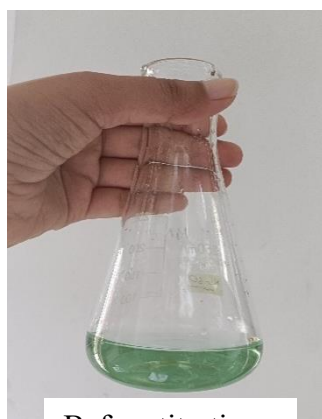
Digestion



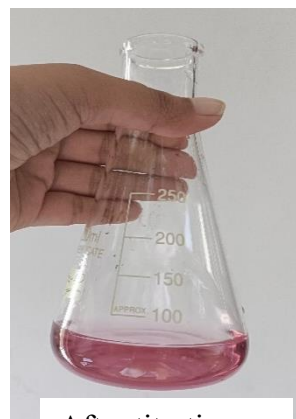
Distillation



Titration



Before titration



After titration

Experiment 1- Role of planting patterns and weed control methods on growth and development of Fennel (*Foeniculum vulgare* Mill.).

The results of the experiment of both years are being discussed under the following sub heads.

4.1 Weed parameters

4.1.1. Weed count (m^{-2})

Weed count is very important parameter indicating weed density per unit area as well as type of weed flora present in the experimental field. Weed count governs losses of crop yield due to the infestations of weeds in a crop. Due to large variation in weed count data, it was subjected to square root transformation after adding one to the original values. The data presented in Table 4.1.1 indicates that differences in weed count (m^{-2}) due to planting patterns and weed control treatments recorded at 60, 90, 120 DAS and at harvest were found to be significant during both the years (Table 4.1.1).

The differences in weed count (m^{-2}) due to planting patterns and weed control treatments recorded 60 DAS were significant during 2023-24 (Table 4.1.1). Among planting patterns, weed count (m^{-2}) was found to be significantly less in flat sowing *fb* earthing up as compared to all other planting patterns. Two rows per bed recorded significantly less weed count (m^{-2}) as compared to ridge sowing and flat sowing methods. Significantly higher weed count was observed in flat sowing as compared to all other planting patterns. Among weed control treatments, hand weeding *fb* rice straw mulch (5 t ha^{-1}) recorded significantly lower weed count than all other weed control treatments recorded at 60 DAS (Table 4.1.1). Weed count (m^{-2}) was significantly less in black plastic mulch as compared to white plastic mulch. Weed count was significantly higher in unweeded (control) than all other weed control treatments. During 2024-2025, among planting patterns, weed count (m^{-2}) recorded in

two rows per bed was found to be significantly less as compared to all other planting patterns (Table 4.1.1). Flat sowing *fb* earthing up recorded significantly less weed count as compared to the planting pattern of flat sowing. Significantly higher weed count was observed in flat sowing as compared to all other planting patterns. Among weed control treatments, hand weeding *fb* straw mulch recorded significantly lower weed count than all other weed control treatments. Weed count was significantly higher in unweeded (control) than all other weed control treatments.

At 90 DAS, the differences in weed count (m^{-2}) were significant among planting patterns and weed control treatments during 2023-24 as shown in Table 4.1.1. Among planting patterns, two rows per bed recorded significantly less weed count (m^{-2}) as compared to all other planting patterns. Weed count in flat sowing *fb* earthing up was at par with ridge sowing and both these planting patterns recorded significantly more weed count than two rows per bed planting pattern. However, significantly higher weed count (m^{-2}) was found in flat sowing treatment as compared to all other planting patterns. Among weed control treatments, weed count (m^{-2}) was found to be significantly lower in black plastic mulch as compared to all other weed control treatments (Table 4.1.1). However, hand weeding *fb* rice straw mulch (5 t ha^{-1}) recorded significantly more weed count than both plastic mulch treatments. Weed count was significantly higher in unweeded (control) than all other treatments. During 2024-25, the differences in weed count (m^{-2}) were found to be significant for planting patterns and weed control treatments (Table 4.1.1). Among planting patterns, flat sowing *fb* earthing up recorded significantly less weed count (m^{-2}) as compared to all other planting patterns. The weed count in two rows per bed was significantly less than ridge sowing and flat sowing methods. Significantly higher weed count was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed count (m^{-2}) was found to be significantly less in black plastic mulch as compared to all other weed control treatments. White plastic mulch recorded significantly less weed count as compared to hand weeding *fb* straw mulch. Weed count was significantly higher in unweeded (control) than all other weed control treatments.

At 120 DAS, the differences in weed count (m^{-2}) were found to be significant both for planting patterns and weed control treatments during 2023-24 as shown in Table 4.1.1. Among planting patterns, flat sowing *fb* earthing up recorded significantly less weed count as compared to all other planting patterns. Two rows per bed recorded significantly less weed count than ridge sowing and flat sowing. However, significantly higher weed count was found in flat sowing as compared to all other planting methods. Among weed control treatments, weed count (m^{-2}) was significantly lower in black plastic mulch as compared to all other weed control treatments. Significantly less weed count was observed in white plastic mulch as compared to hand weeding *fb* straw mulch. Weed count (m^{-2}) was significantly higher in unweeded (control) than all other weed control treatments. During 2024-25, the differences in weed count (m^{-2}) were found to be significant for planting patterns and weed control treatments (Table 4.1.1). Among planting patterns, two rows per bed recorded statistically at par weed count with flat sowing *fb* earthing up. The weed count in flat sowing was found to be significantly higher as compared to all other planting patterns. Among weed control treatments, weed count was significantly less in black plastic mulch as compared to all other weed control treatments (Table 4.1.1). The treatment of white plastic mulch produced significantly less weed count as compared to hand weeding *fb* straw mulch. Significantly more weed count (m^{-2}) was found in unweeded (control) than all other weed control treatments.

At harvest, the differences in weed count (m^{-2}) were found to be significant for planting patterns and weed control treatments during the year 2023-24 (Table 4.1.1). Among planting patterns, flat sowing *fb* earthing up recorded statistically at par weed count with two rows per bed. However, significantly higher weed count was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed count (m^{-2}) was significantly lower in black plastic mulch as compared to all other weed control treatments. White plastic mulch recorded significantly less weed count than hand weeding *fb* straw mulch. Weed count was significantly higher in unweeded (control) than all other weed control treatments. During 2024-25, the differences in weed count (m^{-2}) were found to be significant for planting patterns and weed control treatments (Table 4.1.1). Among planting patterns,

flat sowing *fb* earthing up recorded significantly less weed count as compared to all tried planting patterns. Significantly higher weed count was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed count (m^{-2}) in black plastic mulch was found to be statistically at par with white plastic mulch and both these treatments recorded significantly less weed count than hand weeding *fb* straw mulch. The weed count was significantly higher in unweeded (control) than all tried weed control treatments.

From the results, it can be concluded that planting pattern of flat sowing *fb* earthing up led to minimum weed count as compared to other planting methods which may be due to the reason that during earthing up operation, burying of the weed seeds into deeper soil layers took place and also this operation favoured uprooting of grown-up weeds. Similar results were reported by Patel *et al.* (2018). The lower weed density was observed in plastic mulch treatments due to the effective weed suppression right from initial crop stages which prevents the germination of weed seeds. Plastic mulches were more effective in controlling weeds which may be due to creation of physical barrier which blocked the germinating weed seedlings. Moreover, black plastic mulch performed better as it blocks the penetration of sunlight and helps in moderation of soil temperature. Similar findings were reported by Kaur *et al.* (2022). However, in unweeded (control) treatment, the weeds were allowed to grow freely without any obstructions, which results in higher weed density. These findings were in line with Patil *et al.* (2020) and Dhakad *et al.* (2017).

The interactive effect of planting patterns and weed control treatments for weed count (m^{-2}) was found to be non-significant at 60, 120 DAS and at harvest during both years. However, it was significant at 90 DAS during both years (Table 4.1.2). During 2023-2024, significantly less weed count was recorded in two rows per bed with black plastic mulch as compared to two rows per bed with white plastic mulch treatment. Weed count (m^{-2}) in two rows per bed with white plastic mulch was found to be statistically at par with flat sowing with black plastic mulch. Under planting pattern of flat sowing *fb* earthing up, application of black mulch recorded significantly less weed count (m^{-2}) than hand weeding *fb* straw mulch treatment. During 2024-2025, weed count recorded in flat sowing *fb* earthing up with white plastic mulch was statistically

at par with the planting pattern of two rows per bed with black plastic mulch treatment. Significantly less weed count was recorded in flat sowing *fb* earthing up with black plastic mulch treatment as compared to two rows per bed with white plastic mulch. Flat sowing *fb* earthing up integrated with hand weeding *fb* straw mulch recorded statistically at par weed count with ridge sowing where white plastic mulch was used to control weeds.

Table 4.1.1 Effect of planting patterns and weed control treatments on weed count (m^{-2}) at 60, 90, 120 DAS and at harvest.

Treatment details	Weed count (m^{-2})							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	6.1 (78)	5.9 (75)	7.0 (86)	7.7 (88)	7.3 (93)	6.7 (71)	5.3 (42)	5.6 (42)
Ridge sowing (45 cm)	7.1 (88)	6.7 (85)	9.2 (161)	8.2 (97)	8.6 (110)	7.9 (87)	6.7 (60)	6.4 (53)
Flat sowing (45 cm) <i>fb</i> earthing up	4.9 (31)	7.0 (89)	9.4 (149)	6.6 (69)	6.7 (58)	6.7 (57)	5.3 (37)	5.0 (32)
Flat sowing (45 cm)	9.7 (177)	9.0 (150)	9.8 (181)	9.6 (133)	9.3 (133)	8.8 (109)	7.6 (71)	7.0 (62)
SE(m)±	0.10	0.07	0.27	0.13	0.14	0.17	0.06	0.10
C.D. (5%)	0.37	0.22	0.96	0.44	0.48	0.56	0.22	0.31
Sub-plots (Weed control treatments)								
Black plastic mulch	3.3 (13)	3.0 (10)	2.7 (8)	3.3 (11)	3.9 (16)	4.2 (18)	3.4 (12)	3.6 (13)
White plastic mulch	6.4 (41)	5.9 (34)	4.7 (21)	4.8 (24)	4.8 (22)	4.7 (22)	4.0 (16)	3.9 (15)
Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	1.0 (0)	1.0 (0)	5.5 (30)	6.5 (42)	5.2 (26)	5.3 (27)	4.9 (24)	4.6 (21)
Unweeded (control)	17.0 (321)	18.7 (355)	22.6 (518)	17.5 (309)	18.0 (330)	15.9 (258)	12.6 (159)	11.8 (140)
SE(m)±	0.11	0.07	0.2	0.25	0.12	0.12	0.10	0.17
C.D. (5%)	0.33	0.21	0.65	0.71	0.36	0.35	0.30	0.48
Interaction C.D. (5%)	NS	NS	1.40	1.43	NS	NS	NS	NS
Note: Values within parenthesis are original values and without parentheses are transformed values. Data was subjected to square root transformation ($\sqrt{x+1}$) by adding one to original values for statistical analysis.								

Table 4.1.2 Interactive effect of planting patterns and weed control treatments on weed count (m^{-2}) at 90 DAS during 2023-24 and 2024-25

Weed count (m^{-2}) - 2023-24

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	Unweeded (control)	Mean A
Two rows per bed (90 cm)	2.3	4.3	4.1	17.6	7.0
Ridge sowing (45 cm)	2.7	4.4	5.6	24.3	9.2
Flat sowing (45 cm) <i>fb</i> earthing up	2.7	5.4	6.9	22.6	9.4
Flat sowing (45 cm)	3.3	4.7	5.4	25.7	9.8
Mean B	2.7	4.7	5.5	22.6	
SE(m)±	0.55				
C.D. (5%)	1.40				

Weed count (m^{-2}) - 2024-25

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	Unweeded (control)	Mean A
Two rows per bed (90 cm)	3.0	4.6	6.6	16.7	7.7
Ridge sowing (45 cm)	3.3	5.5	6.5	17.5	8.2
Flat sowing (45 cm) <i>fb</i> earthing up	2.4	3.6	5.3	15.1	6.6
Flat sowing (45 cm)	4.5	5.7	7.5	20.6	9.6
Mean B	3.3	4.8	6.5	17.5	
SE(m)±	0.27				
C.D. (5%)	1.43				

4.1.2 Weed dry matter (q ha^{-1})

Recording dry matter of weeds per unit area (kg ha^{-1} or q ha^{-1}) is more valid parameter than weed count. Sometimes number of weeds per unit area may be high and growth may be less, and this type of data is misleading. So, dry matter of weeds represents actual losses due to weeds in a particular crop. Due to large variation in weed dry matter data, it was subjected to square root transformation ($\sqrt{x + 1}$) after adding one to the original values. The data presented in Table 4.1.3 indicates that differences in weed dry weight (q ha^{-1}) due to planting patterns and weed control treatments recorded at 60, 90, 120 DAS and at harvest were found to be significant during both the years (Table 4.1.3 and Fig 4.1.1).

The differences in weed dry weight (q ha^{-1}) due to planting patterns and weed control treatments at 60 DAS were significant during 2023-24 (Table 4.1.3). Among planting patterns, weed dry weight (q ha^{-1}) recorded in flat sowing *fb* earthing up was found to be significantly less as compared to all other planting patterns. Two rows per bed recorded significantly less weed dry weight as compared to ridge sowing and flat sowing planting methods. Significantly higher weed dry weight was observed in flat sowing as compared to all other planting patterns. Among weed control treatments, hand weeding *fb* rice straw mulch recorded significantly less weed dry weight than all other weed control treatments. Weed dry weight was significantly higher in unweeded (control) than all other weed control treatments. During 2024-2025, among planting patterns, weed dry weight (q ha^{-1}) recorded in two rows per bed was significantly lower as compared to all other planting patterns (Table 4.1.3). Significantly higher weed dry weight (q ha^{-1}) was found in flat sowing as compared to all other planting patterns. Among weed control treatments, hand weeding *fb* rice straw mulch recorded significantly lower weed dry weight (q ha^{-1}) than all other weed control treatments. Weed dry weight was significantly less in black plastic mulch as compared to white plastic mulch treatment. Weed dry weight was significantly higher in unweeded (control) than all other weed control treatments.

At 90 DAS, the differences in weed dry weight (q ha^{-1}) were significant among planting patterns and weed control treatments during 2023-24 as shown in Table 4.1.3.

Among planting patterns, flat sowing *fb* earthing up method recorded significantly less weed dry weight as compared to all other planting patterns. However, significantly higher weed dry weight (q ha^{-1}) was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed dry weight (q ha^{-1}) was found to be significantly less in black plastic mulch as compared to all other weed control treatments. White plastic mulch treatment recorded significantly less weed dry weight as compared to hand weeding *fb* rice straw mulch. Weed dry weight (q ha^{-1}) was significantly higher in unweeded (control) than all other weed control treatments. During 2024-25, the differences in weed dry weight (q ha^{-1}) were found to be significant for planting patterns and weed control treatments (Table 4.1.3). Among planting patterns, flat sowing *fb* earthing up recorded significantly less weed dry weight as compared to ridge sowing and flat sowing methods. Moreover, ridge sowing recorded significantly less weed dry weight as compared to flat sowing. Significantly higher weed dry weight (q ha^{-1}) was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed dry weight was found to be significantly less in black plastic mulch as compared to all other weed control treatments. White plastic mulch treatment recorded significantly less weed dry weight as compared to hand weeding *fb* rice straw mulch. Weed dry weight was significantly higher in unweeded (control) than all other tried weed control treatments.

At 120 DAS, the differences in weed dry weight (q ha^{-1}) were significant for planting patterns and weed control treatments during 2023-24 (Table 4.1.3). Among planting patterns, flat sowing *fb* earthing up recorded significantly lower weed dry weight as compared to all other planting patterns. Weed dry weight (q ha^{-1}) in ridge sowing was found to be significantly less than flat sowing planting patterns. However, significantly higher weed dry weight (q ha^{-1}) was found in flat sowing as compared to all other tried methods. Among weed control treatments, weed dry weight was significantly less in black plastic mulch as compared to all other weed control treatments. Significantly less weed dry weight was found in white plastic mulch as compared to hand weeding *fb* straw mulch treatment. Weed dry weight was significantly higher in unweeded (control) than all other treatments. During 2024-25, the differences in dry matter of weeds (q ha^{-1}) were found to be significant for

planting patterns and weed control treatments (Table 4.1.3). Among planting patterns, weed dry weight recorded in flat sowing *fb* earthing up was significantly less than all other planting patterns. Two rows per bed recorded statistically at par weed dry weight with ridge sowing method. The weed dry weight (q ha^{-1}) in flat sowing was found to be significantly higher as compared to all other planting patterns. Among weed control treatments, weed dry weight was significantly lower in black plastic mulch as compared to all other weed control treatments. Significantly higher weed dry weight (q ha^{-1}) was found in unweeded (control) than all other tried weed control treatments.

At harvest, the differences in weed dry weight (q ha^{-1}) were found to be significant for planting patterns and weed control treatments during 2023-24 (Table 4.1.3). Among planting patterns, weed dry weight in flat sowing *fb* earthing up was significantly less as compared to all other planting patterns. Weed dry weight recorded in ridge sowing was statistically at par with two rows per bed. However, significantly higher weed dry weight was found in flat sowing as compared to all other planting patterns. Among weed control treatments, weed dry weight was significantly less in black plastic mulch as compared to all other weed control treatments (Table 4.1.3). White plastic mulch recorded statistically at par weed dry weight with hand weeding *fb* straw mulch. Weed dry weight was significantly higher in unweeded (control) than all other treatments. During 2024-25, the differences in weed dry weight (q ha^{-1}) were significant for planting patterns and weed control treatments (Table 4.1.3). Among planting patterns, flat sowing *fb* earthing up recorded significantly lower weed dry weight as compared to all other planting patterns. However, the weed dry weight in the planting pattern of two rows per bed was statistically at par with ridge sowing. Significantly higher weed dry weight was found in flat sowing method as compared to flat sowing *fb* earthing up. Among weed control treatments, weed dry weight (q ha^{-1}) in black plastic mulch was significantly lower as compared to all other planting patterns. The weed dry weight was significantly higher in unweeded (control) than all other weed control treatments.

The planting patterns of flat sowing *fb* earthing up and bed sowing with two rows resulted in less weed dry matter which may be due to uprooting of weeds by earthing

up and deep burial of weed seeds in the soil respectively. Similar findings were reported by Sharifi *et al.* (2022). Less dry matter of weeds in plastic mulches treatments were found due to suppression of germination of weed seeds as well as their initial growth which resulted in lowering the weed density. Moreover, there was more mortality of weed seedlings in plastic mulch treatments. Mulching acts as a physical barrier, which inhibited the light interception, and reduce overall weed biomass. These findings were similar with Meena *et al.* (2024). All the weed-control measures significantly reduced the total mean weed density as compared to unweeded (control) which may be due to uninterrupted growth of weeds in unweeded (control).

The interactive effect of planting patterns and weed control treatments on weed dry weight (q ha^{-1}) was found to be non-significant at 60, 90 DAS and at harvest during both years, however, it was significant at 120 DAS during both years (Table 4.1.4). During 2023-24, flat sowing *fb* earthing up integrated with hand weeding *fb* straw mulch recorded significantly less weed dry weight (q ha^{-1}) than flat sowing with white plastic mulch. Weed dry weight in two rows per bed with white plastic mulch was significantly less than flat sowing with white plastic mulch. Flat sowing *fb* earthing up integrated with white plastic mulch recorded significantly less weed dry weight as compared flat sowing with the treatment of black plastic mulch. The planting pattern of flat sowing *fb* earthing up with black plastic mulch recorded significantly less dry weight of weeds than two rows per bed with the treatment of hand weeding *fb* straw mulch. During 2024-25, weed dry weight (q ha^{-1}) recorded in flat sowing *fb* earthing up with white plastic mulch was significantly less as compared to flat sowing with white plastic mulch treatment. Significantly less weed dry weight was recorded in flat sowing *fb* earthing up with black plastic mulch treatment as compared to two rows per bed with white plastic mulch. Flat sowing *fb* earthing up with black plastic mulch recorded significantly less weed dry weight (q ha^{-1}) as compared to hand weeding *fb* straw mulching under similar planting pattern. The planting pattern of two rows per bed with black plastic mulch recorded significantly less dry weight of weeds than ridge sowing with white mulch treatment.

Table 4.1.3 Effect of planting patterns and weed control treatments on weed dry matter (q ha^{-1}) at 60, 90, 120 DAS and at harvest

Treatment details	Weed dry matter (q ha^{-1})							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	1.6 (2)	1.6 (3)	2.6 (10)	2.4 (7)	3.9 (22)	4.7 (30)	4.5 (25)	5.1 (33)
Ridge sowing (45 cm)	1.8 (3)	1.7 (2)	3.1 (13)	2.6 (8)	4.4 (27)	4.8 (31)	4.7 (28)	5.2 (34)
Flat sowing (45 cm) <i>fb</i> earthing up	1.3 (1)	1.8 (3)	2.1 (4)	2.1 (5)	3.3 (14)	3.9 (19)	4.1 (21)	4.5 (25)
Flat sowing (45 cm)	2.3 (6)	2.2 (5)	3.4 (16)	2.8 (9)	4.7 (30)	5.3 (36)	5.2 (34)	5.3 (36)
SE(m)±	0.02	0.02	0.04	0.04	0.05	0.05	0.08	0.06
C.D. (5%)	0.08	0.05	0.13	0.11	0.18	0.18	0.27	0.20
Sub-plots (Weed control treatments)								
Black plastic mulch	1.2 (1)	1.2 (1)	1.5 (1)	1.3 (1)	2.2 (4)	2.3 (4)	3.0 (8)	2.7 (6)
White plastic mulch	1.7 (2)	1.6 (2)	1.9 (3)	1.5 (1)	2.5 (5)	2.6 (6)	3.3 (10)	2.9 (8)
Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	1.0 (0)	1.0 (0)	1.9 (3)	2.4 (5)	2.9 (8)	4.6 (20)	3.4 (11)	4.7 (21)
Unweeded (control)	3.1 (9)	3.5 (12)	5.9 (37)	4.7 (22)	8.7 (76)	9.3 (86)	8.9 (78)	9.7 (94)
SE(m)±	0.02	0.01	0.03	0.04	0.08	0.04	0.08	0.05
C.D. (5%)	0.07	0.04	0.09	0.11	0.24	0.11	0.23	0.14
Interaction C.D. (5%)	NS	NS	NS	NS	0.49	0.24	NS	NS
Note: Values within parenthesis are original values and without parentheses are transformed values. Data was subjected to square root transformation ($\sqrt{x+1}$) by adding one to original values for statistical analysis.								

Table 4.1.4 Interactive effect of planting patterns and weed control treatments on weed dry matter (q ha^{-1}) at 120 DAS during 2023-24 and 2024-25

Weed dry matter (q ha^{-1}) - 2023-24

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	Unweeded (control)	Mean A
Two rows per bed (90 cm)	2.1	2.2	2.7	8.7	3.9
Ridge sowing (45 cm)	2.3	2.5	3.3	9.5	4.4
Flat sowing (45 cm) <i>fb</i> earthing up	1.8	2.1	2.4	6.7	3.3
Flat sowing (45 cm)	2.6	3.1	3.3	9.9	4.7
Mean B	2.2	2.5	2.9	8.7	
SE(m)±	0.10				
C.D. (5%)	0.49				

Weed dry matter (q ha^{-1}) - 2024-25

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5t ha^{-1})	Unweeded (control)	Mean A
Two rows per bed (90 cm)	2.3	2.5	4.4	9.7	4.7
Ridge sowing (45 cm)	2.3	2.6	4.7	9.7	4.8
Flat sowing (45 cm) <i>fb</i> earthing up	2.0	2.5	3.6	7.6	3.9
Flat sowing (45 cm)	2.6	2.9	5.6	10.0	5.3
Mean B	2.3	2.6	4.6	9.3	
SE(m)±	0.11				
C.D. (5%)	0.24				

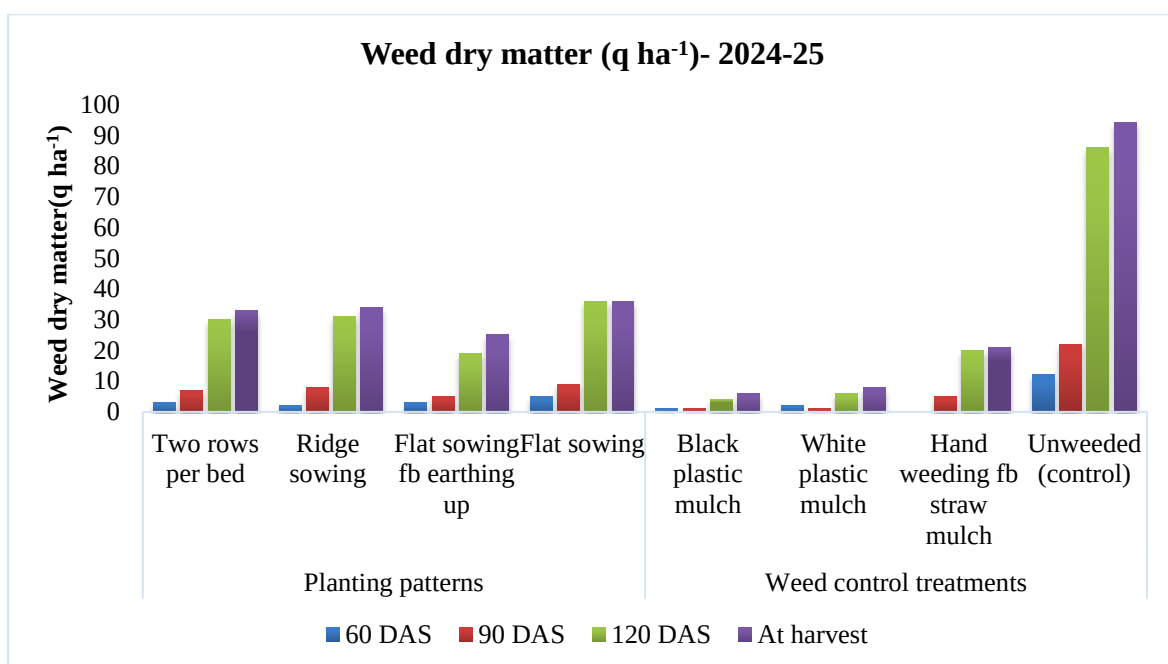
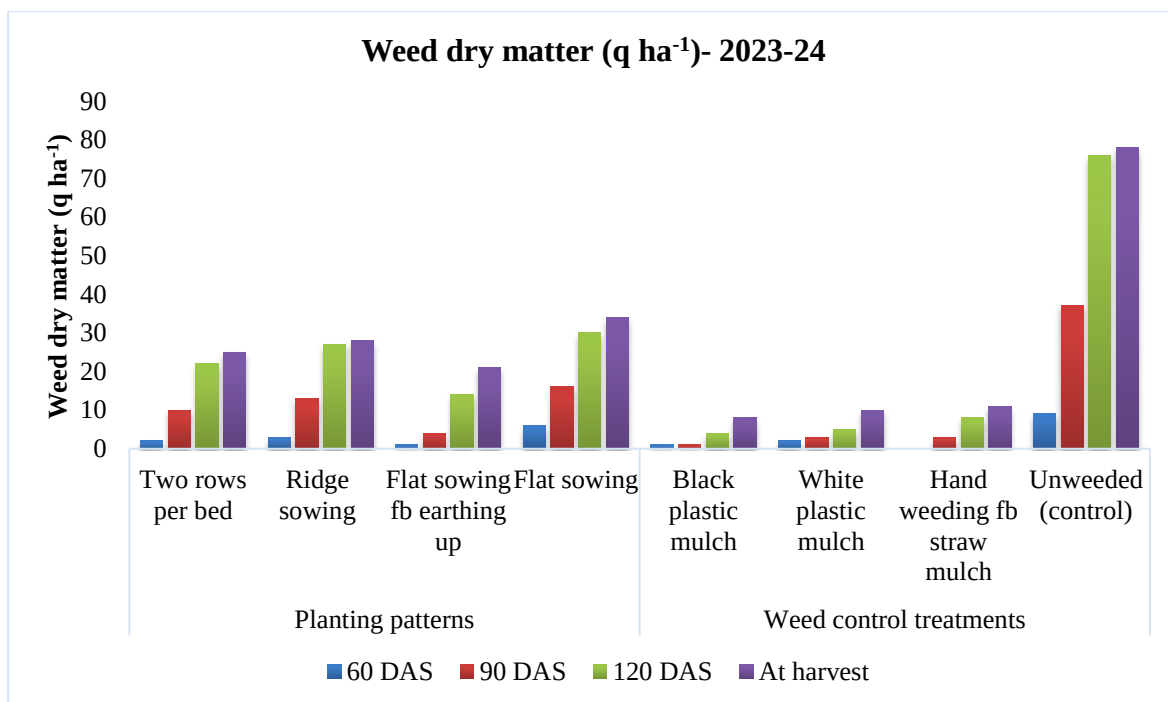


Figure 4.1.1 Effect of planting patterns and weed control treatments on weed dry matter (q ha⁻¹) at 60, 90, 120 DAS and at harvest.

4.1.3 Weed control efficiency (%)

Weed control efficiency (%) was calculated as follows:

$$\text{WCE (\%)} = \frac{X - Y}{X} \times 100$$

X= Weed dry weight (q ha⁻¹) in weedy check (control) plot

Y= Weed dry weight (q ha⁻¹) in treatment for which WCE is to be calculated.

The data for this parameter was not analysed statistically.

The data presented in Table 4.1.5 shows the effect of planting patterns and weed control treatments on weed control efficiency (WCE) at harvest during 2023-24 and 2024-2025 respectively.

During 2023-24, among planting patterns, flat sowing *fb* earthing up recorded highest weed control efficiency (73.78%) followed by two rows per bed (68.54%). Weed control efficiency (%) in flat sowing was lowest (56.9%) among all the planting patterns. Among weed control treatments, black plastic mulch treatment recorded highest weed control efficiency (89.89%) followed by white plastic mulch (87.72%). Lowest weed control efficiency (85.93%) was observed in hand weeding *fb* straw mulch. During 2024-25, weed control efficiency in flat sowing *fb* earthing up (72.78%) was highest among all the planting patterns (Table 4.1.5). Weed control efficiency in two rows per bed (64.56%) was higher than ridge sowing (63.28%). Lowest weed control efficiency (61.25%) was found in flat sowing among the planting patterns. Among weed control treatments, black plastic mulch recorded highest weed control efficiency (93.16%) followed by white plastic mulch treatment (91.78%). Hand weeding *fb* straw mulch recorded lowest weed control efficiency (77.16%) compared to other mulching treatments.

Among planting patterns, higher weed control efficiency was recorded in flat sowing *fb* earthing up and among weed control treatments it was in black plastic mulch treatment which may be due to less weed growth and biomass due to better suppression of weeds effectively in these treatments. Weeds were controlled more efficiently in these treatments which may be due to uprooting of weeds with earthing up and better soil conditions due to black plastic mulch which favoured better crop

growth. These findings were in line with Kumar *et al.* (2023) and Pagadhal *et al.* (2022).

Table 4.1.5 Effect of planting patterns and weed control treatments on weed control efficiency (%) at harvest

	Weed control efficiency (%)	
	At harvest	
	2023-24	2024-25
Main plots (Planting patterns)		
Two rows per bed (90 cm)	68.54	64.56
Ridge sowing (45 cm)	64.32	63.28
Flat sowing (45 cm) <i>fb</i> earthing up	73.78	72.78
Flat sowing (45 cm)	56.90	61.25
Sub-plots (Weed control treatments)		
Black plastic mulch	89.89	93.16
White plastic mulch	87.72	91.78
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	85.93	77.16
Unweeded (control)	-	-
Note: Weed control efficiency was calculated from weed dry matter at harvest. Data for WCE (%) was not analysed statistically.		

4.2 Crop growth parameters

Crop growth parameters are essential indicators of the crop's physiological condition, developmental stage, and yield potential. Together, these characteristics provide information on how the crop reacts to resource availability, environmental factors, and agronomic techniques. Among these, plant height, dry matter accumulation and development of branches are especially important for assessing growth dynamics and estimating production.

4.2.1 Plant height (cm)

The data presented in Table 4.2.1 and graphically depicted in Fig 4.2.1. indicates that differences in crop plant height (cm) due to planting patterns and weed control treatments recorded at 60, 90, 120 DAS and at harvest was found to be significant during both the years.

The differences in plant height (cm) due to planting patterns and weed control treatments at 60 DAS was found to be significant during the year 2023-24 (Table 4.2.1). Among planting patterns, the plant height was found to be significantly higher in two rows per bed as compared to all other planting patterns. However, flat sowing *fb* earthing up recorded significantly more plant height in comparison to ridge sowing method. Significantly less plant height (cm) was found in flat sowing as compared to all other planting patterns. Among weed control treatments, significantly more plant height (cm) was recorded in black plastic mulch as compared to all other weed control treatments. The treatment of white plastic mulch recorded significantly higher plant height (cm) as compared to hand weeding *fb* straw mulch. Plant height (cm) was significantly less in unweeded (control) than all other weed control treatments. Similar results were found during the year 2024-25 also for planting patterns and weed control treatments.

At 90 DAS, the differences in plant height (cm) was found to be significant for planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.1. Among planting patterns, two rows per bed recorded significantly more plant height as compared to ridge sowing and flat sowing. The plant height in flat

sowing *fb* earthing up was found to be statistically at par with the planting pattern of two rows per bed. However, significantly less plant height was found in flat sowing as compared to all other planting patterns. Among weed control treatments, plant height (cm) was found to be significantly higher in black plastic mulch as compared to all other weed control treatments. The treatment of white plastic mulch recorded significantly more plant height as compared to hand weeding *fb* straw mulch. Plant height (cm) was significantly less in unweeded (control) than all other treatments. During 2024-25, the differences in plant height (cm) were found to be significant for planting patterns and weed control treatments at 90 DAS (Table 4.2.1). Among planting patterns, two rows per bed recorded significantly higher plant height (cm) as compared to ridge sowing and flat sowing. The plant height in flat sowing *fb* earthing up was found to be statistically at par with the planting pattern of two rows per bed. Moreover, the plant height in ridge sowing, flat sowing and flat sowing *fb* earthing up methods were found to be statistically at par with each other. Significantly less plant height was found in flat sowing as compared to two rows per bed planting method. Among weed control treatments, plant height (cm) was found to be significantly higher in black plastic mulch as compared to all other weed control treatments. The treatment of white plastic mulch recorded significantly more plant height as compared to hand weeding *fb* straw mulch. Plant height was significantly less in unweeded (control) than all other treatments.

At 120 DAS, the differences in plant height (cm) were found to be significant for planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.1. Among planting patterns, flat sowing *fb* earthing up recorded significantly higher plant height as compared to ridge sowing and flat sowing. Plant height recorded in two rows per bed and flat sowing *fb* earthing up methods was found to be statistically at par with each other. The height of crop plants (cm) in ridge sowing was found to be statistically at par with the planting pattern of two rows per bed. However, significantly lower plant height was found in flat sowing as compared to all other planting patterns. Among weed control treatments, plant height (cm) was found to be significantly higher in black plastic mulch as compared to all other weed control treatments (Table 4.2.1). The treatment of white plastic mulch recorded

significantly more plant height as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Plant height (cm) was significantly less in unweeded (control) than all other weed control treatments. During 2024-25, the differences in plant height (cm) were found to be significant for planting patterns and weed control treatments (Table 4.2.1). Among planting patterns, two rows per bed recorded significantly higher plant height (cm) as compared to ridge sowing and flat sowing. The plant height in flat sowing *fb* earthing up was found to be statistically at par with the planting pattern of two rows per bed. The plant height in ridge sowing was found to be statistically at par with flat sowing *fb* earthing up method. Significantly less plant height was found in flat sowing as compared to two rows per bed and flat sowing *fb* earthing up planting patterns. Among weed control treatments, plant height (cm) was found to be significantly higher in black plastic mulch as compared to all other treatments. The treatment of white plastic mulch recorded significantly more plant height as compared to hand weeding *fb* straw mulch. Plant height was significantly less in unweeded (control) than all other tried weed control treatments.

At harvest, the differences in plant height (cm) were found to be significant for planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.1. Among planting patterns, flat sowing *fb* earthing up recorded significantly higher plant height as compared to flat sowing. The plant height (cm) in flat sowing *fb* earthing up was found at par with bed sowing and ridge sowing planting patterns. However, significantly less plant height was found in flat sowing as compared to flat sowing *fb* earthing up method. Among weed control treatments, plant height (cm) was found to be significantly higher in black plastic mulch as compared to hand weeding *fb* straw mulch treatment. The plant height in black plastic mulch and white plastic mulch was statistically at par with each other. The plant height in unweeded (control) was significantly less than all other weed control treatments. During 2024-25, the differences in plant height (cm) were found to be significant for planting patterns and weed control treatments (Table 4.2.1). Among planting patterns, two rows per bed recorded significantly higher plant height as compared to ridge sowing and flat sowing. However, the plant height in the treatment of two rows per bed was statistically at par with flat sowing *fb* earthing up. Significantly lower plant

height was found in flat sowing as compared to all other planting patterns. Among weed control treatments, plant height was found to be significantly higher in black plastic mulch as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. The plant height in black plastic mulch and white plastic mulch treatments were statistically at par with each other. The plant height was significantly less in unweeded (control) than all other tried weed control treatments.

From the results obtained during 2023-24 and 2024-25, it can be concluded that cultivation of fennel on raised beds or flat sowing *fb* earthing up methods, prevent crop lodging and provides better soil physical conditions for root growth which helps in better crop growth conditions, and thus helps to improve crop growth and hence plant height. Bed sowing or earthing up promotes better growth of fennel as compared to flat sowing. The reason might be improved physical soil conditions and better weed control. Similar results were reported by Singh *et al.*(2019). Black plastic mulch and white mulch treatments provided better growth conditions primarily due to higher weed suppression at initial stages and increased moisture retention ability of soil. Also, by blocking the sunlight, these mulches prevent weed seeds germination and inhibited weed growth, which reduces the overall competition for resources like water, nutrients, light and space. These findings were in line with Kumar *et al.* (2023) and Sharifi *et al.* (2022).

The interactive effect of planting patterns and weed control treatments on plant height (cm) was found to be non-significant at all periodic intervals during both the years (Table 4.2.1).

Table 4.2.1 Effect of planting patterns and weed control treatments on plant height (cm) at 60, 90, 120 DAS and at harvest

	Plant height (cm)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	36.2	36.9	92.3	89.4	127.9	150.6	158.4	168.9
Ridge sowing (45 cm)	31.6	33.6	83.3	85.4	123.6	142.5	156.1	163.6
Flat sowing (45 cm) <i>fb</i> earthing up	34.6	35.5	88.4	87.4	130.3	146.9	163.6	173.3
Flat sowing (45 cm)	29.6	31.2	78.9	84.4	114.4	141.0	150.4	158.4
SE(m)±	0.44	0.14	1.26	0.96	1.82	1.73	2.28	1.50
C.D. (5%)	1.53	0.45	4.46	3.11	6.40	5.61	8.04	4.88
Sub-plots (Weed control treatments)								
Black plastic mulch	41.1	42.7	109.2	107.0	147.3	170.1	175.2	187.2
White plastic mulch	38.0	39.3	97.3	101.4	139.3	163.6	172.2	183.8
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	28.6	30.5	75.7	77.5	117.3	139.6	157.4	168.6
Unweeded (control)	24.2	24.8	60.9	60.7	92.3	107.7	123.7	124.5
SE(m)±	0.50	0.32	1.19	0.93	1.05	2.21	2.08	1.80
C.D. (5%)	1.48	0.92	3.49	2.68	3.08	6.36	6.11	5.17
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS

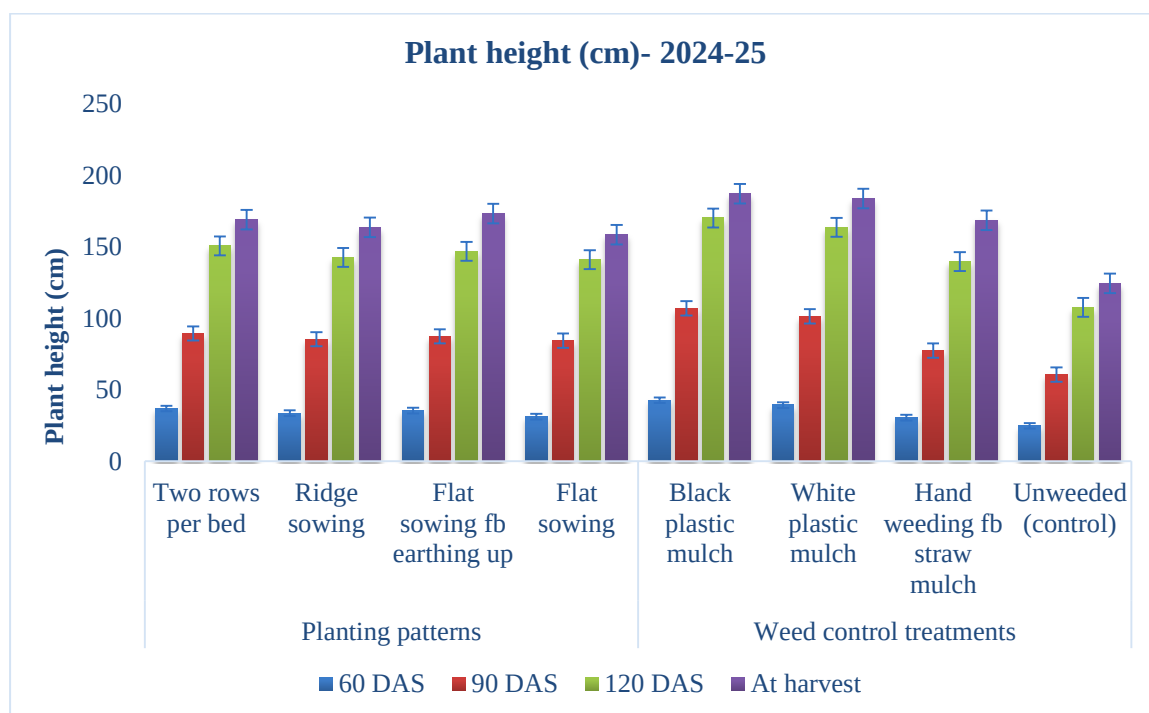
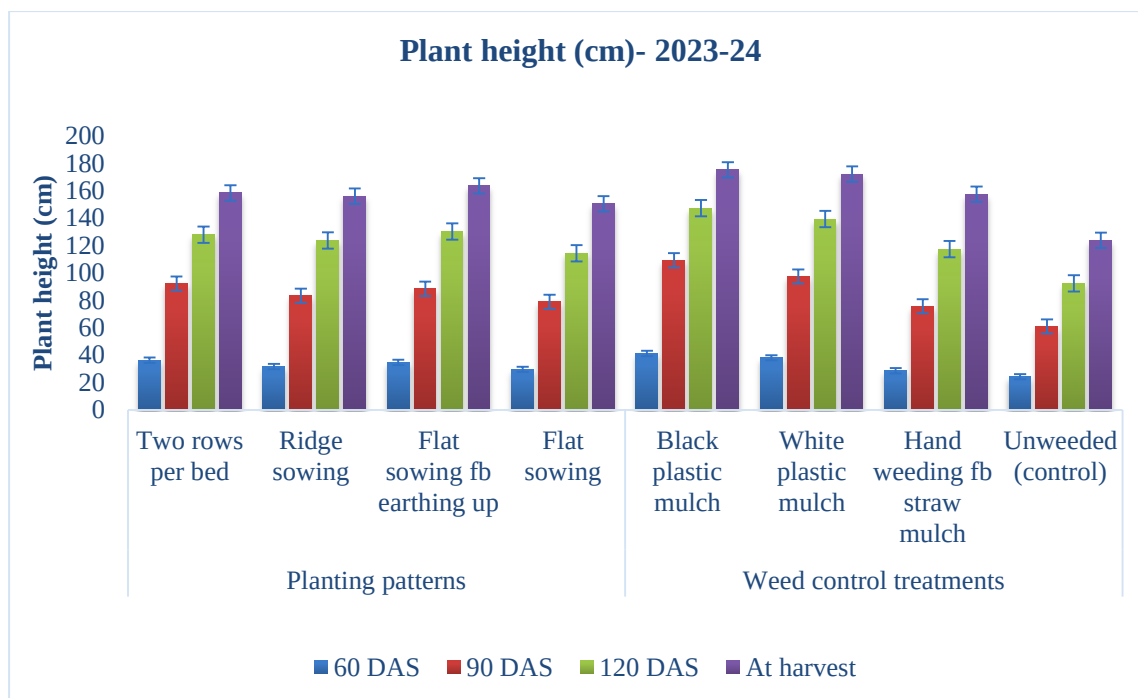


Figure 4.2.1 Effect of planting patterns and weed control treatments on plant height (cm) at 60, 90, 120 DAS and at harvest

4.2.2 Plant dry matter (g plant⁻¹)

The data presented in Table 4.2.2 (depicted in Figure 4.2.2) indicates that differences in plant dry matter (g plant⁻¹) due to planting patterns and weed control treatments recorded at 60, 90, 120 DAS and at harvest was found to be significant during both the years.

The differences in plant dry weight (g plant⁻¹) due to planting patterns and weed control treatments at 60 DAS was significant during the year 2023-24. Among planting patterns, plant dry weight was significantly more in two rows per bed treatment as compared to all other planting methods (Table 4.2.2). However, flat sowing *fb* earthing up recorded significantly more plant dry weight in comparison to ridge sowing and flat sowing methods. Significantly less plant dry matter was recorded in flat sowing than bed sowing and flat sowing *fb* earthing up methods. Among weed control treatments, significantly more plant dry weight (g plant⁻¹) was recorded in black plastic mulch as compared to all other weed control treatments. The white plastic mulch treatment recorded significantly better plant dry matter as compared to hand weeding *fb* straw mulch (5 t ha⁻¹). Plant dry weight was significantly less in unweeded (control) than all other weed control treatments. Similar findings were observed during 2024-25 also except that unweeded (control) recorded significantly less plant dry matter than all other weed control treatments.

At 90 DAS, the differences in plant dry matter (g plant⁻¹) were significant for planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.2. Among planting patterns, two rows per bed recorded significantly higher plant dry matter (g plant⁻¹) as compared to all other planting methods. The plant dry matter in flat sowing *fb* earthing up was significantly more than ridge sowing and flat sowing methods. However, significantly less plant dry matter was observed in flat sowing as compared to two rows per bed and flat sowing *fb* earthing up. Among weed control treatments, plant dry matter (g plant⁻¹) was significantly higher in black plastic mulch as compared to all other weed control treatments. The plant dry matter recorded in white plastic mulch was statistically at par with hand weeding *fb* straw mulch treatment. Plant dry weight was significantly less in unweeded (control) than all other weed control treatments. During 2024-25, among planting patterns, two rows per bed

recorded significantly higher plant dry matter (g plant^{-1}) as compared to all other planting patterns. The plant dry matter in flat sowing *fb* earthing up was significantly more than ridge sowing and flat sowing planting patterns. Flat sowing recorded significantly less plant dry matter as compared to all other planting patterns. Among weed control treatments, plant dry weight (g plant^{-1}) in black plastic mulch was statistically at par with white plastic mulch treatment. The hand weeding *fb* straw mulch treatment recorded significantly less plant dry weight as compared to black plastic mulch and white plastic mulch treatment. Plant dry weight was significantly less in unweeded (control) than all other weed control treatments.

At 120 DAS, the differences in plant dry matter (g plant^{-1}) were significant among planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.2. Among planting patterns, flat sowing *fb* earthing up recorded significantly higher plant dry weight as compared to all other planting patterns. Plant dry matter recorded in two rows per bed was significantly more than ridge sowing and flat sowing methods. The plant dry weight in ridge sowing method was found to be statistically at par with flat sowing. Among weed control treatments, plant dry weight (g plant^{-1}) was found to be significantly higher in black plastic mulch as compared to all other weed control treatments. The treatment of white plastic mulch recorded significantly more plant dry weight (g plant^{-1}) as compared to hand weeding *fb* straw mulch. Plant dry matter was significantly less in unweeded (control) than all other treatments. During 2024-25, the differences in plant dry weight (g plant^{-1}) were significant among planting patterns and weed control treatments (Table 4.2.2). Among planting patterns, flat sowing *fb* earthing up recorded significantly higher plant dry weight as compared to all other planting patterns. Plant dry weight recorded in two rows per bed was significantly more than ridge sowing and flat sowing methods. The plant dry weight in ridge sowing was significantly less than flat sowing *fb* earthing up and two rows per bed planting patterns. Significantly less plant dry weight was recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, plant dry weight was found to be significantly higher in black plastic mulch as compared to all other treatments. The white plastic mulch recorded significantly more plant dry weight as compared to hand weeding *fb* straw mulch

treatment. Plant dry weight recorded in unweeded (control) was significantly less than all tried weed control treatments.

At harvest, the differences in plant dry weight (g plant^{-1}) were found to be significant for planting patterns and weed control treatments during the year 2023-24 as shown in Table 4.2.2. Among planting patterns, plant dry weight in flat sowing *fb* earthing up was found to be statistically at par with the planting pattern of two rows per bed. Significantly more plant dry weight was recorded in ridge sowing than flat sowing method. However, significantly less plant dry weight was found in flat sowing as compared to all other planting patterns. Among weed control treatments, plant dry weight (g plant^{-1}) was found to be significantly higher in black plastic mulch as compared to all other weed control treatments. The plant dry weight in white plastic mulch was significantly more than hand weeding *fb* straw mulch treatment. Significantly less plant dry weight was recorded in hand weeding *fb* straw mulch as compared to black plastic mulch and white plastic mulch treatments. The plant dry weight was significantly less in unweeded (control) than all other weed control treatments. During 2024-25, among planting patterns, significantly higher plant dry weight was recorded in flat sowing *fb* earthing up as compared to all other planting methods (Table 4.2.2). Plant dry weight (g plant^{-1}) in two rows per bed was significantly more than ridge sowing and flat sowing methods. However, the plant dry weight in the ridge sowing was significantly more than flat sowing method. Significantly less plant dry weight was found in flat sowing as compared to all other planting methods. Among weed control treatments, plant dry weight (g plant^{-1}) was found to be significantly higher in black plastic mulch as compared to all other treatments. Plant dry weight recorded in white plastic mulch was significantly more than hand weeding *fb* straw mulch treatment. Plant dry weight was significantly less in unweeded (control) than all other weed control treatments.

From the results obtained during both years, it can be concluded that bed sowing and flat sowing *fb* earthing up planting methods recorded significantly higher plant dry matter than flat sowing due to the creation of better soil conditions under these methods which favoured faster crop growth as compared to flat sown crop. The dry matter per plant was higher in black mulch and white mulch treatments due to lesser

crop- weed competition which resulted in better utilization of moisture, nutrients and light under these treatments. These findings are in agreement with Persiani *et al.* (2025) and Meena *et al.* (2024).

The interactive effect of planting patterns and weed control treatments on plant dry weight (g plant^{-1}) was found to be non-significant at 60 DAS and 90 DAS during both the years (Table 4.2.3). During 2023-24, the interactive effect on plant dry weight was non-significant at 120 DAS and at harvest. However, it was significant both at 120 DAS and at harvest during 2024-25 (Table 4.2.3). At 120 DAS, flat sowing *fb* earthing up integrated with black plastic mulch recorded significantly higher plant dry matter as compared to application of white plastic mulch under the same planting pattern. Two rows per bed with black plastic mulch recorded significantly more plant dry weight (g plant^{-1}) as compared to flat sowing *fb* earthing up in combination with white plastic mulch. The plant dry weight recorded in ridge sowing with white plastic mulch was found to be statistically at par with flat sowing *fb* earthing up in combination with hand weeding *fb* straw mulch. Significantly less plant dry weight (g plant^{-1}) was produced in combination of flat sowing with unweeded (control) as compared to bed sowing as well as flat sowing *fb* earthing up methods under similar weed control methods. At harvest, flat sowing *fb* earthing up with white plastic mulch recorded statistically at par plant dry weight with two rows per bed with black plastic mulch treatment. The plant dry weight (g plant^{-1}) recorded in flat sowing *fb* earthing up in combination with hand weeding *fb* straw mulch was found to be statistically at par with flat sowing with black plastic mulch treatment. Under unweeded (control) conditions, significantly less plant dry weight was recorded in flat sowing (cm) as compared to flat sowing *fb* earthing up and bed sowing under similar weed control method.

Table 4.2.2 Effect of planting patterns and weed control treatments on plant dry matter (g plant⁻¹) at 60, 90, 120 DAS and at harvest

	Plant dry matter (g plant ⁻¹)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	1.31	1.46	27.8	30.5	90.6	93.5	171.2	257.6
Ridge sowing (45 cm)	0.86	1.09	17.4	26.3	65.3	81.1	135.6	230.1
Flat sowing (45 cm) <i>fb</i> earthing up	1.05	1.29	22.3	28.7	105.8	103.2	188.7	290.0
Flat sowing (45 cm)	0.73	0.91	15.4	23.0	51.5	74.1	111.4	210.8
SE(m)±	0.05	0.02	0.66	0.53	3.95	0.92	6.50	4.37
C.D. (5%)	0.17	0.06	2.34	1.72	13.94	2.99	22.94	14.16
Sub-plots (Weed control treatments)								
Black plastic mulch	1.68	1.84	30.7	37.2	122.3	130.4	243.5	340.0
White plastic mulch	1.31	1.51	23.0	36.1	90.2	105.4	178.3	314.6
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	0.54	0.78	21.2	21.6	70.1	76.8	132.2	263.6
Unweeded (control)	0.43	0.62	8.1	13.6	30.6	39.3	52.9	70.3
SE(m)±	0.06	0.02	0.91	0.39	4.67	0.94	6.87	4.71
C.D. (5%)	0.18	0.06	2.68	1.12	13.70	2.70	20.18	13.58
Interaction C.D. (5%)								
Interaction C.D. (5%)	NS	NS	NS	NS	NS	5.57	NS	27.92

Table 4.2.3 Interactive effect of planting patterns and weed control treatments on plant dry matter (g plant⁻¹) at 120 DAS and at harvest during 2024-25

Plant dry matter (g plant⁻¹) - 120 DAS (2024-25)

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	140.2	108.7	85.4	39.9	93.5
Ridge sowing (45 cm)	127.8	99.9	62.5	34.3	81.1
Flat sowing (45 cm) <i>fb</i> earthing up	146.9	114.6	98.1	53.1	103.2
Flat sowing (45 cm)	106.9	98.4	61.2	30.1	74.1
Mean B	130.4	105.4	76.8	39.3	
SE(m)±	1.85				
C.D. (5%)	5.57				

Plant dry matter (g plant⁻¹) - At harvest (2024-25)

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	352.0	340.2	287.3	51.0	257.6
Ridge sowing (45 cm)	337.1	287.3	258.4	37.9	230.1
Flat sowing (45 cm) <i>fb</i> earthing up	357.3	351.6	289.9	161.3	290.0
Flat sowing (45 cm)	313.6	279.4	219.0	31.3	210.8
Mean B	340.0	314.6	263.6	70.3	
SE(m)±	8.73				
C.D. (5%)	27.92				

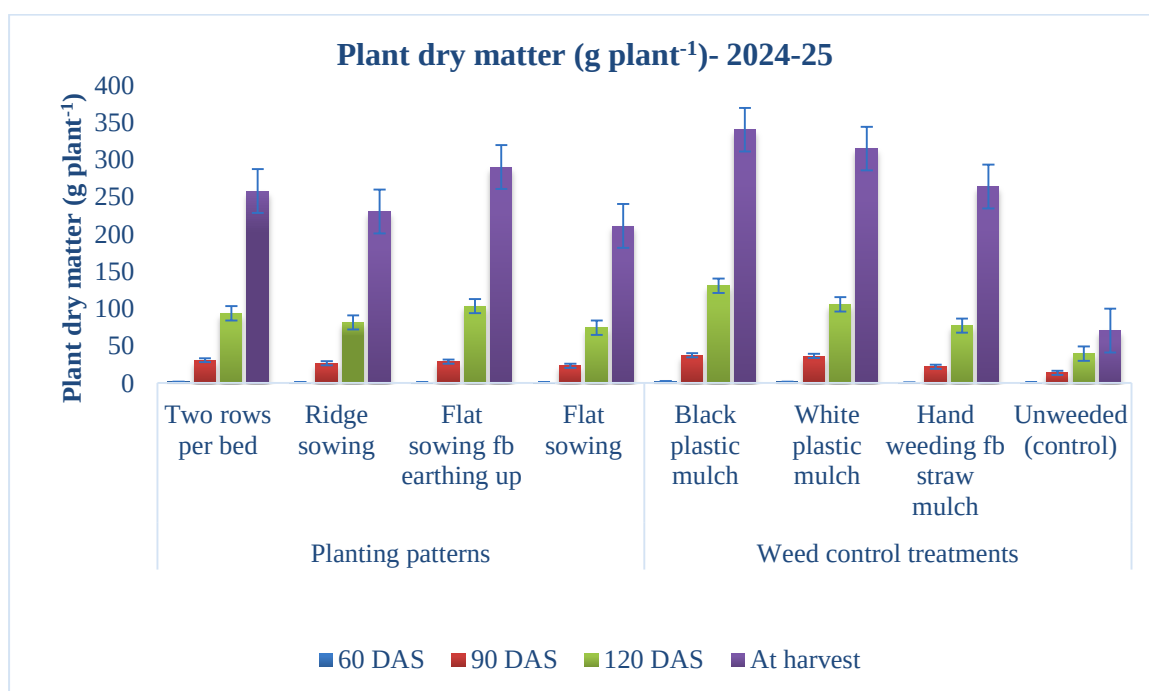
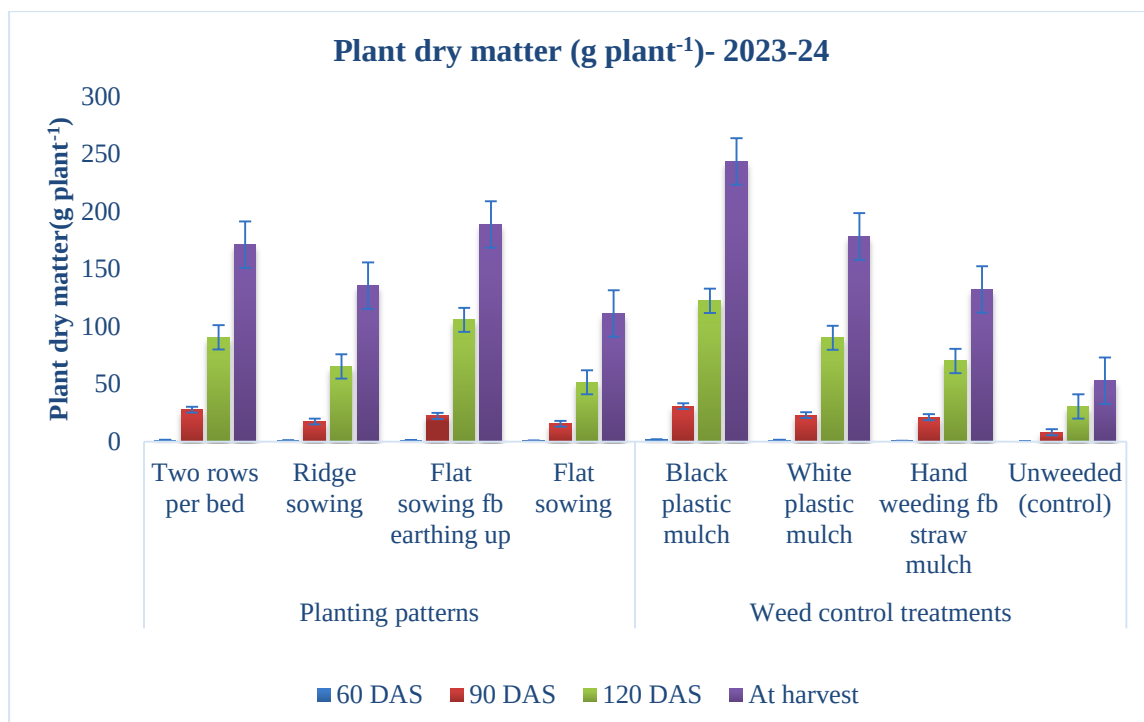


Figure 4.2.2 Effect of planting patterns and weed control treatments on plant dry matter (g plant⁻¹) at 60, 90, 120 DAS and at harvest

4.2.3 Number of plants per meter row length

The data on effect of various planting patterns and weed control treatments on number of plants per meter row length recorded at 60, 90, 120 DAS and at harvest are presented in Table 4.2.4.

At 60 DAS, the differences in number of plants per meter row length were found to be non-significant among various planting patterns during 2023-24 and 2024-25 (Table 4.2.4). Among the weed control treatments, number of plants per meter row in black plastic mulch treatment were statistically at par with white plastic mulch during both years. Black mulch and white mulch treatments recorded significantly more number of plants per meter row length as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Number of plants per meter row in hand weeding *fb* straw mulch and unweeded (control) were statistically at par with each other. Unweeded (control) recorded significantly less number of plants per meter row length as compared to black mulch and white plastic mulch treatments during both years.

At 90 DAS, the differences in number of plants per meter row length were found to be non-significant among various planting patterns during 2023-24 (Table 4.2.4). Among the weed control treatments, number of plants per meter row length in black plastic mulch were statistically at par with white plastic mulch treatment. Black mulch and white mulch treatment recorded significantly more number of plants per meter row as compared to hand weeding *fb* straw mulch and unweeded (control). Number of plants per meter row in hand weeding *fb* straw mulch and unweeded (control) were statistically at par with each other. Unweeded (control) recorded significantly less number of plants per meter row length as compared to black mulch and white plastic mulch treatments. During 2024-2025, number of plants per meter row was non-significant among various planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher number of plants per meter row as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Number of plants per meter in white plastic mulch were found to be statistically at par with black plastic mulch treatment. Unweeded (control) recorded significantly less

number of plants per meter row length as compared to application of black or white plastic mulch treatments.

At 120 DAS, the differences in number of plants per meter row were found to be non-significant among various planting patterns during both years (Table 4.2.4). Among the weed control treatments, number of plants per meter row length during 2023-24 were statistically at par in black and white plastic mulch treatments. Black and white plastic mulch recorded significantly more number of plants per meter row as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Number of plants per meter row in hand weeding *fb* straw mulch and unweeded (control) were statistically at par with each other. Unweeded (control) recorded significantly less number of plants per meter row length as compared to black mulch and white plastic mulch treatments. Among weed control treatments, during 2024-25, black plastic mulch recorded significantly higher number of plants per meter row length as compared to hand weeding *fb* straw mulch treatment. Number of plants per meter row length in white plastic mulch were found to be statistically at par with black plastic mulch treatment. Unweeded (control) recorded significantly lower number of plants per meter row as compared to all other weed control treatments.

At harvest, the differences in number of plants per meter row were found to be non-significant among various planting patterns during 2023-24 (Table 4.2.4). Among the weed control treatments, number of plants per meter row in black plastic mulch were statistically at par with white plastic mulch treatment. Black and white plastic mulch recorded significantly more number of plants per meter row length as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less number of plants per meter row length as compared to all other weed control treatments. Similar findings were observed in 2024-2025 also (Table 4.2.4).

It can be concluded that number of plants per meter row length were found to be more in black and white plastic mulch treatments. This might be due to less crop weed competition and effective suppression of weeds from the very start of the crop growth. This allowed the crop to grow freely without competing for any resources like light, moisture, nutrients, space etc. Whereas, in unweeded (control) the weeds had reduced

the crop growth due to severe competition for resources, which led to mortality of crop plants and reduced the overall crop stand and hence yield was also reduced. Kaur *et al.* (2022) and Patil *et al.* (2020) also reported similar findings.

The interactive effect of planting patterns and weed control treatments on number of primary branches per plant were non-significant at 60, 90, 120 DAS and at harvest during both the years (Table 4.2.4).

Table 4.2.4 Effect of planting patterns and weed control treatments on number of plants per meter row length at 60, 90, 120 DAS and at harvest

	Number of plants per meter row length							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	5.29	5.42	5.25	5.25	5.25	5.13	4.90	4.79
Ridge sowing (45 cm)	5.21	5.25	5.38	5.17	5.33	5.21	4.85	4.75
Flat sowing (45 cm) <i>fb</i> earthing up	5.13	5.29	5.21	5.17	5.21	5.17	4.67	4.79
Flat sowing (45 cm)	5.25	5.25	5.17	5.17	5.13	5.04	4.55	4.54
SE(m)±	0.09	0.09	0.10	0.08	0.07	0.05	0.08	0.09
C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Sub-plots (Weed control treatments)								
Black plastic mulch	5.38	5.58	5.46	5.54	5.46	5.54	5.46	5.42
White plastic mulch	5.46	5.46	5.46	5.33	5.42	5.42	5.38	5.33
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	5.04	5.17	5.13	5.13	5.13	5.04	5.08	5.04
Unweeded (control)	5.00	5.00	4.96	4.75	4.92	4.54	3.04	3.08
SE(m)±	0.09	0.10	0.11	0.10	0.09	0.08	0.08	0.08
C.D. (5%)	0.25	0.28	0.31	0.29	0.26	0.23	0.23	0.23
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS

4.2.4 Number of primary branches (plant⁻¹)

The differences in number of primary branches plant⁻¹ were found to be significant at all periodic intervals among various planting patterns during 2024-25 and weed control treatments during 2023-2024 and 2024-2025 (Table 4.2.5).

At 90 DAS, the differences in number of primary branches (plant⁻¹) among planting patterns during 2023-2024 were non-significant (Table 4.2.5). Among weed control treatments, the number of primary branches in black and white plastic mulch treatments were statistically at par with each other. Hand weeding *fb* straw mulch recorded significantly less number of primary branches as compared to black plastic mulch and white plastic mulch treatments. Unweeded (control) produced significantly less number of primary branches as compared to all the other weed control treatments. During 2024-2025, the differences in number of primary branches were found to be significant among the various planting patterns and weed control treatments (Table 4.2.5). Two rows per bed and ridge sowing methods recorded significantly higher number of primary branches plant⁻¹ as compared to flat sowing method. The number of primary branches recorded in flat sowing *fb* earthing up were found to be statistically at par with two rows per bed and ridge sowing methods. Significantly less number of primary branches were recorded in flat sowing as compared to two rows per bed and ridge sowing planting patterns. Among weed control treatments, number of primary branches were significantly more in black plastic mulch as compared to other weed control treatments. White plastic mulch recorded significantly less number of primary branches (plant⁻¹) than black plastic mulch. Hand weeding *fb* straw mulch recorded significantly less number of primary branches as compared to black and white plastic mulch treatments. Significantly lower number of primary branches were produced by unweeded (control) as compared all other weed control treatments.

At 120 DAS, the differences in number of primary branches among various planting pattern were found to be non-significant during 2023-2024 (Table 4.2.5). Among the weed control treatments, number of primary branches in black plastic mulch treated crop were found to be statistically at par with white plastic mulch treatment. Hand weeding *fb* straw mulch recorded statistically at par number of primary branches

plant⁻¹ with white plastic mulch treated crop. Significantly lower number of primary branches (plant⁻¹) were recorded in unweeded (control) as compared to all other weed control treatments. During 2024-2025, the differences in number of primary branches among planting patterns were found to be significant (Table 4.2.5). Among planting patterns, significantly higher number of primary branches were recorded in two rows per bed as compared to ridge sowing and flat sowing. Flat sowing *fb* earthing up produced statistical at par number of primary branches with two rows per bed planting method. Significantly less number of primary branches were recorded in flat sowing as compared to all the other planting patterns. Among weed control treatments, number of primary branches recorded in black plastic mulch, white plastic mulch and hand weeding *fb* straw mulch treatments were found to be statistically at par with each other. Unweeded (control) produced significantly less number of primary branches as compared to all other weed control treatments.

At harvest, differences in number of primary branches plant⁻¹ were found to be significant among various planting patterns and weed control treatments during 2023-2024 (Table 4.2.5). Among planting patterns, two rows per bed recorded statistically at par number of primary branches (plant⁻¹) with flat sowing *fb* earthing and ridge sown crop. Significantly lower number of primary branches plant⁻¹ were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, number of primary branches plant⁻¹ produced in black plastic mulch, white plastic mulch and hand weeding *fb* straw mulch treatments were found to be statistically at par with each other. Unweeded (control) recorded significantly less number of primary branches as compared to other weed control treatments. During 2024-2025, among planting patterns, flat sowing *fb* earthing up recorded significantly higher number of primary branches as compared to other planting patterns (Table 4.2.5). Significantly more number of primary branches were observed in two rows per bed as compared to ridge sowing and flat sowing methods. Ridge sowing produced significantly less number of primary branches plant⁻¹ as compared to flat sowing *fb* earthing up and two rows per bed planting methods. Flat sowing produced significantly less number of primary branches plant⁻¹ as compared to all other planting patterns. Among weed control treatments, significantly higher number of primary

branches plant⁻¹ were found in black plastic mulch as compared to all other weed control treatments. White plastic mulch produced significantly more number of primary branches plant⁻¹ as compared to hand weeding *fb* straw treatment. The number of primary branches plant⁻¹ in unweeded (control) were significantly less as compared to all the other weed control treatments.

It can be concluded that number of primary branches were higher under earthing up and bed sowing treatment as compared to flat sowing treatment. The reason being that better soil conditions were obtained under these treatments and there was faster initial growth of crop and moreover, weeds were uprooted during earthing up. During the early growth stages, plastic mulch treatments provided weed free conditions for the crop growth assuring favourable crop growth factors like uptake of fertilizers and soil moisture effectively. Therefore, better crop growth was obtained under these treatments. Low weed density under effective treatments would have resulted in higher number of primary branches plant⁻¹. These findings were in line with Mamatha *et al.* (2021) and Farag and Abul-Soud (2020).

The interactive effect of planting patterns and weed control treatments on number of primary branches plant⁻¹ were non-significant at 90, 120 DAS and at harvest during both the years (Table 4.2.5).

Table 4.2.5 Effect of planting patterns and weed control treatments on number of primary branches plant⁻¹ at 90, 120 DAS and at harvest

	Number of primary branches plant ⁻¹					
	90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	6.0	6.6	7.5	10.4	10.1	9.0
Ridge sowing (45 cm)	5.4	6.4	7.5	9.7	9.7	8.5
Flat sowing (45 cm) <i>fb</i> earthing up	5.5	6.3	7.8	10.2	9.7	9.4
Flat sowing (45 cm)	5.1	5.7	6.8	9.3	9.2	7.8
SE(m)±	0.30	0.18	0.19	0.17	0.17	0.11
C.D. (5%)	NS	0.60	NS	0.55	0.60	0.36
Sub-plots (Weed control treatments)						
Black plastic mulch	6.3	7.6	8.4	11.5	10.3	10.5
White plastic mulch	6.1	6.6	8.0	11.4	9.9	9.3
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	5.2	6.1	7.6	9.8	9.6	8.8
Unweeded (control)	4.4	4.8	5.7	7.0	8.8	6.0
SE(m)±	0.20	0.09	0.15	0.14	0.27	0.16
C.D. (5%)	0.60	0.26	0.45	0.41	0.78	0.45
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.2.5 Number of secondary branches (plant⁻¹)

The differences in number of secondary branches plant⁻¹ were found to be significant among various planting patterns and weed control treatments during 2023-2024 and 2024-2025 (Table 4.2.6)

At 90 DAS, the differences in number of secondary branches plant⁻¹ among planting patterns and weed control treatment were significant during 2023-2024 (Table 4.2.6). Among planting patterns, flat sowing *fb* earthing up recorded statistically at par number of secondary branches plant⁻¹ with two rows per bed planting method. Significantly less number of secondary branches plant⁻¹ were recorded in ridge sowing and flat sowing method as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Flat sowing produced significantly less number of secondary branches as compared to all other planting methods. Among weed control treatments, number of secondary branches plant⁻¹ were significantly higher in black plastic mulch than other weed control treatments. White plastic mulch recorded significantly more number of secondary branches plant⁻¹ than hand weeding *fb* straw mulch and unweeded (control) treatments. Hand weeding *fb* straw mulch recorded significantly less number of secondary branches (plant⁻¹) as compared to black plastic mulch and white plastic mulch treatments. Unweeded (control) produced significantly less number of secondary branches plant⁻¹ as compared to all the other weed control treatments. Similar findings were recorded during 2024-25 also.

At 120 DAS, the differences in number of secondary branches plant⁻¹ were found to be significant among the various planting patterns during 2023-2024 (Table 4.2.6). Number of secondary branches plant⁻¹ in flat sowing *fb* earthing up were significantly higher than all other planting patterns. Two rows per bed recorded significantly more number of secondary branches as compared to ridge sowing and flat sowing planting patterns. The number of secondary branches recorded in ridge sowing were found to be significantly more than flat sowing method. Significantly less number of secondary branches were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, number of secondary branches plant⁻¹ were significantly higher in black plastic mulch as compared to other weed control

treatments. White plastic mulch recorded significantly less number of secondary branches than black plastic mulch treatment. Hand weeding *fb* straw mulch recorded significantly less number of secondary branches (plant^{-1}) as compared to black and white plastic mulch treatments. Significantly less number of secondary branches were produced by unweeded (control) as compared to all other weed control treatments. During 2024-2025, the differences in number of secondary branches (plant^{-1}) among planting patterns and weed control treatments were significant (Table 4.2.6). Among planting patterns, significantly higher number of secondary branches plant^{-1} were recorded in two rows per bed as compared to all other planting patterns. Flat sowing *fb* earthing up produced statistical at par number of secondary branches (plant^{-1}) with ridge sowing method. Significantly less number of secondary branches were recorded in flat sowing as compared to all the other planting patterns. Among weed control treatments, number of secondary branches were significantly higher in black plastic mulch as compared to other weed control treatments. White plastic mulch recorded significantly less number of secondary branches than black plastic mulch treatment. Hand weeding *fb* straw mulch recorded significantly less number of secondary branches plant^{-1} as compared to black plastic mulch and white plastic mulch treatments. Significantly less number of secondary branches plant^{-1} were produced by unweeded (control) as compared to all other weed control treatments.

At harvest, differences in number of secondary branches plant^{-1} were found to be significant among various planting patterns and weed control treatments during 2023-2024 (Table 4.2.6). Among planting patterns, two rows per bed recorded statistically at par number of secondary branches plant^{-1} with flat sowing *fb* earthing up method. Ridge sowing produced significantly more number of secondary branches than flat sowing planting pattern. Significantly lower number of secondary branches plant^{-1} were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, more number of secondary branches plant^{-1} were produced in black plastic mulch as compared to all other weed control treatments. White plastic mulch produced significantly more number of secondary branches plant^{-1} as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Unweeded (control) recorded significantly less number of secondary branches as compared to

other weed control treatments. During 2024-2025, among planting patterns, flat sowing *fb* earthing up recorded significantly higher number of secondary branches plant⁻¹ as compared to other planting patterns (Table 4.2.6). Significantly more number of secondary branches were observed in two rows per bed as compared to ridge sowing and flat sowing methods. Ridge sowing produced significantly less number of secondary branches plant⁻¹ as compared to flat sowing *fb* earthing up and two rows per bed planting methods. Flat sowing method produced significantly less number of secondary branches plant⁻¹ compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, significantly more number of secondary branches plant⁻¹ were found in black plastic mulch as compared to all other weed control treatments. White plastic mulch produced significantly more number of secondary branches plant⁻¹ as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. The number of secondary branches plant⁻¹ in unweeded (control) were significantly less as compared to all the other weed control treatments.

Number of secondary branches plant⁻¹ were significantly higher under earthing up and bed sowing planting patterns as compared to flat sowing due to the availability of better soil conditions and efficient utilization of nutrients and moisture by crop under these methods. The crop growing under weed free conditions resulted in better growth and development of roots as well as of plants. Higher number of secondary branches plant⁻¹ were obtained in both plastic mulch treatments which may be due to lesser crop-weed competition in these treatments. These results are consistent with the results obtained by Kolota and Sowinska (2013) and Gohil *et al.* (2015).

The interactive effect of planting patterns and weed control treatments for number of secondary branches plant⁻¹ were non-significant at 90, 120 DAS and at harvest during both the years (Table 4.2.6).

Table 4.2.6 Effect of planting patterns and weed control treatments on number of secondary branches plant⁻¹ at 90, 120 DAS and at harvest

	Number of secondary branches plant ⁻¹					
	90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	3.8	5.4	9.4	12.8	32.1	26.5
Ridge sowing (45 cm)	2.7	4.6	8.2	11.3	26.0	22.1
Flat sowing (45 cm) <i>fb</i> earthing up	3.7	5.1	10.3	11.9	31.2	30.3
Flat sowing (45 cm)	2.2	4.1	7.6	10.1	25.6	20.8
SE(m)±	0.13	0.14	0.13	0.26	0.44	0.77
C.D. (5%)	0.45	0.44	0.44	0.83	1.55	2.50
Sub-plots (Weed control treatments)						
Black plastic mulch	4.6	6.8	11.6	15.8	36.6	34.1
White plastic mulch	3.8	5.8	10.5	13.0	34.8	30.0
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	3.1	4.7	9.4	11.2	32.8	25.3
Unweeded (control)	1.0	1.8	4.0	6.1	10.7	10.3
SE(m)±	0.10	0.08	0.16	0.19	0.49	0.31
C.D. (5%)	0.31	0.23	0.47	0.55	1.44	0.90
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3 Yield parameters

The yield attributes are the important factors that influence the final seed yield and productive efficiency in fennel. These parameters, which include the number of umbels per plant, the number of umbellets per umbel, the number of seeds per umbel, 1000-seed weight, and seed yield, act as integrative indicators of the physiological performance of the plant as well as determines the effectiveness of agronomic practices. The yield attributes viz. number of umbels plant⁻¹, diameter of umbel (cm), number of umbellets per umbel, number of seeds per umbellet, seed weight per umbel (g), 1000 seed weight per main, primary and secondary umbel respectively, were recorded at harvest.

4.3.1 Number of primary and secondary umbels plant⁻¹

The number of primary and secondary umbels plant⁻¹ as influenced by various planting patterns and weed control treatments at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.1 and depicted in Figure 4.3.1.

The differences in number of primary umbels plant⁻¹ were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.1). Among planting patterns, the number of primary umbels plant⁻¹ in flat sowing *fb* earthing up and two rows per bed planting patterns were found to be statistically at par with each other. Ridge and flat sowing methods recorded significantly less number of primary umbels plant⁻¹ as compared to flat sowing *fb* earthing up and two rows per bed methods. The number of primary umbels plant⁻¹ in flat sowing technique were found at par with ridge sowing. Among weed control treatments, black plastic mulch and white plastic mulch treatments recorded statistically at par number of primary umbels plant⁻¹ with each other. Hand weeding *fb* straw mulch produced significantly less number of primary umbels plant⁻¹ as compared to black plastic mulch and white plastic mulch treatments. Significantly less number of primary umbels plant⁻¹ were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among the planting patterns, flat sowing *fb* earthing up produced significantly higher number of primary umbels as compared to all other planting patterns. The number of primary umbels plant⁻¹ in two rows per bed were found to be

statistically at par with ridge sowing method. Flat sowing recorded significantly less number of primary umbels plant^{-1} as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher number of primary umbels plant^{-1} as compared to all other weed control treatments. White plastic mulch produced significantly more number of primary umbels plant^{-1} as compared to hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of primary umbels plant^{-1} as compared to black and white plastic mulch treatments. Significantly less number of primary umbels plant^{-1} were observed in unweeded (control) as compared to all other weed control treatments

The differences in number of secondary umbels plant^{-1} were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.1). Among planting patterns, number of secondary umbels plant^{-1} recorded in flat sowing *fb* earthing up and two rows per bed were found to be statistically at par with each other but were significantly higher than ridge sowing and flat sowing methods. The number of secondary umbels plant^{-1} in flat sowing were found at par with ridge sowing method. Among weed control treatments, black and white plastic mulch treatments recorded statistically at par, number of secondary umbels plant^{-1} . Hand weeding *fb* straw mulch produced significantly less number of secondary umbels plant^{-1} as compared to black plastic mulch and white plastic mulch treatments. Significantly less number of secondary umbels plant^{-1} were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among the planting patterns, flat sowing *fb* earthing up produced significantly higher number of secondary umbels plant^{-1} as compared to all other planting patterns (Table 4.3.1). The number of secondary umbels in two rows per bed were found to be statistically at par with ridge sowing method. Flat sowing recorded significantly less number of secondary umbels plant^{-1} as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher number of secondary umbels plant^{-1} as compared to all other weed control treatments. Hand weeding *fb* straw mulch produced significantly less number of secondary umbels plant^{-1} as compared to both plastic mulch treatments.

Significantly less number of secondary umbels plant⁻¹ were observed in unweeded (control) as compared to all other weed control treatments.

From the results obtained, it was concluded that the number of primary and secondary umbels plant⁻¹ were higher in flat sowing *fb* earthing up treatment and among weed control treatments, these were higher in black plastic mulch which may be due to uprooting of weeds and creation of better soil physical conditions in earthing up planting pattern. Black mulch provided more than 90% control of weeds and hence better crop growth was obtained under this treatment. Also, there was more soil moisture conservation for better crop growth in the plastic mulch treatment apart from restriction in weed seed germination and growth. Therefore, above said treatments resulted in better utilization of available nutrients and moisture by the crop which in addition increased the yield attributes like number of primary and secondary umbels per plant. These findings were consistent with the results of Yadav *et al.* (2013) Meena and Mehta (2010).

The interactive effect of planting patterns and weed control treatments on number of primary umbels and number of secondary umbels was non-significant recorded at harvest during both years (Table 4.3.1).

Table 4.3.1 Effect of planting patterns and weed control treatments on number of primary and secondary umbels plant⁻¹

	Number of primary umbels plant ⁻¹		Number of secondary umbels plant ⁻¹	
	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)				
Two rows per bed (90 cm)	9.5	8.9	24.2	23.3
Ridge sowing (45 cm)	8.4	8.7	20.5	22.4
Flat sowing (45 cm) <i>fb</i> earthing up	9.2	9.6	25.7	25.5
Flat sowing (45 cm)	8.3	8.4	18.2	20.7
SE(m)±	0.16	0.17	0.44	0.58
C.D. (5%)	0.57	0.53	1.54	1.89
Sub-plots (Weed control treatments)				
Black plastic mulch	10.1	10.7	27.4	30.2
White plastic mulch	9.7	9.9	25.9	26.8
Hand weeding <i>fb</i> straw mulch (5t ha ⁻¹)	8.8	8.6	22.4	23.5
Unweeded (control)	6.9	6.3	13.0	11.3
SE(m)±	0.15	0.18	0.70	0.49
C.D. (5%)	0.43	0.52	2.06	1.41
Interaction C.D. (5%)	NS	NS	NS	NS

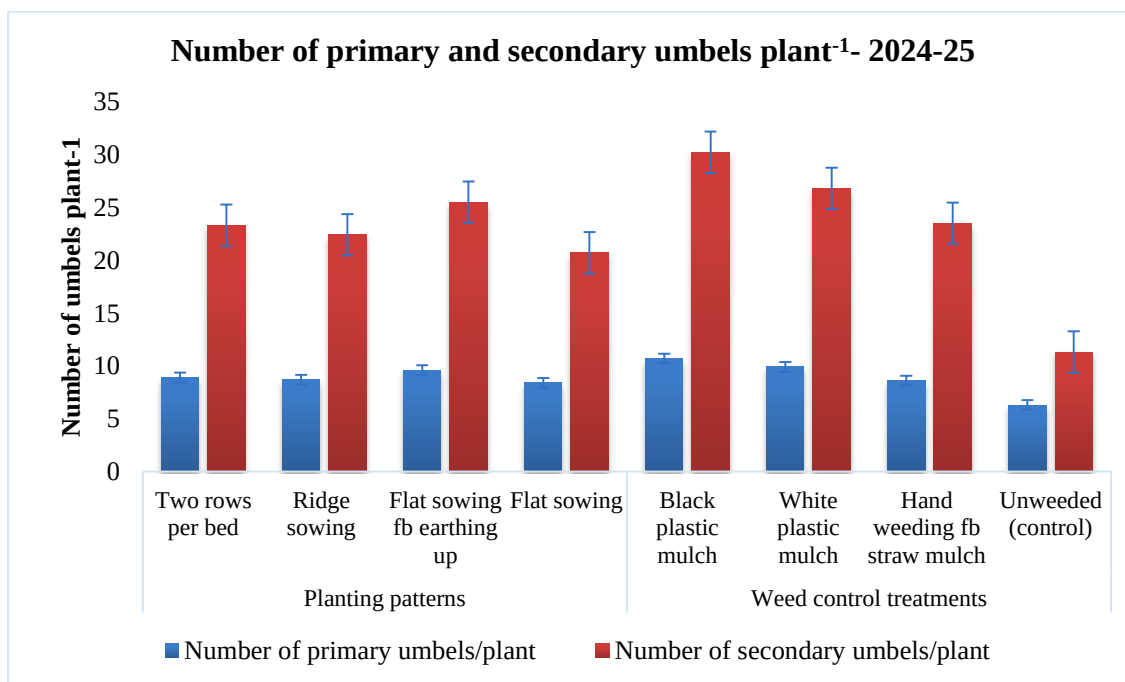
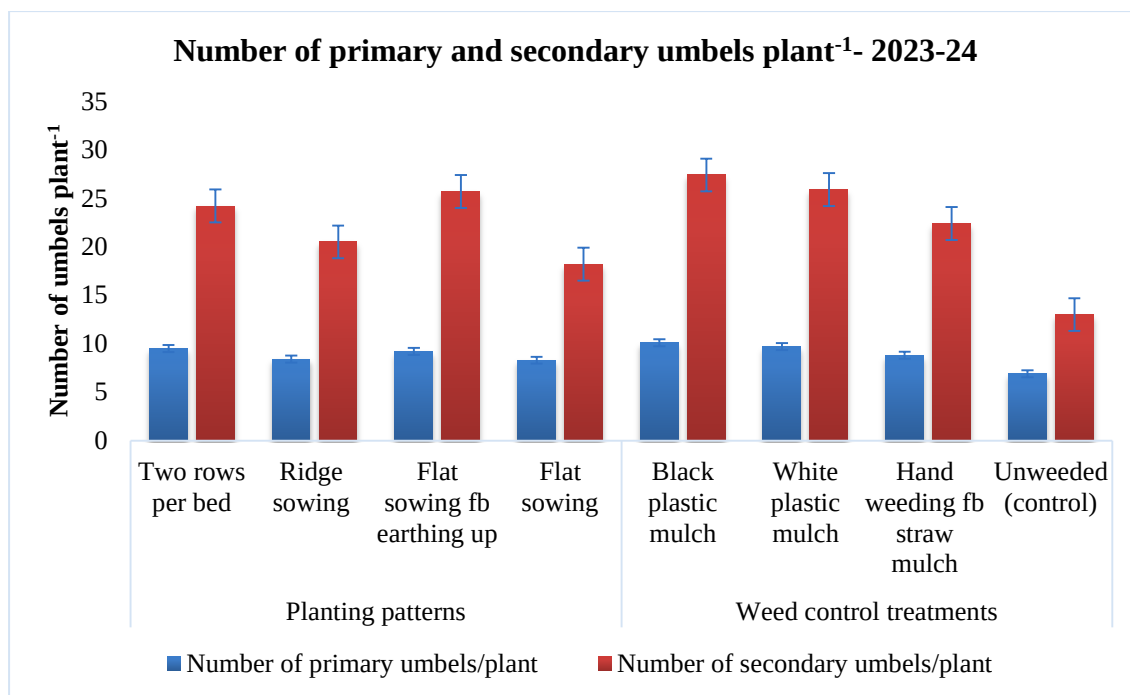


Figure 4.3.1 Effect of planting patterns and weed control treatments on number of primary and secondary umbels plant⁻¹

4.3.2 Diameter of main, primary and secondary umbels (cm)

The diameter of main, primary and secondary umbels (cm) as influenced by various planting patterns and weed control treatments recorded at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.2.

The differences in diameter of main umbel (cm) were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.2). Among planting patterns, the diameter of main umbel recorded in flat sowing *fb* earthing up and two rows per bed were found to be statistically at par with each other and it was significantly more than ridge sowing and flat sowing planting methods. Among weed control treatments, black and white plastic mulch treatments recorded statistically at par diameter of main umbel with each other. Hand weeding *fb* straw mulch (5 t ha^{-1}) produced significantly less diameter of main umbel as compared to black plastic mulch and white plastic mulch treatments. Significantly less diameter of main umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced significantly more diameter of main umbel (cm) as compared to all other planting patterns. The diameter of main umbel in two rows per bed was found to be statistically at par with ridge sowing method. Flat sowing recorded significantly less diameter of main umbel as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded statistically at par diameter of main umbel with white plastic mulch treatment and both these treatments were significantly better than the treatment of hand weeding *fb* straw mulch. Significantly lower diameter of main umbel was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in diameter of primary umbel (cm) were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.2). Among planting patterns, the diameter of primary umbel recorded in flat sowing *fb* earthing up and two rows per bed were statistically at par with each other. Ridge sowing recorded significantly less diameter of primary umbel as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Significantly less diameter of primary umbel was recorded in flat sowing as compared to other planting patterns.

Among weed control treatments, black and white plastic mulch treatments recorded statistically at par diameter of primary umbel (cm) with each other. Hand weeding *fb* straw mulch produced significantly less diameter of primary umbel as compared to black plastic mulch and white plastic mulch treatments. Significantly less diameter of primary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced significantly more diameter of primary umbel (cm) as compared to all other planting patterns. The diameter of primary umbel (cm) in two rows per bed was significantly more than ridge sowing and flat sowing methods. Flat sowing recorded significantly less diameter of primary umbel as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded statistically at par diameter of primary umbel with white plastic mulch treatment, and both these treatments produce significantly more diameter of primary umbel than hand weeding *fb* straw mulch treatment. Significantly less diameter of primary umbel (cm) was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in diameter of secondary umbel (cm) were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.2). Among planting patterns, the diameter of secondary umbel recorded in flat sowing *fb* earthing up was significantly higher than all other planting methods. The diameter of secondary umbel in ridge sowing and flat sowing was found at par with each other but was significantly less than two rows per bed planting pattern. Among weed control treatments, black plastic mulch produced significantly more diameter of secondary umbel as compared to all other weed control treatments. White plastic mulch and hand weeding *fb* straw mulch recorded statistically at par diameter of secondary umbel with each other. Significantly less diameter of secondary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced significantly higher diameter of secondary umbel (cm) as compared to all other planting patterns. The diameter of secondary umbel in two rows per bed was found to be statistically at par with ridge sowing and flat sowing. Among weed control treatments, diameter of

secondary umbel recorded in black plastic mulch was statistically at par with white plastic mulch treatment. Hand weeding *fb* straw mulch produced significantly less diameter of secondary umbel as compared to both plastic mulch treatments. Significantly less diameter of secondary umbel was recorded in unweeded (control) as compared to all other weed control treatments.

From the results, it can be concluded that the diameter of main, primary and secondary umbels were significantly more in flat sowing *fb* earthing up and in black plastic mulch treatments which may be due to the effective suppression of weeds in these treatments and better crop growth which led to better utilization of nutrients and water and finally resulted in vigorous growth and development of crop. The results were in line with Kaur *et al.* (2022) and Gohil *et al.* (2014).

The interactive effect of planting patterns and weed control treatments on diameter of umbels (main, primary and secondary) was found to be non-significant at harvest during both the years (Table 4.3.2).

Table 4.3.2 Effect of planting patterns and weed control treatments on diameter of main, primary and secondary umbel (cm)

	Diameter of main umbel (cm)		Diameter of primary umbel (cm)		Diameter of secondary umbel (cm)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	16.3	14.1	13.3	12.6	7.9	7.9
Ridge sowing (45 cm)	13.9	13.5	11.4	12.1	6.8	7.6
Flat sowing (45 cm) <i>fb</i> earthing up	15.5	15.0	13.7	13.1	8.7	8.5
Flat sowing (45 cm)	13.8	12.8	10.6	11.9	6.5	7.6
SE(m)±	0.27	0.22	0.18	0.10	0.16	0.13
C.D. (5%)	0.95	0.72	0.63	0.31	0.57	0.43
Sub-plots (Weed control treatments)						
Black plastic mulch	16.3	15.2	13.3	13.5	8.4	8.8
White plastic mulch	16.0	14.9	13.3	13.1	7.8	8.6
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	15.3	14.1	12.5	12.2	7.8	7.8
Unweeded (control)	11.9	11.1	10.0	10.9	5.9	6.5
SE(m)±	0.20	0.22	0.17	0.21	0.17	0.13
C.D. (5%)	0.59	0.63	0.48	0.62	0.49	0.37
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

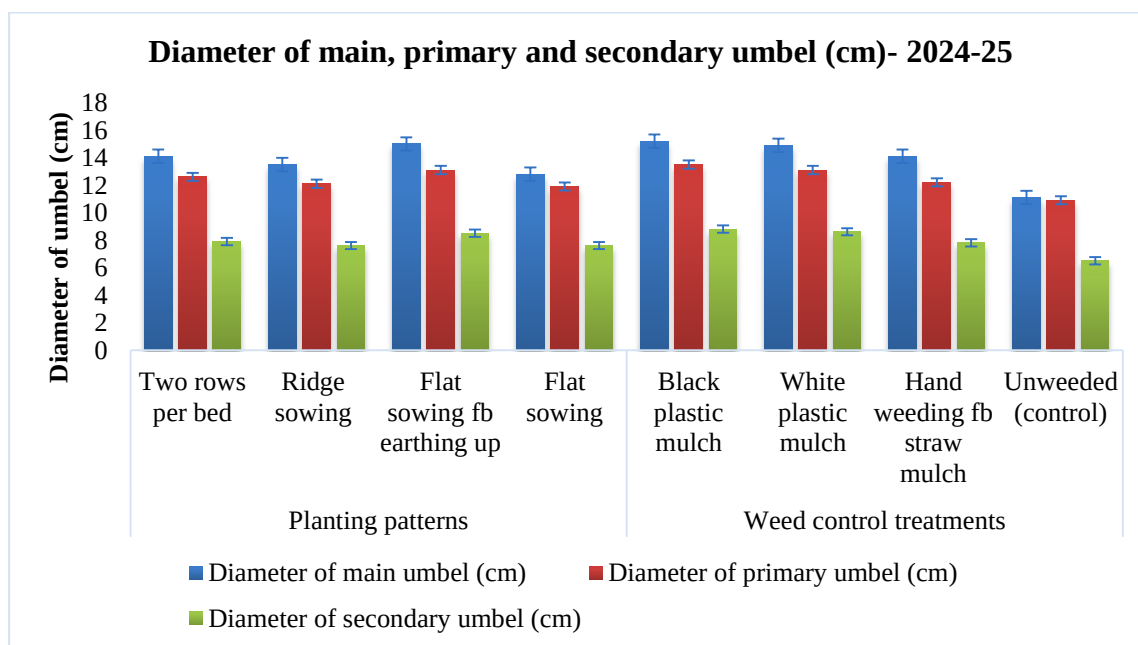
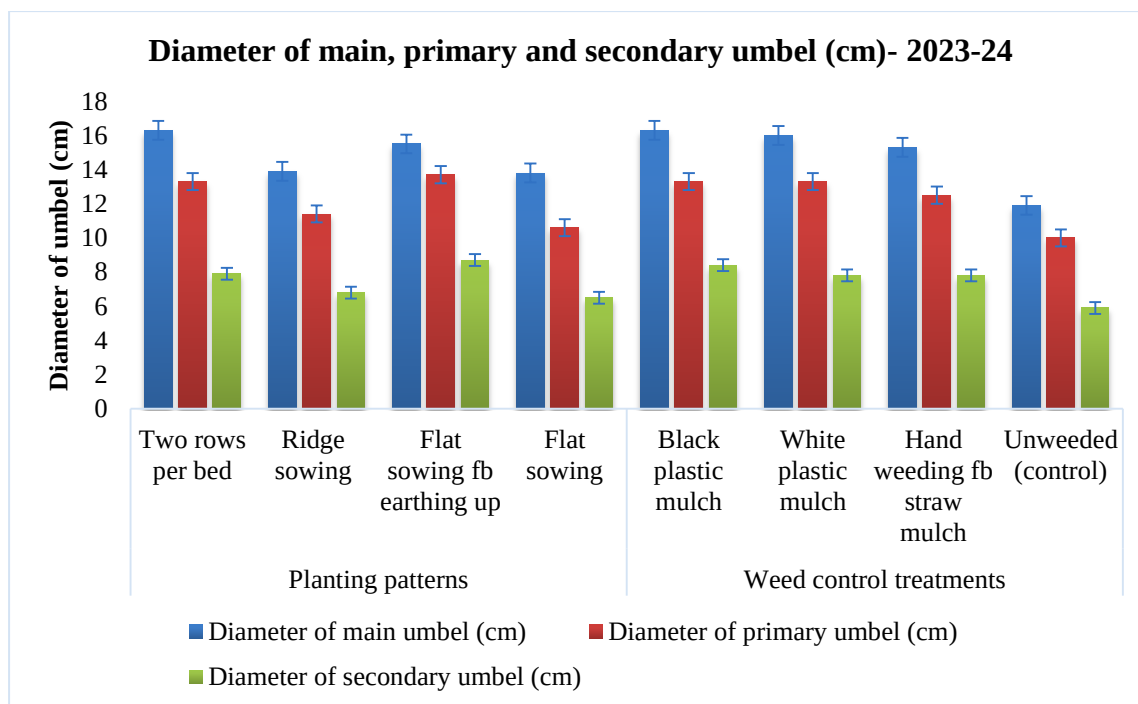


Figure 4.3.2 Effect of planting patterns and weed control treatments on diameter of main, primary and secondary umbel (cm)

4.3.3 Number of umbellets per main, primary and secondary umbel

The impact on number of umbellets per main, primary and secondary umbel as influenced by various planting patterns and weed control treatments recorded at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.3.

The differences in number of umbellets per main umbel were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.3). Among planting patterns, number of umbellets per main umbel were significantly higher in flat sowing *fb* earthing up than all other planting patterns. Number of umbellets per main umbel recorded in two rows per bed were found to be statistically at par with ridge sowing and flat sowing planting patterns. Among weed control treatments, number of umbellets per main umbel in black and white plastic mulch treatments were statistically at par with each other. Hand weeding *fb* straw mulch produced statistically at par number of umbellets per main umbel with white plastic mulch. Significantly less number of umbellets per main umbel were observed in unweeded (control) as compared to black and white plastic mulch treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced statistically at par number of umbellets per main umbel with two rows per bed method. The number of umbellets per main umbel in two rows per bed were found to be statistically at par with ridge sowing. Flat sowing recorded significantly less number of umbellets per main umbel as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded statistically at par number of umbellets per main umbel with white plastic mulch treatment. Hand weeding *fb* straw mulch was found statistically at par with white plastic mulch treatment. Significantly less number of umbellets per main umbel was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in number of umbellets per primary umbel were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.3). Among planting patterns, number of umbellets per primary umbel in flat sowing *fb* earthing up were found to be statistically at par with two rows per bed and ridge sowing planting patterns. Significantly less number of umbellets per primary umbel were

recorded in flat sowing as compared to in flat sowing *fb* earthing up method. Among weed control treatments, black plastic mulch and white plastic mulch treatments recorded statistically at par number of umbellets per primary umbel with each other. Hand weeding *fb* straw mulch produced statistically at par number of umbellets per primary umbel with white plastic mulch treatment. Significantly less number of umbellets per primary umbel were observed in unweeded (control) as compared to black and white plastic mulch treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced statistically at par number of umbellets per primary umbel with two rows per bed and ridge sowing methods. The number of umbellets per primary umbel in two rows per bed were found to be statistically at par with ridge sowing and flat sowing planting patterns. Flat sowing recorded significantly less number of umbellets per primary umbel as compared to flat sowing *fb* earthing up. Among weed control treatments, black plastic mulch recorded statistically at par number of umbellets per primary umbel with white plastic mulch treatment. Hand weeding *fb* straw mulch produced statistically at par number of umbellets per primary umbel with white plastic mulch. Significantly less number of umbellets per primary umbel were recorded in unweeded (control) as compared to all other weed control treatments.

The differences in number of umbellets per secondary umbel were significant among the planting patterns and weed control treatments during 2023-24 (Table 4.3.3). Among planting patterns, number of umbellets per secondary umbel recorded in flat sowing *fb* earthing up were significantly higher than all other planting methods. Two rows per bed recorded statistically at par number of umbellets per secondary umbel with ridge sowing. Significantly lower number of umbellets per secondary umbel were recorded in flat sowing as compared to in flat sowing *fb* earthing up and two rows per bed planting methods. Among weed control treatments, black and white plastic mulch treatments were found statistically at par with each other. Hand weeding *fb* straw mulch produced significantly less number of umbellets per secondary umbel than black and white plastic mulch treatments. Significantly lower number of umbellets per secondary umbel were observed in unweeded (control) as compared to black and white plastic mulch treatments. These findings hold good for 2024-25 also.

The improved growing conditions provided by earthing up and black mulch treatments resulted in higher number of umbellets per umbel (main, primary and secondary). Availability of consistent moisture due to these treatments enabled better nutrient uptake and plant growth which promoted more number of umbellets per umbel. By providing better nutrient availability, improved soil moisture, soil temperature, and reduced competition, these treatments provide optimum conditions for overall reproductive development and hence, more umbellets per umbel. These findings were similar with Patil *et al.* (2020) and Dhakad *et al.* (2017).

The interactive effect of planting patterns and weed control treatments on number of umbellets per umbel (main, primary and secondary) was found to be non-significant at harvest during both the years (Table 4.3.3).

Table 4.3.3 Effect of planting patterns and weed control treatments on number of umbellets per main, primary and secondary umbel

	Number of umbellets per umbel					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	39.4	41.0	33.9	34.8	19.1	20.0
Ridge sowing (45 cm)	38.3	39.5	33.5	33.8	18.5	19.4
Flat sowing (45 cm) <i>fb</i> earthing up	42.6	42.6	35.7	36.0	21.8	22.0
Flat sowing (45 cm)	38.0	38.4	31.8	32.5	17.5	18.0
SE(m)±	0.71	0.63	0.70	0.66	0.32	0.42
C.D. (5%)	2.51	2.23	2.48	2.31	1.12	1.49
Sub-plots (Weed control treatments)						
Black plastic mulch	42.4	43.8	36.3	37.1	20.7	21.8
White plastic mulch	41.0	41.9	34.8	35.3	20.0	20.9
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	38.8	39.3	32.9	33.5	18.5	18.9
Unweeded (control)	36.1	36.6	30.9	31.1	17.8	17.9
SE(m)±	1.03	0.82	0.80	0.66	0.32	0.41
C.D. (5%)	3.02	2.40	2.35	1.93	0.95	1.20
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.4 Number of seeds per umbellet of main, primary and secondary umbel

The impact on number of seeds per umbellet (main, primary and secondary umbel) as influenced by various planting patterns and weed control treatments at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.4.

The differences in number of seeds per umbellet of main umbel were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.4). Among planting patterns, number of seeds per umbellet of main umbel in flat sowing *fb* earthing up method were statistically at par with two rows per bed and ridge sowing methods. Significantly less number of seeds per umbellet of main umbel were recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded significantly more number of seeds per umbellet of main umbel than all other weed control treatments. Number of seeds per umbellet in main umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet of main umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per umbellet of main umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, number of seeds per umbellet of main umbel recorded in flat sowing *fb* earthing up were statistically at par with two rows per bed and ridge sowing (Table 4.3.4). Significantly less number of seeds per umbellet of main umbel were recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per umbellet of main umbel than all other weed control treatments. Number of seeds per umbellet of main umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet of main umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per umbellet of main umbel were observed in unweeded (control) as compared to all other weed control treatments.

The differences in number of seeds per umbellet of primary umbel were significant among the planting patterns and weed control treatments during 2023-24 (Table

4.3.4). Among planting patterns, number of seeds per umbellet of primary umbel in flat sowing *fb* earthing up were found to be statistically at par with two rows per bed planting pattern. The number of seeds per umbellet of primary umbel were found to be statistically at par among two rows per bed and ridge sowing methods. Significantly less number of seeds per umbellet of primary umbel were recorded in flat sowing as compared to in flat sowing *fb* earthing up and two rows per bed planting methods. Among weed control treatments, black plastic mulch recorded significantly more number of seeds per umbellet of primary umbel as compared to all other weed control treatments. Number of seeds per umbellet of primary umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet of primary umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per umbellet of primary umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced statistically at par number of seeds per umbellet of primary umbel with two rows per bed (Table 4.3.4). The number of seeds per umbellet of primary umbel in two rows per bed were found to be statistically at par with ridge sowing. Flat sowing recorded significantly less number of seeds per umbellet of primary umbel as compared to flat sowing *fb* earthing up and two rows per bed methods. Among weed control treatments, black plastic mulch recorded significantly more number of seeds per umbellet of primary umbel compared to all other weed control methods. The number of seeds per umbellet of primary umbel in white plastic mulch were significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet of primary umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per umbellet of primary umbel were recorded in unweeded (control) as compared to all other weed control treatments.

The differences in number of seeds per umbellet of secondary umbel were significant among various planting patterns and weed control treatments during 2023-24 (Table 4.3.4). Among planting patterns, number of seeds per umbellet of secondary umbel in flat sowing *fb* earthing up were significantly higher than all other planting methods.

Two rows per bed recorded statistically at par number of seeds per umbellet of secondary umbel with ridge sowing. Significantly less number of seeds per umbellet of secondary umbel were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch produced significantly higher number of seeds per umbellet of secondary umbel as compared to other weed control treatments. The number of seeds per umbellet of secondary umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet of secondary umbel than black plastic mulch and white plastic mulch treatments. Significantly lower number of seeds per umbellet of secondary umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, number of seeds per umbellet of secondary umbel recorded in flat sowing *fb* earthing up were found to be statistically at par with two rows per bed (Table 4.3.4). Two rows per bed produced statistically at par number of seeds per umbellet with ridge sowing. Significantly less number of seeds per umbellet of secondary umbel were recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch produced significantly higher number of seeds per umbellet of secondary umbel as compared to other weed control treatments. The number of seeds per umbellet in white plastic mulch were significantly more than hand weeding *fb* straw mulch and unweeded (control) treatments. Hand weeding *fb* straw mulch produced significantly less number of seeds per umbellet than black and white plastic mulch treatments. Significantly lower number of seeds per umbellet of secondary umbel were found in unweeded (control) as compared to all other weed control treatments.

From the results obtained, it can be concluded that number of seeds per umbellet in earthing up method and black plastic mulch treatment were higher due to lesser crop weed competition in both treatments which resulted in better utilization of available nutrients and moisture by the crop which led to increased yield attributes like number of seeds per umbellet. Also, crop growth was better in these treatments due to

availability of better soil physical conditions. Similar findings were given by Kaur *et al.* (2022).

The interactive effect of planting patterns and weed control treatments on number of seeds per umbellet of main, primary and secondary umbel were non-significant at harvest during both the years (Table 4.3.4).

Table 4.3.4 Effect of planting patterns and weed control treatments on number of seeds per umbellet of main, primary and secondary umbel

	Number of seeds per umbellet					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	32.0	32.5	26.4	26.9	21.0	22.4
Ridge sowing (45 cm)	31.2	31.4	25.1	25.7	20.1	21.0
Flat sowing (45 cm) <i>fb</i> earthing up	32.7	33.2	27.0	27.9	23.5	24.1
Flat sowing (45 cm)	27.2	29.1	23.3	24.1	17.9	19.2
SE(m)±	0.72	0.58	0.73	0.53	0.42	0.62
C.D. (5%)	2.54	2.05	2.58	1.88	1.50	2.20
Sub-plots (Weed control treatments)						
Black plastic mulch	35.6	36.3	29.7	30.5	24.8	25.6
White plastic mulch	33.7	34.5	27.9	28.9	21.4	22.8
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	29.8	31.5	24.3	25.1	19.1	19.9
Unweeded (control)	24.1	23.9	19.8	20.1	17.3	18.4
SE(m)±	0.59	0.46	0.53	0.38	0.27	0.36
C.D. (5%)	1.74	1.35	1.56	1.13	0.80	1.06
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.5 Number of seeds per main, primary and secondary umbel

The impact on number of seeds per main, primary and secondary umbel as affected by various planting patterns and weed control treatments at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.5 and graphically depicted in Figure 4.3.3.

The differences in number of seeds per main umbel were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.5). Among planting patterns, number of seeds per main umbel recorded in flat sowing *fb* earthing up were statistically at par with two rows per bed. Significantly less number of seeds per main umbel were recorded in flat sowing as compared to flat sowing *fb* earthing up planting pattern. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per main umbel than all other weed control treatments. Number of seeds per main umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less number of seeds per main umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per main umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, number of seeds per main umbel recorded in flat sowing *fb* earthing up were significantly higher than all other planting methods (Table 4.3.5). Two rows per bed produced significantly more number of seeds per main umbel than ridge sowing and flat sowing methods. Significantly less number of seeds per main umbel were recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per main umbel than all other weed control treatments. Number of seeds per main umbel in white plastic mulch were significantly less than black plastic mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of seeds per main umbel than black plastic mulch and white plastic mulch. Significantly less number of seeds per main umbel were observed in unweeded (control) as compared to all other tried weed control treatments.

The differences in number of seeds per primary umbel were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.5). Among

planting patterns, number of seeds per primary umbel recorded in flat sowing *fb* earthing up were significantly higher than all other planting patterns. The number of seeds per primary umbel were found to be statistically at par among two rows per bed and ridge sowing methods. Significantly less number of seeds per primary umbel were recorded in flat sowing as compared to other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per primary umbel as compared to all other weed control treatments. Number of seeds per primary umbel in white plastic mulch were found to be statistically at par with hand weeding *fb* straw mulch treatment. Significantly less number of seeds per primary umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up recorded statistically at par number of seeds per primary umbel with two rows per bed (Table 4.3.5). The number of seeds per primary umbel in two rows per bed planting pattern were found to be statistically at par with ridge sowing method. Flat sowing recorded significantly less number of seeds per primary umbel as compared to all other planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per primary umbel compared to all other weed control methods. The number of seeds per primary umbel in white plastic mulch treatment were significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of seeds per primary umbel than black and white plastic mulch treatments. Significantly less number of seeds per primary umbel were recorded in unweeded (control) as compared to all other weed control treatments.

The differences in number of seeds per secondary umbel were significant among various planting patterns and weed control treatments during 2023-24 (Table 4.3.5). Among planting patterns, number of seeds per secondary umbel recorded in flat sowing *fb* earthing up were statistically at par with two rows per bed. Ridge sowing recorded significantly less number of seeds per secondary umbel than flat sowing *fb* earthing up and two rows per bed planting patterns. Significantly less number of seeds per secondary umbel were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch produced statistically at

par number of seeds per secondary umbel with white plastic mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of seeds per secondary umbel than black and white plastic mulch treatments. Significantly less number of seeds per secondary umbel were observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, number of seeds per secondary umbel recorded in flat sowing *fb* earthing up were statistically at par with two rows per bed planting method (Table 4.3.5). Two rows per bed produced statistically at par number of seeds per secondary umbel with ridge sowing method. Significantly lower number of seeds per secondary umbel were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch produced significantly higher number of seeds per secondary umbel as compared to other weed control treatments. The number of seeds per secondary umbel in white plastic mulch were significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less number of seeds per secondary umbel than black plastic mulch and white plastic mulch treatments. Significantly less number of seeds per secondary umbel were found in unweeded (control) as compared to all other weed control treatments.

The higher number of seeds per umbel in flat sowing *fb* earthing up method and black plastic mulch treatments were due to improvement in soil physical conditions which provided better growth environment for the crop and better resource utilization efficiency. Weed free environment in these treatments improves the soil microclimatic conditions and stimulates microbial activity and further enhances the mineralization and uptake of nutrients. Due to this, there is better reproductive growth and higher number of seeds per main, primary and secondary umbels are obtained. These findings were in conformity with Kumar *et al.* (2019) and Gohil *et al.* (2014).

The interactive effect of planting patterns and weed control treatments on number of seeds per main, primary and secondary umbels was non-significant at harvest during both the years (Table 4.3.5).

Table 4.3.5 Effect of planting patterns and weed control treatments on number of seeds per main, primary and secondary umbel

	Number of seeds per umbel					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	871.2	943.4	738.0	805.2	425.8	450.8
Ridge sowing (45 cm)	842.3	863.9	710.7	739.5	397.9	417.3
Flat sowing (45 cm) <i>fb</i> earthing up	911.6	1019.0	798.0	866.1	438.3	477.7
Flat sowing (45 cm)	830.9	829.3	654.1	677.3	362.9	349.8
SE(m)±	12.36	19.18	10.78	24.83	5.73	12.69
C.D. (5%)	43.59	67.67	38.02	87.60	20.20	44.76
Sub-plots (Weed control treatments)						
Black plastic mulch	1,002.5	1117.3	827.5	933.0	471.4	521.1
White plastic mulch	944.9	995.0	732.8	826.5	454.8	462.7
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	846.5	881.8	693.6	718.3	378.8	387.2
Unweeded (control)	662.0	661.6	646.8	610.4	319.8	324.6
SE(m)±	11.40	20.07	13.80	20.72	9.40	9.34
C.D. (5%)	33.47	58.93	40.51	60.83	27.61	27.41
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

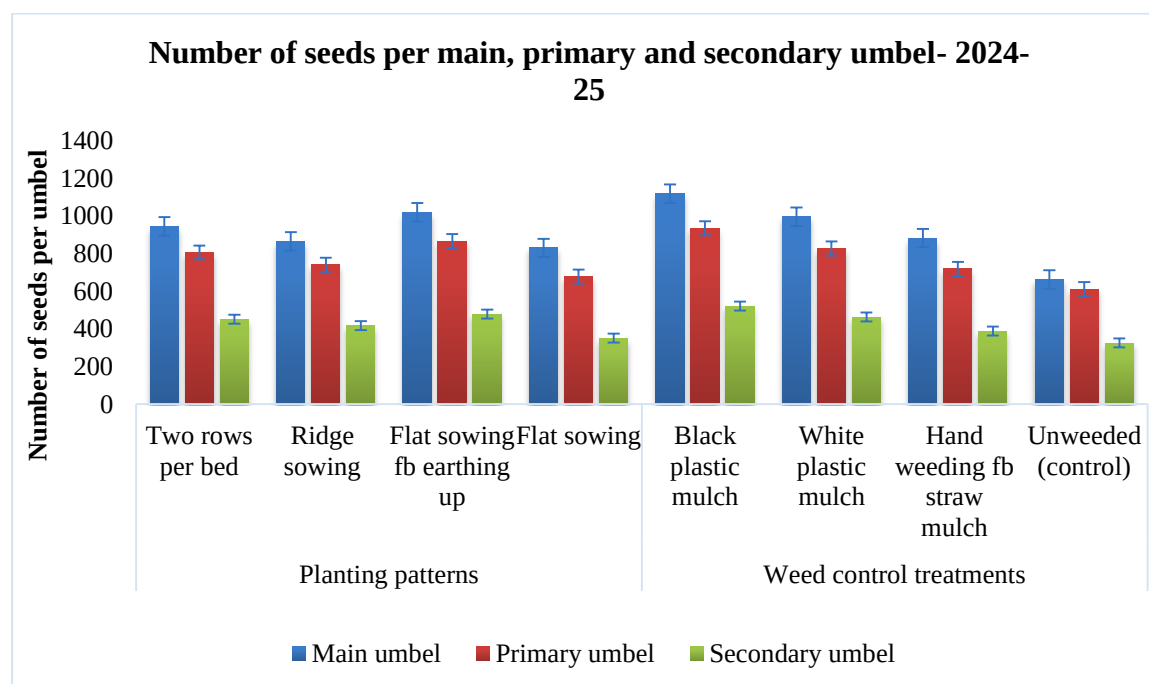
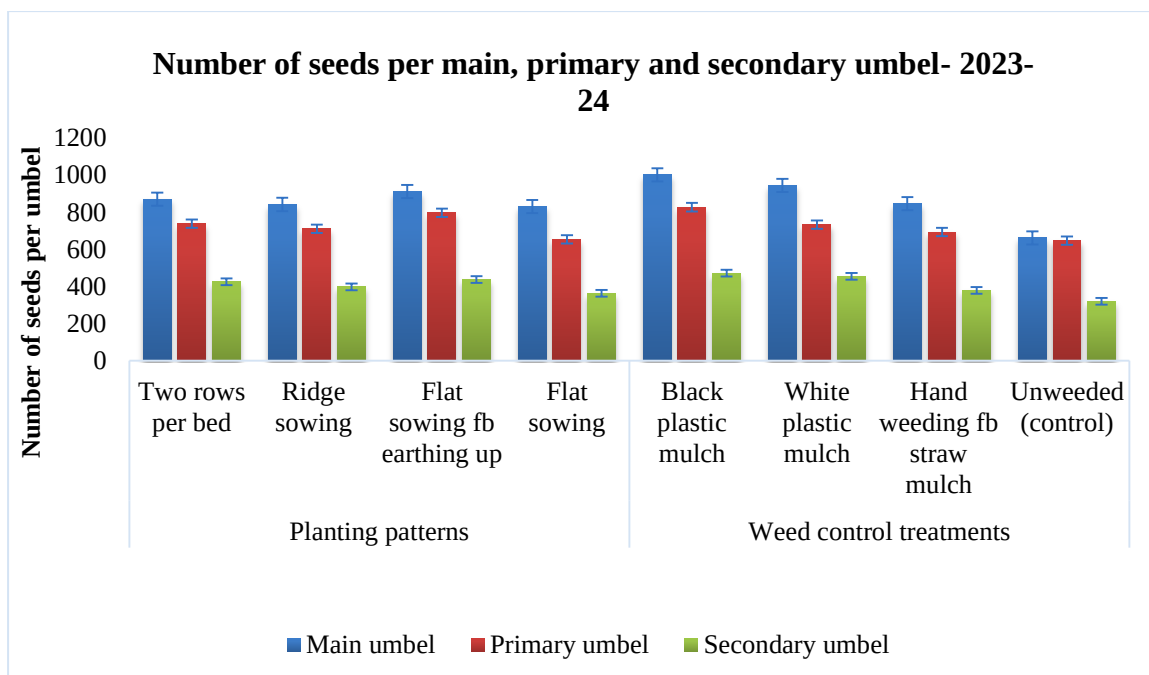


Figure 4.3.3 Effect of planting patterns and weed control treatments on number of seeds per main, primary and secondary umbel

4.3.6 Seed weight (g) of main, primary and secondary umbel

The impact of various planting patterns and weed control treatments on seed weight per main, primary and secondary umbel recorded at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.6 and graphically depicted in Figure 4.3.4.

The differences in seed weight per main umbel (g) were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.6). Among planting patterns, seed weight per main umbel recorded in flat sowing *fb* earthing up was significantly higher as compared to other planting patterns. Two rows per bed produced statistically at par seed weight per main umbel with ridge sowing method. Significantly less seed weight per main umbel was recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher seed weight per main umbel than all other weed control treatments. Seed weight (g) per main umbel in white plastic mulch were significantly less than black plastic mulch. Hand weeding *fb* straw mulch produced significantly less seed weight per main umbel than black and white plastic mulch treatments. Significantly less seed weight per main umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, seed weight per main umbel (g) recorded in flat sowing *fb* earthing up was significantly higher than all other planting methods (Table 4.3.6). Two rows per bed produced significantly more seed weight per main umbel than ridge sowing and flat sowing. Significantly less seed weight per main umbel was recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher seed weight (g) per main umbel than all other weed control treatments. Seed weight per main umbel in white plastic mulch was significantly less than black plastic mulch treatment. Hand weeding *fb* straw mulch produced significantly less seed weight per main umbel than black and white plastic mulch. Significantly less seed weight per main umbel (g) was observed in unweeded (control) as compared to all other weed control treatments.

The differences in seed weight per primary umbel (g) were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.6). Among planting patterns, seed weight (g) per primary umbel recorded in flat sowing *fb* earthing up

was significantly higher than all other planting patterns. Seed weight per primary umbel in two rows per bed was significantly more than ridge sowing and flat sowing methods. Significantly less seed weight per primary umbel was recorded in flat sowing as compared to other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher seed weight per primary umbel (g) as compared to all other weed control treatments. Seed weight per primary umbel in white plastic mulch was significantly more than hand weeding *fb* straw mulch. Significantly less seed weight per primary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, flat sowing *fb* earthing up produced statistically at par seed weight per primary umbel (g) with two rows per bed planting method (Table 4.3.6). Seed weight (g) per primary umbel in ridge sowing was significantly less than flat sowing *fb* earthing up and two rows per bed planting methods. Flat sowing recorded significantly less seed weight per primary umbel as compared to all other planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher seed weight per primary umbel (g) compared to all other weed control methods. Seed weight per primary umbel observed in white plastic mulch treatment was significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less seed weight per primary umbel than black and white plastic mulch treatments. Significantly less seed weight per primary umbel was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in seed weight per secondary umbel (g) were significant among various planting patterns and weed control treatments during 2023-24 (Table 4.3.6). Among planting patterns, seed weight per secondary umbel recorded in flat sowing *fb* earthing up was significantly higher as compared to all other planting patterns. Two rows per bed recorded significantly more seed weight (g) per secondary umbel than ridge sowing method. Ridge sowing recorded significantly less seed weight (g) per secondary umbel than flat sowing *fb* earthing up and two rows per bed planting methods. Significantly less seed weight per secondary umbel (g) was recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting methods. Among weed control treatments, black plastic mulch produced significantly

higher seed weight per secondary umbel compared to all other weed control treatments. Significantly more seed weight per secondary umbel (g) was observed in white plastic mulch as compared to hand weeding *fb* straw mulch and unweeded (control) treatments. Hand weeding *fb* straw mulch produced significantly less seed weight (g) per secondary umbel than black plastic mulch and white plastic mulch treatments. Significantly less seed weight (g) per secondary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, seed weight per secondary umbel (g) recorded in flat sowing *fb* earthing up was statistically at par with two rows per bed planting methods (Table 4.3.6). Ridge sowing produced significantly less seed weight per secondary umbel as compared to flat sown crop *fb* earthing up and two rows per bed planting patterns. Significantly less seed weight per secondary umbel were recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch produced significantly higher seed weight (g) per secondary umbel as compared to other weed control treatments. Seed weight per secondary umbel in white plastic mulch was significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less seed weight per secondary umbel than black and white plastic mulch treatments. Significantly less seed weight per secondary umbel was observed in unweeded (control) as compared to all other weed control treatments.

From the results obtained, it can be concluded that flat sowing *fb* earthing up and black mulch treatments recorded higher seed weight per umbel (g) as compared to all other treatments. This may be due to more vigorous growth of the crop and higher number of seeds per umbel under these treatments. Due to less crop weed competition and better soil conditions, the seed formation was enhanced in these treatments which resulted in higher seed weight per umbel. These findings were in line with Kumar *et al.* (2019) and Mamatha *et al.* (2021).

The interactive effect of planting patterns and weed control treatments on seed weight per main, primary and secondary umbel was non-significant at harvest during both the years (Table 4.3.6).

Table 4.3.6 Effect of planting patterns and weed control treatments on seed weight (g) of main, primary and secondary umbel

	Seed weight (g)					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	6.4	6.9	6.2	6.5	1.2	1.3
Ridge sowing (45 cm)	6.1	6.3	5.7	5.8	1.0	1.1
Flat sowing (45 cm) <i>fb</i> earthing up	6.8	7.6	6.8	7.1	1.3	1.4
Flat sowing (45 cm)	5.4	5.5	5.2	5.2	1.0	0.9
SE(m)±	0.11	0.12	0.10	0.17	0.03	0.05
C.D. (5%)	0.38	0.43	0.35	0.60	0.09	0.17
Sub-plots (Weed control treatments)						
Black plastic mulch	7.4	8.3	7.1	7.7	1.4	1.6
White plastic mulch	6.9	7.2	6.1	6.8	1.2	1.3
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	5.9	6.3	5.8	5.7	1.1	1.0
Unweeded (control)	4.4	4.5	4.8	4.5	0.8	0.8
SE(m)±	0.12	0.09	0.09	0.15	0.03	0.04
C.D. (5%)	0.34	0.26	0.25	0.43	0.08	0.11
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

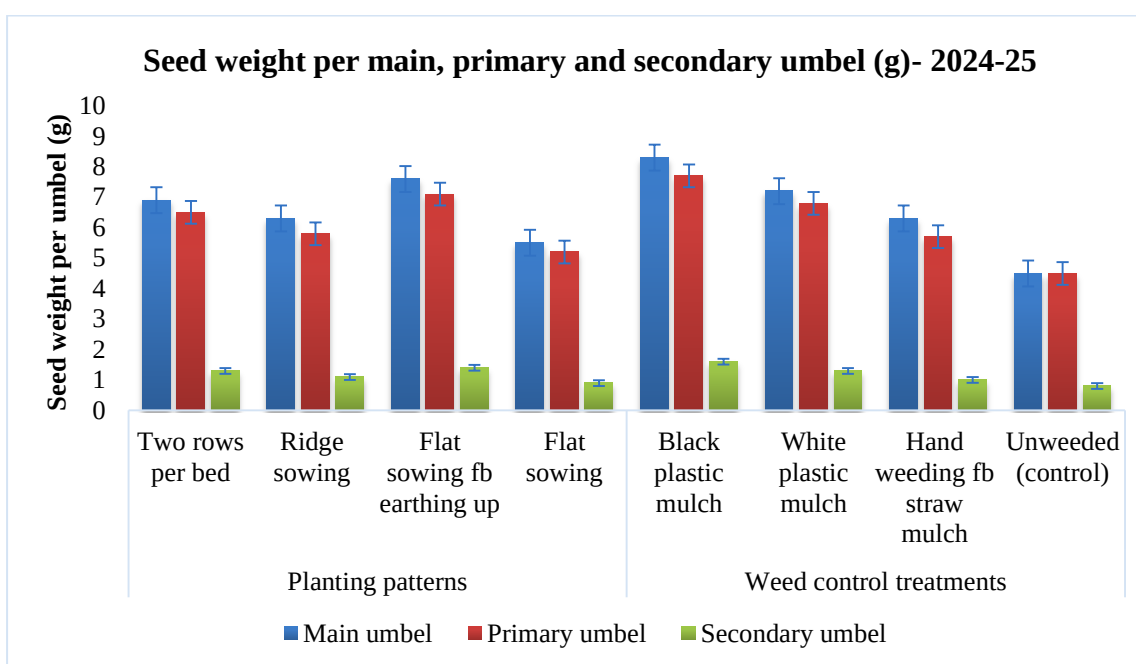
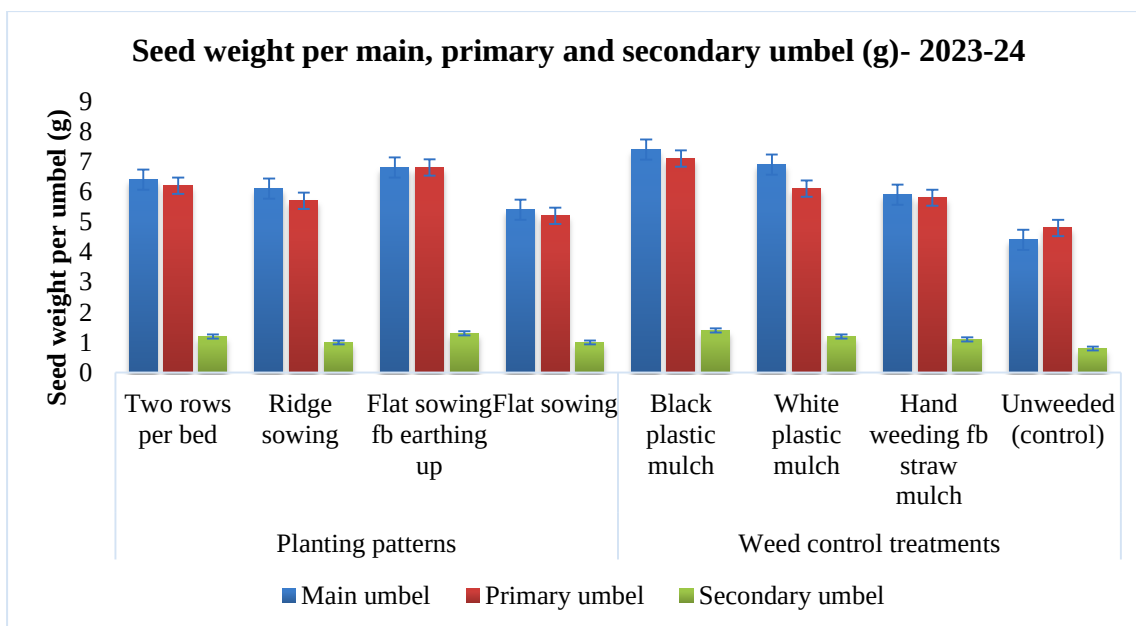


Figure 4.3.4 Effect of planting patterns and weed control treatments on seed weight of main, primary and secondary umbel (g)

4.3.7 1000 seed weight (g) of main, primary and secondary umbel

The impact on 1000 seed weight (g) of main, primary and secondary umbel as affected by various planting patterns and weed control treatments at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.7.

The differences in 1000 seed weight (test weight) of main umbel was significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.7). Among planting patterns, 1000 seed weight (g) of main umbel recorded in flat sowing *fb* earthing up was statistically at par with two rows per bed and ridge sowing methods. Significantly less 1000 seed weight of main umbel was recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, black plastic mulch produced statistically at par 1000 seed weight of main umbel with white plastic mulch treatment. Hand weeding *fb* straw mulch produced significantly less 1000 seed weight (g) of main umbel than black plastic mulch and white plastic mulch treatments. Significantly less 1000 seed weight of main umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, 1000 seed weight (g) of main umbel recorded in flat sowing *fb* earthing up was statistically at par with two rows per bed and ridge sowing methods (Table 4.3.7). Significantly less 1000 seed weight of main umbel was recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded statistically at par 1000 seed weight of main umbel with white plastic mulch and hand weeding *fb* straw mulch treatments. Significantly lower 1000 seed weight (g) of main umbel was observed in unweeded (control) as compared to all other weed control treatments.

The differences in 1000 seed weight (g) of primary umbels were significant among planting patterns and weed control treatments during 2023-24 (Table 4.3.7). Among planting patterns, 1000 seed weight of primary umbel recorded in flat sowing *fb* earthing up and two rows per bed was found to be statistically at par with each other. The test weight of primary umbels in ridge sowing was significantly less than flat sowing *fb* earthing up and two rows per bed sowing planting patterns. Significantly less 1000 seed weight of primary umbel was recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting methods. Among weed

control treatments, application of black plastic mulch recorded significantly higher 1000 seed weight (g) of primary umbels as compared to all other weed control treatments. Test weight (g) of primary umbel in white plastic mulch was found to be statistically at par with hand weeding *fb* straw mulch treatment. Significantly less 1000 seed weight of primary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, the differences in 1000 seed weight of primary umbel among various planting patterns were non-significant (Table 4.3.7). Among weed control treatments, black plastic mulch recorded statistically at par 1000 seed weight of primary umbel with white plastic mulch treatment. Test weight of primary umbel observed in hand weeding *fb* straw mulch treatment was significantly less than black plastic mulch and white plastic mulch treatments. Significantly less 1000 seed weight (g) of primary umbel was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in 1000 seed weight of secondary umbel were significant among various planting patterns and weed control treatments during 2023-24 (Table 4.3.7). Among planting patterns, 1000 seed weight (g) of secondary umbel recorded in flat sowing *fb* earthing up was significantly higher as compared to all other planting patterns. Two rows per bed recorded significantly more 1000 seed weight of secondary umbel than ridge sowing and flat sowing planting patterns. Ridge sowing recorded significantly less 1000 seed weight of secondary umbels than flat sowing *fb* earthing up and two rows per bed methods. Significantly less 1000 seed weight (g) of secondary umbel was recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Among weed control treatments, black plastic mulch produced significantly higher 1000 seed weight of secondary umbel compared to all other weed control treatments. The 1000 seed weight of secondary umbel observed in white plastic mulch was statistically at par with hand weeding *fb* straw mulch. Hand weeding *fb* straw mulch produced significantly less 1000 seed weight of secondary umbel than black plastic mulch. Significantly less 1000 seed weight of secondary umbel was observed in unweeded (control) as compared to all other weed control treatments. During 2024-25, differences in 1000 seed weight of secondary umbel among various planting patterns were found to be non-significant

(Table 4.3.7). Among weed control treatments, black plastic mulch produced statistically at par 1000 seed weight of secondary umbel with white plastic mulch. Test weight of secondary umbel observed in white plastic mulch was significantly more than hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less 1000 seed weight of secondary umbel than black plastic mulch and white plastic mulch treatment. Significantly less 1000 seed weight of secondary umbel was observed in unweeded (control) as compared to all other weed control treatments.

The improved crop growth under flat sowing *fb* earthing up treatment led to better yield attributes including number of seeds per umbel, seed weight per umbel and 1000 seed weight. Black mulch treatment reduced the competition between crop and weeds and improved the soil physical conditions which promoted growth of the crop resulting in positive impact on yield attributes of the crop. Test weight of flat sowing *fb* earthing up planting method was higher than other methods which may be due to better crop growth attained because of availability of better physical conditions of soil. Similar findings were given by Mamatha *et al.* (2021) and Meena *et al.* (2024).

The interactive effect of planting patterns and weed control treatments on 1000 seed weight (g) of main, primary and secondary umbel was non-significant at harvest during 2023-34 and 2024-25 (Table 4.3.7).

Table 4.3.7 Effect of planting patterns and weed control treatments on 1000 seed weight (g) of main, primary and secondary umbel

	1000 seed weight(g)					
	Main umbel		Primary Umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	7.3	7.3	8.4	8.0	2.7	2.8
Ridge sowing (45 cm)	7.2	7.3	7.9	7.8	2.5	2.7
Flat sowing (45 cm) <i>fb</i> earthing up	7.5	7.4	8.6	8.2	2.9	2.9
Flat sowing (45 cm)	6.7	6.6	7.8	7.7	2.4	2.6
SE(m)±	0.09	0.15	0.12	0.12	0.04	0.07
C.D. (5%)	0.33	0.51	0.43	NS	0.16	NS
Sub-plots (Weed control treatments)						
Black plastic mulch	7.6	7.4	8.8	8.3	2.9	3.0
White plastic mulch	7.4	7.2	8.3	8.2	2.6	2.9
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	7.1	7.2	8.1	7.9	2.6	2.7
Unweeded (control)	6.6	6.8	7.4	7.3	2.4	2.4
SE(m)±	0.09	0.11	0.14	0.09	0.05	0.06
C.D. (5%)	0.27	0.32	0.41	0.27	0.15	0.17
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.8 Seed yield (q ha^{-1}) and stover yield (q ha^{-1})

The seed yield is the economic part of the crop which is ultimate product of crop growth factors and yield attributes. The treatment with higher seed yield is considered to be the best treatment. The data on effect of various planting patterns and weed control treatments on seed yield (q ha^{-1}) and stover yield (q ha^{-1}) during 2023-24 and 2024-25 has been presented in Table 4.3.8 and graphically depicted in Figure 4.3.5.

The seed yield (q ha^{-1}) of fennel was influenced significantly by various planting patterns and weed control treatments during 2023-24 (Table 4.3.8). Among planting patterns, seed yield (q ha^{-1}) in flat sowing *fb* earthing up and two rows per bed planting patterns was found to be statistically at par with each other. Ridge sowing recorded significantly less seed yield than flat sowing *fb* earthing up and two rows per bed planting patterns. Significantly less seed yield was recorded in flat sowing as compared to all other tried planting methods. Among weed control treatments, black plastic mulch recorded significantly higher seed yield (q ha^{-1}) as compared to all other weed control treatments. Seed yield recorded in white plastic mulch was found to be significantly more than hand weeding *fb* straw mulch treatment. However, significantly less seed yield was recorded in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, seed yield (q ha^{-1}) produced in flat sowing *fb* earthing up was significantly higher as compared to other planting patterns (Table 4.3.8). Two rows per bed produced significantly more seed yield as compared to ridge sowing and flat sowing methods. Ridge sowing recorded significantly less seed yield than flat sowing *fb* earthing up and two rows per bed planting methods. Significantly less seed yield was recorded in flat sowing as compared to all tried planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher seed yield as compared to all other weed control treatments. Seed yield (q ha^{-1}) recorded in white plastic mulch was found to be significantly more than hand weeding *fb* straw mulch. Significantly less seed yield was recorded in unweeded (control) as compared to all other weed control treatments.

Among main plots, significantly higher seed yield under the planting patterns of flat sowing *fb* earthing up and two rows per bed as compared to flat or ridge sowing may

be due to effective weed control (Table 4.1.1 to 4.1.5), increased crop growth factors (Table 4.2.1 to 4.2.6) and better yield attributes of fennel (Table 4.3.1 to 4.3.7). Higher yields under above said methods may be attributed to better weed control due to deep burial of weed seeds as well as availability of better soil physical conditions which favoured better crop growth. Similar results were reported by Patel *et al.* (2018). Among sub plots, significantly more seed yield was recorded in application of black plastic mulch treatment as compared to all other weed control treatments which may be due to better weed control (Table 4.1.1 to 4.1.5), increased growth factors (Table 4.2.1 to 4.2.6) and better yield attributes (Table 4.3.1 to 4.3.7) under black mulch treated crop. Higher yield in black plastic mulch treatment may also be due to very effective control of weeds in this treatment compared to other weed control treatments as well as due to availability of better crop growing conditions, conservation of soil moisture, moderation of soil temperature etc. with black mulch. Similar results were reported by Meena *et al.* (2024). On the basis of average of two years, flat sowing *fb* earthing up, two rows per bed and ridge sowing increased seed yield of fennel by 40.20, 30.93 and 9.28 percent respectively as compared to conventional method i.e. flat sowing. Among weed control treatments, based on average of 2023-24 and 2024-25 data, black plastic mulch, white plastic mulch and hand weeding *fb* straw mulch increased the seed yield of fennel by 458.06, 390.32 and 254.84 percent, respectively as compared to unweeded (control) treatment.

The interactive effect of planting patterns and weed control treatment for seed yield (q ha^{-1}) was found to be significant during both the years (Table 4.3.9). During 2023-24, two rows per bed with black plastic mulch recorded significantly higher seed yield (q ha^{-1}) as compared to flat sowing *fb* earthing up with white plastic mulch treatment. Flat sowing *fb* earthing up with hand weeding *fb* straw mulch produced statistically at par seed yield with two rows per bed with white plastic mulch. Flat sowing *fb* earthing up with white plastic mulch produced significantly more seed yield as compared to two rows per bed with hand weeding *fb* straw mulch treatment. During 2024-25, flat sowing *fb* earthing up with black plastic mulch produced statistically at par seed yield with flat sowing *fb* earthing up with white plastic mulch. Ridge sowing with black plastic mulch recorded statistically at par seed yield with flat sowing *fb* earthing up

with white plastic mulch. Significantly more seed yield was recorded in flat sowing with black plastic mulch as compared to ridge sowing with white plastic mulch.

The stover yield (qha^{-1}) of fennel was influenced significantly by various planting patterns and weed control treatments during 2023-24 (Table 4.3.8). Among planting patterns, stover yield (qha^{-1}) produced in flat sowing *fb* earthing up and two rows per bed sowing method was found to be statistically at par with each other. Ridge sowing recorded significantly less stover yield than flat sowing *fb* earthing up and two rows per bed planting methods. Significantly less stover yield was recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher stover yield as compared to all other weed control treatments. Stover yield recorded in white plastic mulch treated crop was found to be significantly more than hand weeding *fb* straw mulch treatment. Significantly less stover yield was recorded in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, stover yield (qha^{-1}) recorded in flat sowing *fb* earthing up was significantly higher as compared to other planting patterns. Two rows per bed sowing method produced significantly more stover yield as compared to ridge sowing and flat sowing methods. Ridge sowing recorded significantly less stover yield than flat sowing *fb* earthing up and two rows per bed method. Significantly less stover yield was recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting methods. Stover yield (q ha^{-1}) recorded in ridge sowing and flat sowing was found to be statistically at par with each other. Among weed control treatments, black plastic mulch recorded significantly higher stover yield as compared to all other weed control treatments. Stover yield (q ha^{-1}) recorded in white plastic mulch was found to be significantly more than hand weeding *fb* straw mulch. Significantly less stover yield was recorded in unweeded (control) as compared to all other weed control treatments.

Increase in yield attributes due to earthing up and bed sowing methods had a direct and positive effect for increasing the stover yield. Earthing up and bed sowing enhanced the soil physical conditions and reduced the weed growth in early stages by deep burial of weed seeds into the soil. Similar findings were reported by Patel *et al.* (2018) and Singh *et al.* (2019). Similarly, stover yield under black mulch treatment

might be due to suppression of weeds from very start of the germination, which provided weed free environment for the crop and led to less crop weed competition and also helped in moderation of soil temperature. Due to this, the crop was able to utilize the fertilizers applied more efficiently and enhanced the growth and yield of the crop. Similar findings were reported by Meena *et al.* (2024) and Kumar *et al.* (2023).

The interactive effect of planting patterns and weed control treatments on stover yield (q ha^{-1}) was found to be non-significant during 2023-24 and 2024-25 (Table 4.3.8).

Table 4.3.8 Effect of planting patterns and weed control treatments on seed and stover yield (q ha⁻¹)

Treatment details	Seed yield (q ha ⁻¹)			Stover yield (q ha ⁻¹)	
	2023-24	2024-25	Average of two years	2023-24	2024-25
Main plots (Planting patterns)					
Two rows per bed (90 cm)	11.9	13.4	12.7	61.3	58.3
Ridge sowing (45 cm)	9.4	11.9	10.6	48.6	49.5
Flat sowing (45 cm) <i>fb</i> earthing up	12.4	14.8	13.6	65.0	62.5
Flat sowing (45 cm)	8.2	11.2	9.7	43.8	49.6
SE(m)±	0.18	0.32	-	1.27	1.11
C.D. (5%)	0.64	1.04	-	4.46	3.60
Sub-plots (Weed control treatments)					
Black plastic mulch	15.2	19.4	17.3	79.4	81.3
White plastic mulch	13.5	16.9	15.2	69.8	68.3
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	11.0	11.0	11.0	59.2	54.4
Unweeded (control)	2.2	3.9	3.1	10.3	16.0
SE(m)±	0.19	0.28	-	1.10	0.90
C.D. (5%)	0.56	0.79	-	3.24	2.58
Interaction C.D. (5%)					
Interaction C.D. (5%)	1.17	1.65	-	NS	NS

Table 4.3.9 Interactive effect of planting patterns and weed control treatments on seed yield (q ha⁻¹) during 2023-24 and 2024-25

Seed yield (q ha⁻¹) - 2023-24

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	19.0	14.4	12.4	1.8	11.9
Ridge sowing (45 cm)	14.0	13.0	9.4	1.1	9.4
Flat sowing (45 cm) <i>fb</i> earthing up	15.4	14.9	13.9	5.2	12.4
Flat sowing (45 cm)	12.2	11.8	8.2	0.8	8.2
Mean B	15.2	13.5	11.0	2.2	
SE(m)±	0.37				
C.D. (5%)	1.17				

Seed yield (q ha⁻¹) - 2024-25

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	19.7	18.9	11.0	4.1	13.4
Ridge sowing (45 cm)	18.9	15.0	10.9	2.7	11.9
Flat sowing (45 cm) <i>fb</i> earthing up	20.9	19.4	12.5	6.3	14.8
Flat sowing (45 cm)	18.2	14.4	9.6	2.5	11.2
Mean B	19.4	16.9	11.0	3.9	0.3
SE(m)±	0.64				
C.D. (5%)	1.65				

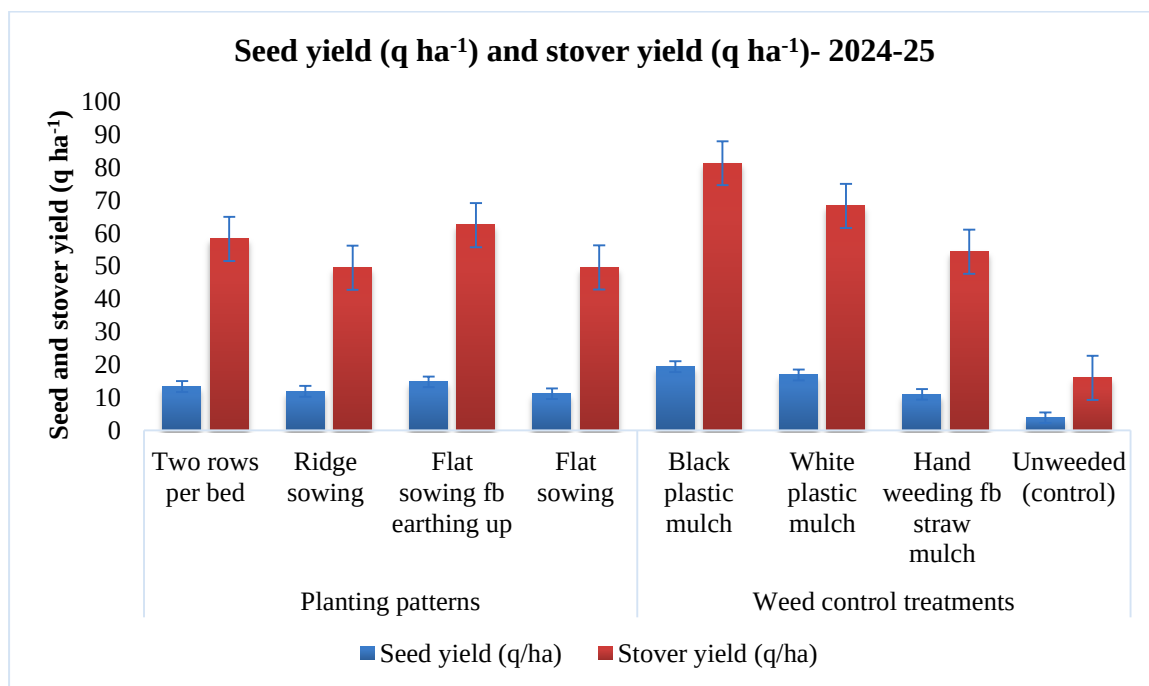
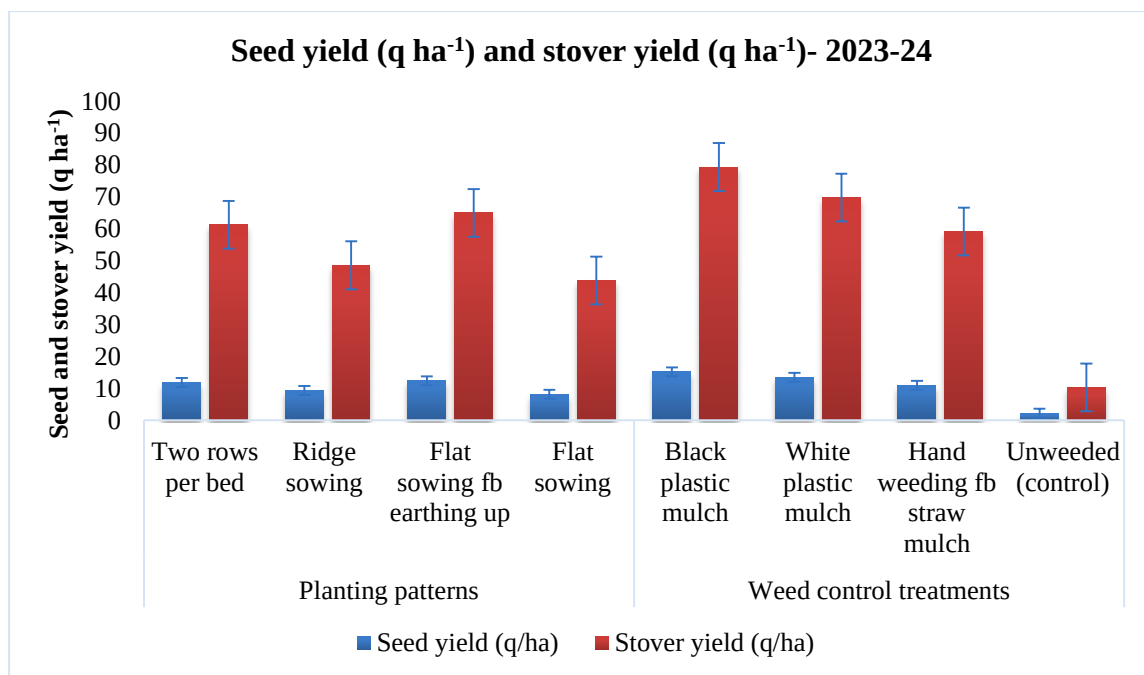


Figure 4.3.5 Effect of planting patterns and weed control treatments on seed and stover yield (q ha⁻¹).

4.3.9 Biological yield (q ha^{-1}) and harvest index (%)

The data on effect of planting patterns and weed control treatments on biological yield (q ha^{-1}) and harvest index (%) has been presented in Table 4.3.10.

The biological yield (q ha^{-1}) influenced by various planting patterns and weed control treatments was found to be significant during 2023-24 (Table 4.3.10). Among planting patterns, biological yield (q ha^{-1}) recorded in flat sowing *fb* earthing up and two rows per bed sowing methods was found to be statistically at par with each other. Ridge sowing recorded significantly less biological yield than flat sowing *fb* earthing up and two rows per bed planting methods. Significantly less biological yield was recorded in flat sowing as compared to all other planting methods. Among weed control treatments, black plastic mulch recorded significantly higher biological yield as compared to all other weed control treatments. Biological yield recorded in white plastic mulch was significantly more than hand weeding *fb* straw mulch. Significantly less biological yield was recorded in unweeded (control) as compared to all other weed control treatments. During 2024-25, among planting patterns, biological yield (q ha^{-1}) in flat sowing *fb* earthing up was significantly higher as compared to other planting patterns. Two rows per bed sowing method recorded significantly more biological yield as compared to ridge sowing and flat sowing methods. Ridge sowing recorded significantly less biological yield than flat sowing *fb* earthing up and two rows per bed planting methods. Significantly less biological yield was recorded in flat sowing as compared to flat sowing *fb* earthing up and two rows per bed planting patterns. Biological yield recorded in ridge sowing and flat sowing was found to be statistically at par with each other. Among weed control treatments, black plastic mulch recorded significantly higher biological yield as compared to all other weed control treatments. Biological yield recorded in white plastic mulch was significantly more than hand weeding *fb* straw mulch treatment. Significantly less biological yield was recorded in unweeded (control) as compared to all other weed control treatments.

The differences in harvest index (%) as influenced by various planting patterns and weed control treatments were found to be significant during 2023-24 (Table 4.3.10). Among planting patterns, harvest index (%) recorded in two rows per bed sowing

method was significantly higher as compared to all other planting methods. Flat sowing *fb* earthing up and ridge sowing produced statistically at par harvest index (%) with each other. Significantly less harvest index was recorded in flat sowing as compared to two rows per bed method. Among weed control treatments, unweeded (control) recorded significantly higher harvest index as compared to all other weed control treatments. Harvest index (%) recorded in white plastic mulch and black plastic mulch was statistically at par with hand weeding *fb* straw mulch treatment. Hand weeding *fb* straw mulch produced significantly less harvest index as compared to unweeded (control). During 2024-25, among planting patterns, harvest index (%) recorded in flat sowing *fb* earthing up was statistically at par with two rows per bed and ridge sowing methods. Harvest index (%) recorded in ridge sowing and flat sowing was found to be statistically at par with two rows per bed planting method. Flat sowing recorded significantly less harvest index than flat sowing *fb* earthing up. Among weed control treatments, black plastic mulch recorded statistically at par harvest index (%) with white plastic mulch. Harvest index (%) recorded in black plastic mulch treatment was statistically at par with unweeded (control). Hand weeding *fb* straw mulch produced significantly less harvest index as compared to all other weed control treatments.

The higher biological yield of the crop in earthing up treatment and plastic mulch treatments might be due to improved soil conditions and moderation of soil temperature. There was less crop weed competition and better utilization of resources which enhanced the biomass of the crop. Similar findings were given by Pagadhal *et al.* (2022) and Patel *et al.* (2018).

The interactive effect of planting patterns and weed control treatments on biological yield (q ha^{-1}) and harvest index (%) was found to be non-significant during 2023-24 and 2024-25 (Table 4.3.10).

Table 4.3.10 Effect of planting patterns and weed control treatments on biological yield (q ha⁻¹) and harvest index (%)

	Biological yield (q ha ⁻¹)		Harvest index (%)	
	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)				
Two rows per bed (90 cm)	73.2	71.7	17.0	18.9
Ridge sowing (45 cm)	58.0	61.4	16.1	18.6
Flat sowing (45 cm) <i>fb</i> earthing up	77.4	77.3	16.4	19.6
Flat sowing (45 cm)	52.0	60.7	15.9	17.7
SE(m)±	1.41	1.12	0.15	0.40
C.D. (5%)	4.98	3.65	0.53	1.29
Sub-plots (Weed control treatments)				
Black plastic mulch	94.5	100.7	16.0	19.3
White plastic mulch	83.3	85.2	16.3	19.9
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	70.2	65.4	15.8	16.9
Unweeded (control)	12.5	19.9	17.2	18.8
SE(m)±	1.24	0.97	0.28	0.38
C.D. (5%)	3.65	2.80	0.82	1.09
Interaction C.D. (5%)	NS	NS	NS	NS

4.4 Economics

Data on economics of fennel was presented in Table 4.4.1. On the basis of average of two years data (2023-24 and 2024-25), the treatment combination of two rows per bed applied with black plastic mulch gave highest net returns (173261.9 ₹ ha⁻¹) as well as highest benefit cost ratio (2.52) as compared to all other treatment combinations. The benefit cost ratio in flat sowing *fb* earthing up applied with black plastic mulch was 2.41 and in bed sowing applied with white plastic mulch, it was 2.11 and these values were better than ridge sowing applied with black plastic mulch (1.98). The treatment combination of flat sowing *fb* earthing up applied with white plastic mulch gave higher net returns (149485.5 ₹ ha⁻¹) as well as benefit cost ratio as compared to ridge sowing applied with white plastic mulch (108553.1 ₹ ha⁻¹). The net returns were found to be negative in unweeded (control) when combined with all three planting patterns, because of more weed infestation leading to significant losses in seed yield.

Table 4.4.1 Effect of planting patterns and weed control treatments on economics of fennel

Treatments	Cost of cultivation (₹ ha⁻¹)	Gross returns (₹ ha⁻¹)	Net returns (₹ ha⁻¹)	B:C ratio
Two rows per bed + black plastic mulch	68852.08	242114.0	173261.9	2.52
Two rows per bed + white plastic mulch	66852.08	207859.7	141007.6	2.11
Two rows per bed + One hand weeding <i>fb</i> straw mulch	57302.08	146681.5	89379.4	1.56
Two rows per bed + unweeded (control)	47052.08	37111.3	-9940.8	-0.21
Ridge sowing + black plastic mulch	68852.08	205252.6	136400.6	1.98
Ridge sowing + white plastic mulch	66852.08	175405.2	108553.1	1.62
Ridge sowing + One hand weeding <i>fb</i> straw mulch	57302.08	126904.1	69602.1	1.21
Ridge sowing + unweeded (control)	47052.08	23741.2	-23310.9	-0.50
Flat sowing <i>fb</i> earthing up + black plastic mulch	66602.08	227133.1	160531.1	2.41
Flat sowing <i>fb</i> earthing up + white plastic mulch	64602.08	214087.5	149485.5	2.31
Flat sowing <i>fb</i> earthing up + One hand weeding <i>fb</i> straw mulch	55052.08	165072.4	110020.3	2.00
Flat sowing <i>fb</i> earthing up + unweeded (control)	44802.08	71834.0	27031.9	0.60
Flat sowing + black plastic mulch	59852.08	189616.0	129763.9	2.17
Flat sowing + white plastic mulch	57852.08	163378.6	105526.5	1.82
Flat sowing + One hand weeding <i>fb</i> straw mulch	48302.08	111643.3	63341.2	1.31
Flat sowing + unweeded (control)	38052.08	20222.0	-17830.1	-0.47

4.5 Quality parameters

4.5.1 N content in seed (%), protein content in seed (%), oil content in seed (%) and N content in stover (%)

N content in seed is one of the important quality parameter and protein content of seed depends upon its N content. The data on effect of planting patterns and weed control treatments on N content in seed, protein content in seed, oil content in seed and N content in stover during 2023-24 and 2024-25 has been presented in Table 4.5.1.

The differences in N content in seed (%) as influenced by planting patterns were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among weed control treatments, the N content in seed (%) was also found to be non-significant during both the years.

The differences in protein content in seed (%) as influenced by planting patterns were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among weed control treatments, protein content in seed (%) was also found to be non-significant during both the years.

The differences in oil content in seed (%) as influenced by planting patterns were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among weed control treatments, oil content in seed (%) was also found to be non-significant during both the years.

The differences in N content in stover (%) as influenced by planting patterns were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among weed control treatments, N content in stover (%) was also found to be non-significant during both the years.

The interactive effect of planting patterns and weed control treatments on N content in seed (%), protein content in seed (%), oil content in seed (%) and N content in stover was found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1).

Table 4.5.1 Effect of planting patterns and weed control treatments on N content in seed (%), protein content in seed (%), oil content in seed (%) and N content in stover (%)

	N content in seed (%)		Protein content in seed (%)		Oil content in seed (%)		N content in stover (%)	
	2023-24	2023-24	2023-24	2023-24	2023-24	2023-24	2023-24	2024-25
Main plots (Planting patterns)								
Two rows per bed (90 cm)	1.47	1.50	9.19	9.39	1.60	1.64	0.41	0.40
Ridge sowing (45 cm)	1.49	1.49	9.31	9.31	1.55	1.60	0.41	0.39
Flat sowing (45 cm) <i>fb</i> earthing up	1.51	1.52	9.45	9.49	1.57	1.66	0.42	0.39
Flat sowing (45 cm)	1.52	1.53	9.47	9.57	1.55	1.60	0.42	0.41
SE(m)±	0.02	0.02	0.11	0.12	0.01	0.01	0.004	0.006
C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Sub plots (Weed control treatments)								
Black plastic mulch	1.49	1.50	9.31	9.39	1.58	1.64	0.41	0.39
White plastic mulch	1.51	1.51	9.41	9.45	1.58	1.64	0.42	0.40
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	1.50	1.52	9.35	9.51	1.57	1.62	0.42	0.40
Unweeded (control)	1.50	1.51	9.35	9.43	1.54	1.60	0.41	0.40
SE(m)±	0.01	0.01	0.08	0.08	0.01	0.01	0.005	0.005
C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction C.D. (5%)								
	NS	NS	NS	NS	NS	NS	NS	NS

4.5.2 N uptake by seed, stover and total N uptake by crop (kg ha⁻¹)

The impact of various planting patterns and weed control treatments on N uptake by seed (kg ha⁻¹), N uptake by stover (kg ha⁻¹) and total N uptake by crop (kg ha⁻¹) at harvest during 2023-24 and 2024-25 has been presented in Table 4.5.2. and graphically depicted in Figure 4.5.1.

The differences in N uptake by seed (kg ha⁻¹) were significant among planting patterns and weed control treatments during 2023-24 (Table 4.5.2). Among planting patterns, flat sowing *fb* earthing up recorded significantly higher uptake of N by seed as compared to all other planting patterns. The N uptake by seed under two rows per bed and flat sowing *fb* earthing up was significantly higher than ridge sowing planting pattern. Flat sown treatment recorded significantly less uptake of N by seed as compared to all other planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher N uptake by seed (kg ha⁻¹) as compared to all other weed control treatments. The N uptake by seed under white plastic mulch was found to be significantly more as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less N uptake by seed (kg ha⁻¹) as compared to all other weed control treatments. Similar results were obtained during 2024-25 also (Table 4.5.2).

The differences in N uptake by stover (kg ha⁻¹) were significant among planting patterns and weed control treatments during 2023-24 and 2024-25 (Table 4.5.2). Among planting patterns, flat sowing *fb* earthing up recorded significantly higher uptake of N by stover as compared to all other planting patterns. The N uptake by stover under two rows per bed was significantly more than ridge sowing treatment. Flat sown treatment recorded significantly less uptake of N by stover as compared to all other planting patterns. Among weed control treatments, black plastic mulch recorded significantly higher N uptake by stover (kg ha⁻¹) as compared to all other weed control treatments. The N uptake by stover under white plastic mulch was found to be significantly more as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly lower N uptake by stover as compared to all other weed control treatments. During 2024-25, among planting patterns, N uptake by stover (kg ha⁻¹) recorded in flat sowing *fb* earthing up was significantly higher than

all other planting methods (Table 4.5.2). The N uptake by stover under two rows per bed was significantly higher than ridge sowing method. The N uptake by stover in ridge sowing and flat sowing treatment was found to be statistically at par with each other and both these treatments recorded significantly less N uptake by stover as compared to flat sowing *fb* earthing up method. Among weed control treatments, crop with the application of black plastic mulch recorded significantly more N uptake by stover (kg ha^{-1}) as compared to all other weed control treatments. The N uptake by stover under white plastic mulch was found to be significantly more as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly lower N uptake by stover as compared to all other weed control treatments.

The differences in total N uptake by crop (kg ha^{-1}) were significant among planting patterns and weed control treatments during 2023-24 and 2024-25 (Table 4.5.2). Among planting patterns, flat sowing *fb* earthing up recorded significantly more total N uptake by crop (uptake by seed + uptake by stover) as compared to all other planting patterns. Total N uptake by crop under two rows per bed was significantly higher than ridge sowing treatment. The total N uptake by crop was significantly less in flat sown crop as compared to all other planting patterns. Among weed control treatments, application of black plastic mulch recorded significantly more total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments. Total N uptake by crop treated with white plastic mulch was found to be significantly more as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less total N uptake by crop as compared to all other weed control treatments. During 2024-25, among planting patterns, total N uptake by crop (kg ha^{-1}) recorded in flat sowing *fb* earthing up was significantly more than all other planting methods (Table 4.5.2). Total N uptake by crop under two rows per bed was significantly higher than ridge sowing treatment. Total N uptake by crop (kg ha^{-1}) in ridge sowing and flat sowing treatment was found to be statistically at par with each other and both these treatments recorded significantly less total N uptake by crop as compared to flat sowing *fb* earthing up. Among weed control treatments, black plastic mulch treated crop recorded significantly higher total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments. Total N uptake by crop applied with

white plastic mulch was found to be significantly more as compared to hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments.

The interactive effect of planting patterns and weed control treatments on N uptake by seed (kg ha^{-1}) and N uptake by stover (kg ha^{-1}) was found to be non-significant at harvest during both the years (Table 4.5.2). However, interactive effects of total uptake of N by crop (kg ha^{-1}) during both years were significant (Table 4.5.2).

During 2023-24, the total uptake of N by crop (kg ha^{-1}) in two rows per bed applied with black plastic mulch was significantly higher as compared to flat sown *fb* earthing up integrated with black plastic mulch (Table 4.5.3). The total N uptake by crop in flat sowing *fb* earthing up applied with black plastic mulch was found to be significantly more than two rows per bed integrated with white plastic mulch. The total N uptake by crop (kg ha^{-1}) in ridge sowing with black plastic mulch was statistically at par with flat sowing *fb* earthing up applied with white plastic mulch. During 2024-25, crop sown by flat sowing *fb* earthing up method and applied with black plastic mulch recorded significantly higher uptake of N by crop (kg ha^{-1}) as compared to application of white plastic mulch under same planting pattern (Table 4.5.3). Total N uptake by crop in two rows per bed method applied with black plastic mulch was statistically at par with the combination of flat sowing *fb* earthing up applied with white plastic mulch. The planting pattern of ridge sowing with white plastic mulch recorded statistically at par total uptake of N by crop as compared to flat sowing *fb* earthing up method and with hand weeding *fb* straw mulch weed control method.

Higher uptake of N by seeds and stover might be due to better utilization of resources and better growth conditions provided by flat sown *fb* earthing up and bed sowing methods. Black mulch and white mulch provided effective weed free conditions which reduced the crop-weed competition and the crop was able to utilize the resources efficiently (Choudhary *et al.*, 2022; Meena *et al.*, 2020).

Table 4.5.2 Effect of planting patterns and weed control treatments on N uptake by seed, stover and crop (kg ha⁻¹)

	N uptake by seed (kg ha ⁻¹)		N uptake by stover (kg ha ⁻¹)		Total N uptake by crop (kg ha ⁻¹)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)						
Two rows per bed (90 cm)	17.5	20.4	25.3	23.2	42.7	43.6
Ridge sowing (45 cm)	14.0	17.5	20.0	19.6	34.1	37.1
Flat sowing (45 cm) <i>fb</i> earthing up	18.6	22.9	27.4	24.5	46.1	47.4
Flat sowing (45 cm)	12.5	16.9	18.5	19.5	31.0	36.4
SE(m)±	0.18	0.26	0.39	0.32	0.49	0.38
C.D. (5%)	0.65	0.91	1.37	1.14	1.72	1.36
Sub plots (Weed control treatments)						
Black plastic mulch	22.5	29.8	32.6	31.4	55.1	61.1
White plastic mulch	20.3	25.2	29.6	27.9	49.9	53.1
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	16.4	16.9	24.8	21.3	41.3	38.2
Unweeded (control)	3.3	5.8	4.2	6.3	7.5	12.1
SE(m)±	0.27	0.35	0.29	0.28	0.48	0.50
C.D. (5%)	0.80	1.02	0.84	0.81	1.40	1.46
Interaction C.D. (5%)						
Interaction C.D. (5%)	NS	NS	NS	NS	2.94	3.01

Table 4.5.3 Interactive effect of planting patterns and weed control treatments on total N uptake by crop (kg ha⁻¹) during 2023-24 and 2024-25.

Total N uptake by crop (kg ha⁻¹) - 2023-24

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	63.5	53.2	48.5	5.7	42.7
Ridge sowing (45 cm)	51.8	45.3	35.1	4.0	34.1
Flat sowing (45 cm) <i>fb</i> earthing up	57.7	57.3	51.7	17.6	46.1
Flat sowing (45 cm)	47.4	43.9	29.6	2.8	31.0
Mean B	55.1	49.9	41.3	7.5	
SE(m)±	0.97				
C.D. (5%)	2.94				

Total N uptake by crop (kg ha⁻¹) - 2024-25

	Black plastic mulch	White plastic mulch	Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	Unweeded (control)	Mean A
Two rows per bed (90 cm)	62.4	60.7	39.0	12.3	43.6
Ridge sowing (45 cm)	60.0	44.3	34.7	9.4	37.1
Flat sowing (45 cm) <i>fb</i> earthing up	66.4	60.8	45.1	17.4	47.4
Flat sowing (45 cm)	55.8	46.7	33.8	9.3	36.4
Mean B	61.1	53.1	38.2	12.1	
SE(m)±	0.77				
C.D. (5%)	3.01				

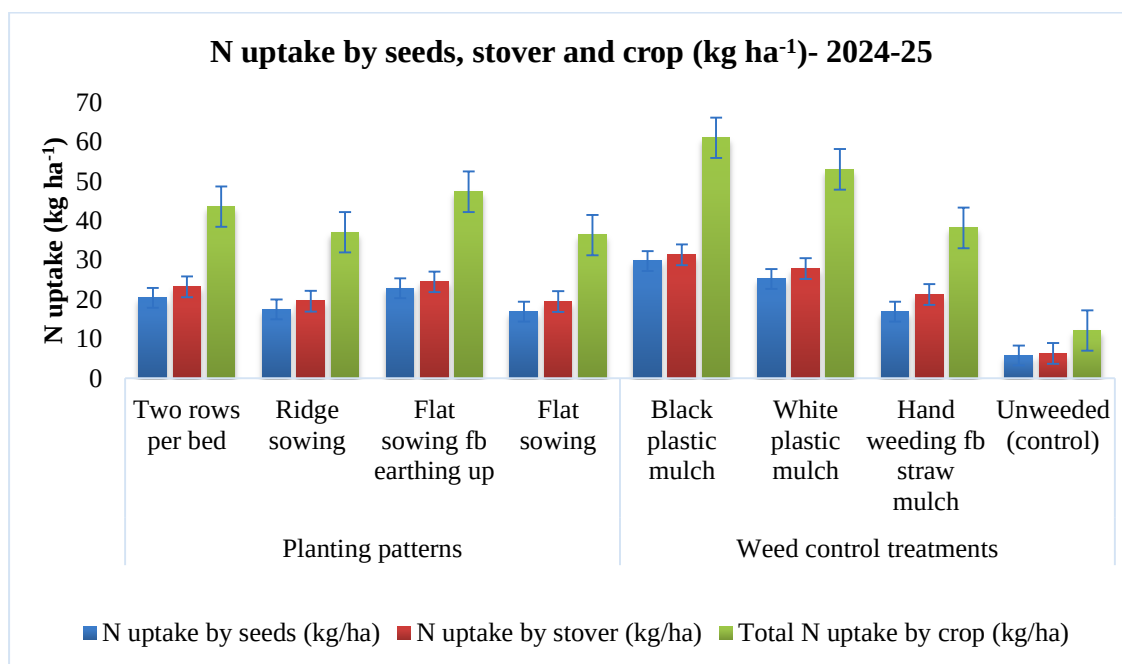
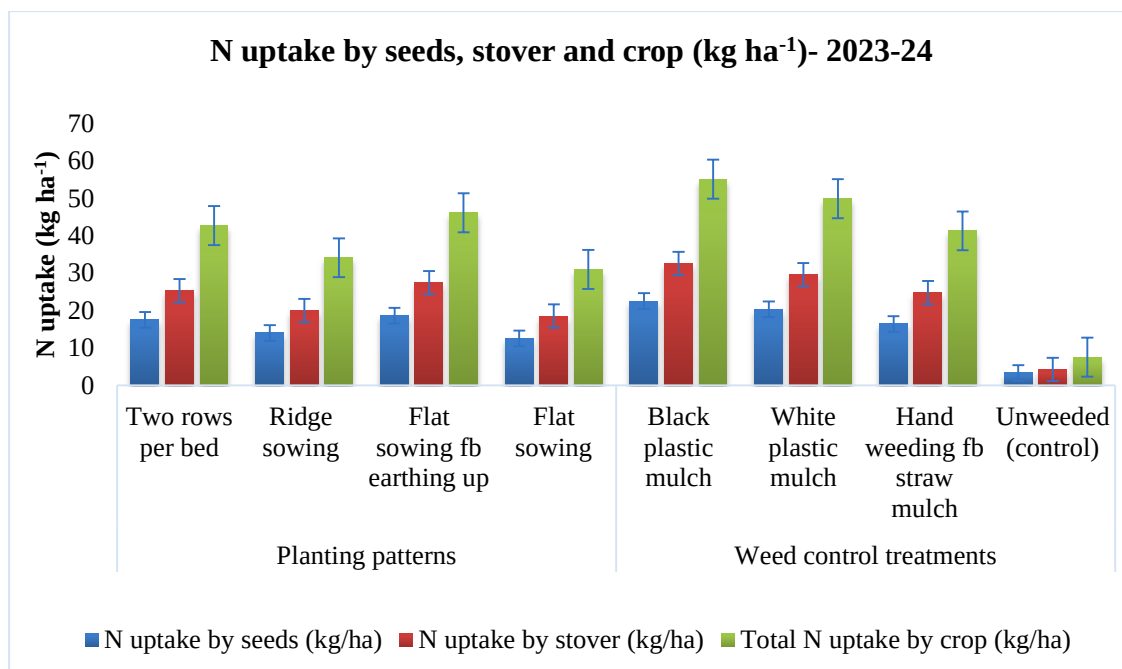


Figure 4.5.1 Effect of planting patterns and weed control treatments on N uptake by seed, stover and crop (kg ha⁻¹)

4.5.3 N content in weeds (%) and N uptake by weeds (kg ha⁻¹)

The impact of various planting patterns and weed control treatments on N content in weeds (%) and N uptake by weeds (kg ha⁻¹) at harvest during 2023-24 and 2024-25 has been presented in Table 4.5.4.

The differences in N content in weeds (%) as influenced by planting patterns were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.4). Among weed control treatments, the N content in weeds (%) was also found to be non-significant during both the years.

The differences in N uptake by weeds (kg ha⁻¹) were significant among planting patterns and weed control treatments during 2023-24 and 2024-25 (Table 4.5.4). Among planting patterns, flat sowing *fb* earthing up recorded significantly less N uptake by weeds (kg ha⁻¹) as compared to all other planting patterns. The N uptake by weeds in two rows per bed treatment was significantly less than ridge sown treatment. Significantly more uptake of N by weeds (kg ha⁻¹) was recorded in flat sowing as compared to all other planting patterns. Among weed control treatments, application of black plastic mulch recorded significantly less uptake of N by weeds (kg ha⁻¹) as compared to hand weeding *fb* straw mulch treatment. The N uptake by weeds in black plastic mulch and white mulch was found to be statistically at par with each other. Unweeded (control) treatment recorded significantly more uptake of N by weeds as compared to all other weed control treatments. During 2024-25, among planting patterns, N uptake by weeds (kg ha⁻¹) in flat sowing *fb* earthing up was significantly less than all other planting methods (Table 4.5.4). The uptake of N by weeds in two rows per bed was significantly less than flat sowing planting method. The uptake of N by weeds in flat sowing and ridge sowing treatments were statistically at par with each other. Among weed control treatments, application of black plastic mulch recorded significantly less uptake of N by weeds (kg ha⁻¹) as compared to hand weeding *fb* straw mulch treatment. The N uptake by weeds in black and white plastic mulch was found to be statistically at par with each other. Unweeded (control) recorded significantly higher uptake of N by weeds as compared to all other weed control treatments.

The interactive effect of planting patterns and weed control treatments on N content in weeds (%) and N uptake by weeds (kg ha^{-1}) was non-significant at harvest during both the years (Table 4.5.4).

Higher nitrogen uptake by weeds in flat sowing method may be due to poor crop growth and availability of proper growing conditions for weed growth. The crop growth was better in two rows per bed and flat sown *fb* earthing up planting patterns due to the availability of better soil physical conditions and the crop suppressed the weeds very effectively. The nitrogen uptake by weeds in weed control treatments was less as compared to unweeded (control) treatment. This might be due to suppression of weeds in black mulch and white mulch application and better crop growth conditions. Similar results were obtained by Sumathi *et al.* (2009) and Dalavai *et al.* (2008).

Table 4.5.4 Effect of planting patterns and weed control treatments on N content in weeds(%) and N uptake by weeds (kg ha⁻¹)

	N content in weeds (%)		N uptake by weeds (kg ha ⁻¹)	
	2023-24	2024-25	2023-24	2024-25
Main plots (Planting patterns)				
Two rows per bed (90 cm)	0.87	0.87	21.0	28.2
Ridge sowing (45 cm)	0.89	0.87	24.6	29.2
Flat sowing (45 cm) <i>fb</i> earthing up	0.91	0.93	18.6	23.7
Flat sowing (45 cm)	0.89	0.88	29.0	31.4
SE(m)±	0.01	0.01	0.66	0.84
C.D. (5%)	NS	NS	2.31	2.97
Sub plots (Weed control treatments)				
Black plastic mulch	0.90	0.89	7.3	5.5
White plastic mulch	0.89	0.90	8.7	7.1
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	0.90	0.88	10.0	19.2
Unweeded (control)	0.88	0.88	67.1	80.7
SE(m)±	0.01	0.01	0.74	0.67
C.D. (5%)	NS	NS	2.17	1.96
Interaction C.D. (5%)	NS	NS	NS	NS

4.6 Soil properties

The important soil properties that influence crop growth and yield are soil pH, EC, OC (%) and available soil N. The most important factor of the soil is its capacity to provide nutrition to the crop.

4.6.1 Soil pH, EC, OC (%) and available soil N (kg ha⁻¹)

Soil pH indicates the nature of the soil, which can be acidic, basic or neutral. Most of the crops require neutral soil pH for better growth and production. Soil EC indicates the nature of soil health which provides information on soil salinity, nutrient availability and fertility of the soil. Soil OC (%) is also an indicator of soil health. It acts as reservoir for carbon sequestration and supports microbial activity. The data on soil pH, EC and OC (%) after harvest has been presented in Table 4.6.1.

The differences in pH of soil samples collected after harvest were found to be non-significant among the planting patterns (Table 4.6.1). Among weed control treatments, the soil pH was non-significant at harvest. The soil pH varied from 7.35 to 7.44.

The soil electrical conductivity (EC) after harvest was found to be non-significant during harvest of the crop among various planting patterns (Table 4.6.1). Among the weed control treatments, soil EC did not differ significantly at harvest. The soil EC of the experiment ranged from 0.31 to 0.32 dS m⁻¹.

The soil OC (%) after harvesting was found to be non-significant among various planting patterns (Table 4.6.1). The weed control treatments did not influence soil OC (%) significantly at harvest of the crop. The soil organic carbon ranged from 0.40 to 0.43%.

The differences in available soil nitrogen were non-significant among various planting patterns (Table 4.6.1). The available soil nitrogen was also found to be non-significant among various weed control treatments. The range of available nitrogen varies from 221.4 to 226.6 kg ha⁻¹.

The interactive effect of planting patterns and weed control treatments on soil pH, EC, OC (%) and available soil nitrogen (kg ha⁻¹) were non-significant in soil collected

after harvest of the crop (Table 4.6.1). The soil parameters were not affected by any of the planting patterns and weed control treatments. Similar results were obtained by Raghuwanshi *et al.* (2024) and Gaurav *et al.* (2018).

Table 4.6.1 Effect of planting patterns and weed control treatments on soil pH, EC (dS m⁻¹), OC (%) and available soil N (kg ha⁻¹) after harvest

	Soil pH	Soil EC (dS m ⁻¹)	Soil OC (%)	Available soil N (kg ha ⁻¹)
Main plots (Planting patterns)				
Two rows per bed (90 cm)	7.36	0.32	0.40	222.8
Ridge sowing (45 cm)	7.41	0.31	0.40	221.3
Flat sowing (45 cm) <i>fb</i> earthing up	7.44	0.32	0.43	226.6
Flat sowing (45 cm)	7.40	0.32	0.42	222.2
SE(m)±	0.02	0.01	0.01	1.46
C.D. (5%)	NS	NS	NS	NS
Sub plots (Weed control treatments)				
Black plastic mulch	7.41	0.31	0.40	223.9
White plastic mulch	7.35	0.32	0.41	225.3
Hand weeding <i>fb</i> straw mulch (5 t ha ⁻¹)	7.43	0.31	0.42	222.2
Unweeded (control)	7.42	0.32	0.42	221.4
SE(m)±	0.02	0.01	0.01	1.33
C.D. (5%)	NS	NS	NS	NS
Interaction C.D. (5%)	NS	NS	NS	NS
Initial values	7.40	0.31	0.43	224.3

Experiment 2- Response of Fennel (*Foeniculum vulgare* Mill.) to nitrogen and FYM in relation to weed control strategies

The results of the experiment of both years are being discussed under the following sub heads.

4.1 Weed parameters

4.1.1. Weed count (m^{-2})

Weed count per unit area is very important parameter indicating weed density in the experimental field as well as type of weed flora present in the experimental plots. Due to large variation in data, it was subjected to square root transformation after adding one to the original values. The data presented in Table 4.1.1 indicates that differences in weed count (m^{-2}) due to weed control treatments and nutrition levels recorded at 60, 90, 120 DAS and at harvest were found to be significant during 2023-24 and 2024-25 (Table 4.1.1).

The differences in weed count (m^{-2}) due to different weed control treatments and nutrition levels recorded at 60 DAS were found to be significant during 2023-24 and 2024-25 (Table 4.1.1). Among weed control treatments, one hand weeding *fb* straw mulch recorded significantly less weed count per m^2 as compared to all other treatments because hand weeding was done before recording the observations. Weed count in pendimethalin *fb* one hand weeding was statistically at par with black plastic mulch treatment. Unweeded (control) treatment recorded significantly more weed count than all other weed control treatments. Among nutrition levels, 25 kg N ha^{-1} recorded significantly less weed count than 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Weed count was found significantly higher in 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} as compared to all other nutrition level treatments. These findings were recorded during both the years.

At 90 DAS, the differences in weed count (m^{-2}) were found to be significant among the various weed control and nutrition level treatments during 2023-24 (Table 4.1.1). Among weed control treatments, black plastic mulch recorded significantly less weed count as compared to all other weed control treatments. The weed count in one hand weeding *fb* straw mulch was statistically at par with pendimethalin *fb* one hand weeding treatment. Unweeded (control) recorded significantly higher weed count as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha^{-1} recorded significantly less weed count as compared to 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Weed count in 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} was statistically at par with 50 kg N ha^{-1} . Weed count was found significantly higher in 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} as compared to all other treatments. Similar findings were recorded during 2024-25 also.

At 120 DAS, the differences in weed count (m^{-2}) were found to be significant among the various weed control and nutrition level treatments during 2023-24 (Table 4.1.1). Among weed control treatments, application of black plastic mulch recorded significantly less weed count as compared to all other weed control treatments. The weed count (m^{-2}) in one hand weeding *fb* straw mulch was statistically at par with pendimethalin *fb* one hand weeding. Unweeded (control) treatment recorded significantly higher weed count than all other weed control treatments. Among nutrition levels, application of 25 kg N ha^{-1} recorded significantly lower weed count as compared to 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Weed count in 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} was statistically at par with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . During 2024-25, the differences in weed count (m^{-2}) were found to be significant among the various weed control treatments and nutrition levels (Table 4.1.1). Among weed control treatments, application of black plastic mulch recorded significantly less weed count as compared to all other weed control treatments. Weed count in one hand weeding *fb* straw mulch was more than pendimethalin *fb* one hand weeding treatment. Unweeded (control) treatment recorded significantly higher weed count as compared to all other weed control treatments. Among nutrition levels, the treatment of 25 kg N ha^{-1} recorded significantly less weed count as compared to 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Weed count in 25 kg N

ha^{-1} + FYM 15.0 t ha^{-1} was statistically at par with 50 kg N ha^{-1} . Weed count in 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} was significantly higher than all other nutrition level treatments.

At harvest, the differences in weed count (m^{-2}) were found to be significant among the various weed control and nutrition level treatments during 2023-24 (Table 4.1.1). Among weed control treatments, the treatment of black plastic mulch recorded significantly less weed count as compared to all other weed control treatments. The weed count in one hand weeding *fb* straw mulch was statistically at par with pendimethalin *fb* one hand weeding treatment. Unweeded (control) treatment recorded significantly higher weed count as compared to all other weed control treatments. Among nutrition levels, application of 25 kg N ha^{-1} recorded significantly less weed count as compared to all other weed control treatments. The weed count in 50 kg N ha^{-1} was found to be significantly lower than 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} treatments. During 2024-25, the differences in weed count (m^{-2}) were found to be significant among the various weed control and nutrition level treatments (Table 4.1.1). Among weed control treatments, black plastic mulch recorded significantly less weed count (m^{-2}) as compared to all other weed control treatments. Unweeded (control) treatment recorded significantly higher weed count as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha^{-1} recorded significantly less weed count as compared to all other weed control treatments. The weed count in the treatment of 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} and 50 kg N ha^{-1} was statistically at par with each other. Significantly higher weed count was found in the treatment of 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} as compared to all other nutrition level treatments.

From the results obtained, it can be concluded that significantly less weed count (m^{-2}) in the superior treatments may be due to effective control of weeds since from germination to harvest of the crop by these treatments. Black plastic mulch acts as a physical barrier which lead to suppression of weeds (Patel *et al.*, 2018). However, in unweeded (control) there was unrestricted weed growth resulting into higher weed count per m^{-2} (Meena and Mehta, 2009). The higher weed count in integrated treatments of nitrogen with organic manure was due to the presence of viable weed

seeds in FYM which were added to the soil. Moreover, fast growing weeds respond quickly to higher dose of nitrogen (Fogawat *et al.*, 2024).

The interactive effect of weed control and nutrition treatments on weed count (m^{-2}) at all periodic intervals was found to be non-significant during 2023-24 and 2024-25 (Table 4.1.1).

Table 4.1.1 Effect of weed control and nutrition level treatments on weed count (m⁻²) at 60, 90, 120 DAS and at harvest

	Weed count (m ⁻²)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)								
Plastic mulch (Black)	3.7 (14)	3.4 (11)	3.8 (14)	2.5 (6)	3.2 (9)	3.3 (10)	3.3 (11)	3.4 (11)
One hand weeding <i>fb</i> straw mulch	1.0 (0)	1.0 (0)	6.9 (46)	8.3 (70)	5.0 (24)	5.4 (29)	4.9 (23)	5.1 (25)
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	3.2 (15)	3.0 (12)	6.5 (43)	7.4 (56)	4.8 (22)	4.9 (24)	4.8 (23)	5.1 (25)
Unweeded (control)	24.1 (585)	23.3 (543)	23.9 (571)	18.4 (338)	17.9 (320)	16.9 (286)	13.0 (171)	12.7 (163)
SE(m)±	0.36	0.15	0.14	0.36	0.17	0.11	0.16	0.11
C.D. (5%)	1.28	0.50	0.48	1.15	0.60	0.35	0.57	0.37
Sub-plots (Nutrition levels)								
25 kg N ha ⁻¹	6.7 (122)	6.8 (128)	9.4 (146)	8.8 (111)	7.0 (84)	7.0 (77)	5.5 (41)	5.7 (42)
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	8.6 (159)	8.2 (147)	10.4 (172)	9.2 (115)	8.0 (98)	7.8 (89)	6.9 (63)	6.8 (59)
50 kg N ha ⁻¹	7.0 (133)	7.0 (134)	10.0 (159)	9.0 (114)	7.4 (86)	7.4 (84)	6.2 (55)	6.4 (54)
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	9.7 (200)	8.6 (157)	11.3 (197)	9.8 (130)	8.4 (108)	8.3 (100)	7.4 (69)	7.4 (69)
SE(m)±	0.28	0.13	0.25	0.22	0.14	0.16	0.19	0.16
C.D. (5%)	0.81	0.36	0.73	0.63	0.41	0.45	0.55	0.45
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Note: Values within parenthesis are original values and without parentheses are transformed values. Data was subjected to square root transformation ($\sqrt{x+1}$) by adding one to original values for statistical analysis.								

4.1.2 Weed dry matter (q ha^{-1})

Recording dry matter of weeds per unit area (kg ha^{-1} or q ha^{-1}) is more valid parameter than weed count as sometimes number of weeds per unit area may be high and growth may be less, and this type of data is misleading. So, recording dry matter of weeds is very valid parameter which indicates actual losses due to weeds in a particular crop. The data presented in Table 4.1.2 indicates that differences in weed dry matter (q ha^{-1}) due to weed control treatments and nutrition levels recorded 60, 90, 120 DAS and at harvest were found to be significant during both the years (Table 4.1.2). The periodic weed dry matter data has been depicted graphically in Figure 4.1.1.

The differences in weed dry matter (q ha^{-1}) due to weed control treatments and nutrition levels recorded 60 DAS were found to be significant during 2023-24 (Table 4.1.2). Among weed control treatments, the weed dry matter in black plastic mulch, one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding were statistically at par with each other. Unweeded (control) treatment recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha^{-1} recorded significantly less weed dry matter than $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$. Weed dry matter was found to be significantly higher in $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ as compared to all other treatments. During 2024-25, the differences in weed dry matter (kg ha^{-1}) were found to be significant among the various weed control treatments and nutrition levels (Table 4.1.2). Among weed control treatments, weed dry matter in black plastic mulch, pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch treatments were found to be statistically at par with each other. Unweeded (control) treatment recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha^{-1} recorded significantly less weed dry matter than $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ treatments. Significantly higher weed dry matter was found in $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ as compared to all other nutritional treatments.

At 90 DAS, the differences in weed dry matter (q ha^{-1}) due to weed control treatments and nutrition levels were found to be significant during 2023-24 (Table 4.1.2). Among weed control treatments, black plastic mulch recorded significantly less dry weight of

weeds than one hand weeding *fb* straw mulch. The weed dry matter in black plastic mulch and pendimethalin *fb* one hand weeding treatments was statistically at par with each other. Unweeded (control) treatment recorded significantly more weed dry matter as compared to all other weed control treatments. Among nutrition level treatments, 25 kg N ha⁻¹ recorded significantly less weed dry matter than 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments. Significantly higher weed dry matter was found in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in weed dry matter were found to be significant among the various weed control and nutrition level treatments (Table 4.1.2). Among weed control treatments, weed dry matter (q ha⁻¹) in black plastic mulch was found to be significantly less as compared to all other treatments. Pendimethalin *fb* one hand weeding recorded significantly less weed dry matter as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha⁻¹ recorded significantly less weed dry matter as compared to all other treatments. However, weed dry matter recorded in the treatment of 50 kg N ha⁻¹, 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with each other.

At 120 DAS, the differences in weed dry matter (q ha⁻¹) due to weed control and nutrition level treatments were found to be significant during 2023-24 (Table 4.1.2). Among weed control treatments, weed dry matter in black plastic mulch was found to be significantly less as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly less weed dry matter (q ha⁻¹) as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition levels, 25 kg N ha⁻¹ recorded significantly less weed dry matter as compared to all other nutrition level treatments. Application of 50 kg N ha⁻¹ recorded significantly less weed dry matter as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more weed dry matter as compared to all other nutrition level treatments. Similar results were obtained during 2024-25 also.

At harvest, the differences in weed dry matter (q ha^{-1}) due to weed control treatments were found to be significant during 2023-24 (Table 4.1.2). Among weed control treatments, weed dry matter in black plastic mulch was found to be significantly less as compared to one hand weeding *fb* straw mulch treatment. The weed dry matter in black plastic mulch and pendimethalin *fb* one hand weeding were statistically at par with each other. Unweeded (control) treatment recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition level treatments, application of 25 kg N ha^{-1} recorded significantly less weed dry matter (q ha^{-1}) as compared to all other nutritional level treatments. Significantly less weed dry matter was recorded in 25 kg N ha^{-1} as compared to all other nutritional level treatments. During 2024-25, the differences in weed dry matter were found to be significant among the various weed control and nutrition level treatments (Table 4.1.2). Among weed control treatments, weed dry matter in black plastic mulch was found to be significantly less as compared to all other weed control treatments. Unweeded (control) recorded significantly higher weed dry matter as compared to all other weed control treatments. Among nutrition level treatments, 25 kg N ha^{-1} recorded significantly less weed dry matter as compared to all other treatments. Application of 50 kg N ha^{-1} recorded significantly less weed dry matter as compared to $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ treatments. Significantly more weed dry matter was recorded in $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ as compared to all other nutrition level treatments.

Plastic mulching treatment has a good weed-suppressing effect which was due to limited amount of sunlight reaching the soil surface and ultimately reducing the germination and growth of weeds. Therefore, weed dry matter was less in black mulch treatment. The unweeded (control) treatment recorded the highest dry matter of weeds due to uncontrolled condition which favoured the growth of weeds leading to increased weed dry matter. Higher dose of fertilizer and FYM enhanced the weed growth due to utilization of more nutrients by the weeds. The viable seeds present in FYM also germinate and grow vigorously resulting in higher weed dry matter (Patel *et al.*, 2019).

The interactive effect of weed control treatments and nutrition levels on weed dry matter (q ha^{-1}) was non-significant at 60, 90 DAS and at harvest but it was significant at 120 DAS during both the years (Table 4.1.3).

During 2023-24, weed dry matter in black plastic mulch integrated with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} was found to be significantly less as compared to pendimethalin *fb* one hand weeding integrated with 50 kg N ha^{-1} . The weed dry matter in black plastic mulch in combination with 25 kg N ha^{-1} was found to be significantly less as compared to pendimethalin *fb* one hand weeding treatment supplied with 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Weed dry matter in (q ha^{-1}) the treatment combination of one hand weeding *fb* straw mulch supplied with 25 kg N ha^{-1} was found to be statistically at par with pendimethalin *fb* one hand weeding with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Application of 50 kg N ha^{-1} recorded significantly less dry matter of weeds as compared to the crop supplied with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} under similar weed control treatment i.e. application of black mulch. During 2024-25, the weed dry matter in black plastic mulch applied with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} was found to be significantly less as compared to pendimethalin *fb* one hand weeding applied with 25 kg N ha^{-1} (Table 4.3.1). Weed dry matter in combination of one hand weeding *fb* straw mulch with 50 kg N ha^{-1} was found to be statistically at par with the combination of pendimethalin *fb* one hand weeding with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . One hand weeding *fb* straw mulch applied with 25 kg N ha^{-1} produced significantly higher dry matter of weeds as compared to the treatment combination of black plastic mulch with application of 50 kg N ha^{-1} along with 15.0 t ha^{-1} of FYM, indicating that black plastic mulch can control high intensity of weeds.

Table 4.1.2 Effect of weed control and nutrition level treatments on weed dry matter (q ha⁻¹) at 60, 90, 120 DAS and at harvest

	Weed dry matter (q ha ⁻¹)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)								
Plastic mulch (Black)	1.1 (0)	1.1 (0)	1.6 (2)	1.8 (2)	2.0 (3)	2.3 (4)	2.7 (6)	2.9 (8)
One hand weeding <i>fb</i> straw mulch	1.1 (0)	1.1 (0)	2.2 (4)	2.8 (7)	3.4 (11)	4.2 (17)	4.3 (18)	5.1 (26)
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1.1 (0)	1.1 (0)	1.9 (3)	2.1 (4)	2.7 (6)	3.9 (15)	3.7 (13)	4.4 (19)
Unweeded (control)	2.9 (8)	3.1 (9)	7.1 (50)	5.9 (35)	9.1 (81)	9.0 (81)	9.5 (89)	9.7 (94)
SE(m)±	0.04	0.01	0.09	0.04	0.03	0.05	0.10	0.06
C.D. (5%)	0.14	0.03	0.32	0.12	0.10	0.17	0.88	0.20
Sub-plots (Nutrition levels)								
25 kg N ha ⁻¹	1.4 (1)	1.5 (2)	2.9 (12)	2.9 (10)	3.9 (22)	4.4 (23)	4.6 (27)	5.2 (32)
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.5 (2)	1.6 (2)	3.3 (15)	3.3 (13)	4.4 (26)	5.0 (31)	5.1 (33)	5.6 (37)
50 kg N ha ⁻¹	1.4 (2)	1.5 (2)	3.0 (13)	3.2 (12)	4.1 (24)	4.7 (27)	5.1 (32)	5.4 (35)
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.8 (3)	1.8 (3)	3.6 (17)	3.3 (13)	4.6 (29)	5.3 (35)	5.3 (35)	6.0 (42)
SE(m)±	0.02	0.01	0.08	0.05	0.05	0.06	0.10	0.06
C.D. (5%)	0.06	0.03	0.23	0.13	0.13	0.16	0.28	0.16
Interaction C.D. (5%)	NS	NS	NS	NS	0.27	0.32	NS	NS
Note: Values within parenthesis are original values and without parentheses are transformed values. Data was subjected to square root transformation ($\sqrt{x + 1}$) by adding one to original values for statistical analysis.								

Table 4.1.3 Interactive effect of weed control and nutrition level treatments on weed dry matter (q ha^{-1}) at 120 DAS during 2023-24 and 2024-25

Weed dry matter (q ha^{-1}) - 2023-24 at 120 DAS

	25 kg N ha^{-1}	25 kg N ha^{-1} + FYM 15.0 t ha^{-1}	50 kg N ha^{-1}	50 kg N ha^{-1} + FYM 15.0 t ha^{-1}	Mean A
Plastic mulch (Black)	1.8	2.0	1.8	2.3	2.0
One hand weeding <i>fb</i> straw mulch	3.2	3.5	3.3	3.6	3.4
Pendimethalin (0.45 kg ha^{-1}) <i>fb</i> one hand weeding	2.0	2.8	2.6	3.2	2.7
Unweeded (control)	8.7	9.2	8.8	9.5	9.1
Mean B	3.9	4.4	4.1	4.6	
SE(m)±	0.06				
C.D. (5%)	0.27				

Weed dry matter (q ha^{-1}) - 2024-25 at 120 DAS

	25 kg N ha^{-1}	25 kg N ha^{-1} + FYM 15.0 t ha^{-1}	50 kg N ha^{-1}	50 kg N ha^{-1} + FYM 15.0 t ha^{-1}	Mean A
Plastic mulch (Black)	2.2	2.3	2.2	2.5	2.3
One hand weeding <i>fb</i> straw mulch	3.8	4.3	4.1	4.6	4.2
Pendimethalin (0.45 kg ha^{-1}) <i>fb</i> one hand weeding	3.6	4.2	3.7	4.2	3.9
Unweeded (control)	7.9	9.4	8.7	9.9	9.0
Mean B	4.4	5.0	4.7	5.3	
SE(m)±	0.10				
C.D. (5%)	0.32				

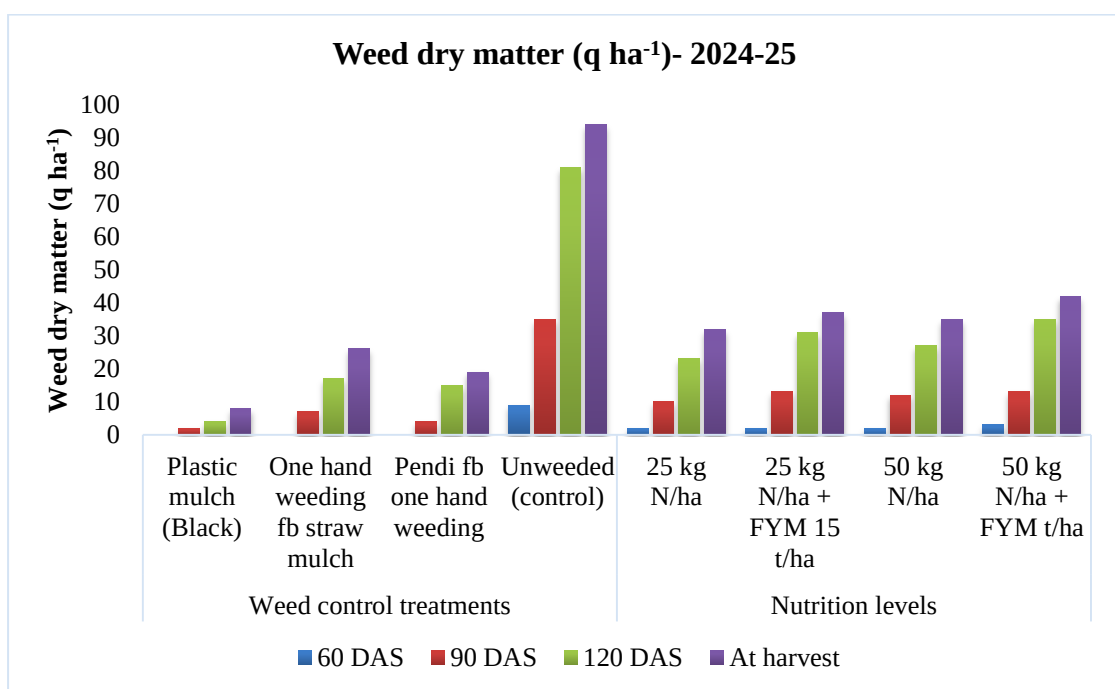
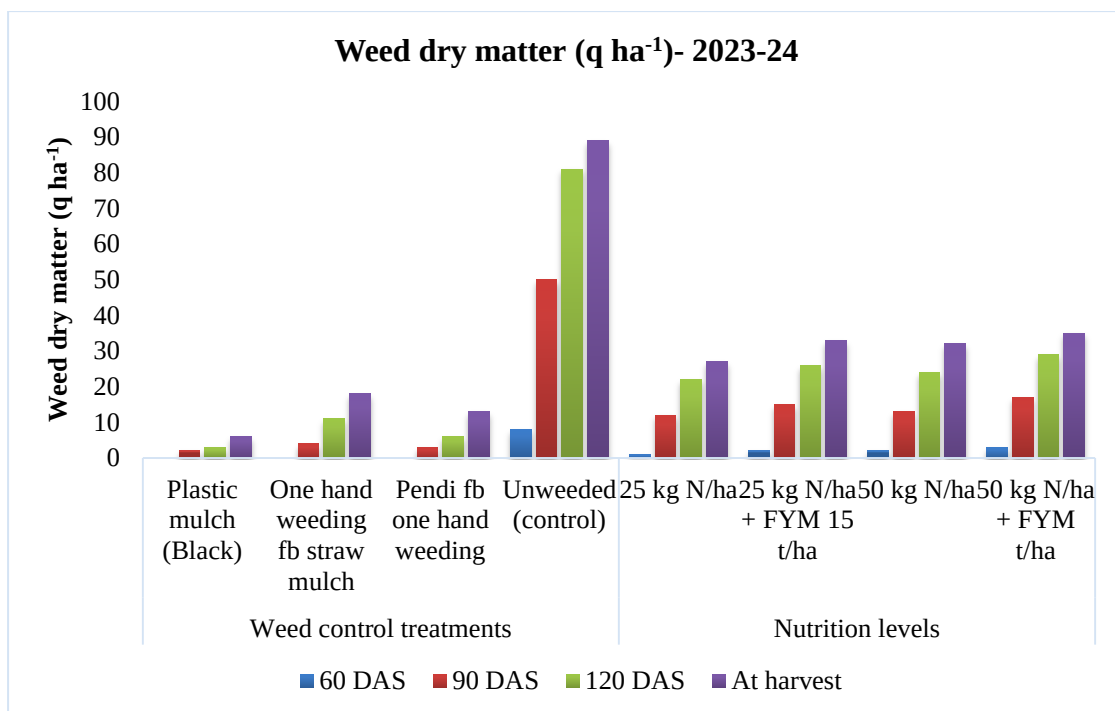


Figure 4.1.1 Effect of weed control and nutrition level treatments on weed dry matter (q ha⁻¹) at 60, 90, 120 DAS and at harvest.

4.1.3 Weed control efficiency (%)

The data presented in Table 4.1.4 shows the effect of weed control treatments and nutrition levels on weed control efficiency (WCE) at harvest during 2023-24 and 2024-2025.

During 2023-24, among weed control treatments, black plastic mulch recorded highest weed control efficiency (93.25%) followed by pendimethalin *fb* one hand weeding (85.39%) treatment (Table 4.1.4). Weed control efficiency (%) in one hand weeding *fb* straw mulch was lowest (79.77%) among all the weed control treatments. Among nutrition levels, 25 kg N ha⁻¹ recorded highest (69.66%) weed control efficiency followed by 50 kg N ha⁻¹ (64.04%) treatment. Weed control efficiency with the application of 50 kg N ha⁻¹ was higher (64.04%) than 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (62.92%). Lowest weed control efficiency (60.67%) was observed in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. During 2024-25, weed control efficiency in black plastic mulch was highest (92.92%) among all the weed control treatments followed by pendimethalin *fb* one hand weeding (87.30%) treatment (Table 4.1.4). Lowest weed control efficiency (79.77%) was found in one hand weeding *fb* straw mulch, among all the weed control treatments. Among nutrition levels, 25 kg N ha⁻¹ (69.55%) recorded highest weed control efficiency followed by 50 kg N ha⁻¹ (64.94%). Weed control efficiency in 50 kg N ha⁻¹ was higher than 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (64.15%). Application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded lowest weed control efficiency (61.46%) compared to other nutrition levels.

The higher weed control efficiency under black plastic mulch and pendimethalin *fb* one hand weeding treatments might be due to less weed growth and their biomass due to suppression of weeds effectively. Weeds were controlled more efficiently in these treatments. This was due to less interception of light and availability of better initial weed free conditions for crop growth and development. Less WCE in both FYM treatments may be due to addition of more seed bank and better growth of weeds. These findings were in line with Kumar *et al.* (2023) and Patel *et al.* (2019).

Table 4.1.4 Effect of weed control and nutrition level treatments on weed control efficiency (%) at harvest

	Weed control efficiency (%)	
	At harvest	
	2023-24	2024-25
Main plots (Weed control treatments)		
Plastic mulch (Black)	93.25	91.82
One hand weeding <i>fb</i> straw mulch	79.77	72.92
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	85.39	80.04
Unweeded (control)	-	-
Sub-plots (Nutrition levels)		
25 kg N ha ⁻¹	69.66	65.60
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	62.92	60.29
50 kg N ha ⁻¹	64.04	63.05
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	60.67	55.83
Note: Weed control efficiency was calculated from weed dry matter at harvest. Data for WCE (%) was not analysed statistically.		

4.2 Crop growth parameters

Crop growth parameters are essential indicators of the crop's physiological condition, developmental stage and hence yield potential. Together, these characteristics provide information on how the crop reacts to resource availability, environmental factors, and agronomic techniques. Among these, plant height, dry matter accumulation and number of branches per plant are especially important for assessing growth dynamics and estimating production.

4.2.1 Plant height (cm)

The data presented in Table 4.2.1 and Figure 4.2.1 indicates that differences in plant height (cm) due to weed control treatments and nutrition levels recorded at 60, 90, 120 DAS and at harvest were found to be significant during both the years.

The differences in plant height (cm) due to weed control treatments and nutrition levels at 60 DAS were found to be significant during 2023-24 (Table 4.2.1). Among weed control treatments, the plant height in black plastic mulch, was found to be significantly higher than all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height (cm) as compared to one hand weeding *fb* straw mulch. The plant height (cm) was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant height as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Plant height in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with each other. Significantly less plant height (cm) was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-2025, the differences in plant height (cm) were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.1). Among weed control treatments, plant height in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height as compared to one hand weeding *fb* straw mulch. The plant height (cm) was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, application of 50 kg N ha⁻¹ +

FYM 15.0 t ha⁻¹ recorded significantly higher plant height as compared to all other nutrition level treatments. Significantly more plant height was recorded in treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ treatments. The plant height was significantly lower in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

At 90 DAS, the differences in plant height (cm) were found to be significant for weed control treatments and nutrition levels during the year 2023-24 as shown in Table 4.2.1. Among weed control treatments, plant height (cm) in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height (cm) as compared to one hand weeding *fb* straw mulch treatment. The plant height was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant height as compared to all other treatments. Plant height in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ treatments were found to be statistically at par with each other. Significantly less plant height (cm) was recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels. During 2024-25, the differences in plant height (cm) were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.1). Among weed control treatments, plant height in black plastic mulch was found to be significantly higher as compared to all other treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height (cm) as compared to one hand weeding *fb* straw mulch treatment. The plant height was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, integrated treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant height as compared to all other treatments. Plant height (cm) recorded in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ treatments. The plant height was significantly less in 25 kg N ha⁻¹ as compared to all other nutrition levels.

At 120 DAS, the differences in plant height (cm) were found to be significant for weed control and nutrition level treatments during the year 2023-24 as shown in Table

4.2.1. Among weed control treatments, plant height in black plastic mulch was found to be significantly higher as compared to all other treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height (cm) as compared to one hand weeding *fb* straw mulch treatment. The plant height was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, plant height (cm) in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with the treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Significantly more plant height was observed in integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. During 2024-2025, the differences in plant height (cm) were found to be significant among the various weed control and nutrition level treatments (Table 4.2.1). Among weed control treatments, plant height (cm) in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height as compared to one hand weeding *fb* straw mulch treatment. The plant height (cm) was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, plant height in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with the treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Plant height (cm) in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with each other. Significantly less plant height was recorded in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments.

At harvest, the differences in plant height (cm) were found to be significant for weed control and nutrition level treatments during the year 2023-24 as shown in Table 4.2.1. Among weed control treatments, plant height (cm) in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant height as compared to one hand weeding *fb* straw mulch treatment. The plant height was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, plant height in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatment. Plant height in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par

with each other. Application of 25 kg N ha^{-1} recorded significantly less plant height as compared to $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$. During 2024-2025, the differences in plant height (cm) were found to be significant among the various weed control and nutrition level treatments (Table 4.2.1). Among weed control treatments, plant height (cm) in black plastic mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Plant height (cm) in black plastic mulch was significantly higher than one hand weeding *fb* straw mulch treatment. The plant height was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, plant height (cm) in $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was found to be significantly higher as compared to all other nutrition level treatments. Application of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher plant height as compared to the treatments of 50 kg N ha^{-1} and 25 kg N ha^{-1} . Plant height in 25 kg N ha^{-1} was significantly less as compared to all other nutrition level treatments.

Among weed control treatments, application of black mulch gave very effective weed control in fennel as it provided physical barrier for weed seed germination and growth. The higher plant height (cm) in black plastic mulch might be due to better utilization of available nutrients and moisture by the crop which resulted from lesser cropweed competition that leads to vigorous growth of crop. Similar findings were reported by Kaur *et al.* (2022). The combination of inorganic and organic manure (FYM) ensures availability of all the micro and macro nutrients readily throughout the growing period. Therefore, the plant height is more in these treatments. These findings were similar to that of Shivran & Jat (2015).

The interactive effect of weed control treatments and nutrition levels on plant height (cm) was found to be non-significant during 2023-24 and 2024-25 (Table 4.2.1).

Table 4.2.1 Effect of weed control and nutrition level treatments on plant height (cm) at 60, 90, 120 DAS and at harvest

Treatment details	Plant height (cm)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)								
Plastic mulch (Black)	45.4	45.6	108.4	107.0	163.9	179.1	184.8	190.7
One hand weeding fb straw mulch	28.9	30.4	77.6	85.8	127.7	148.3	159.2	171.5
Pendimethalin (0.45 kg ha ⁻¹) fb one hand weeding	36.3	37.2	95.1	100.3	143.2	170.4	174.0	183.2
Unweeded (control)	27.0	26.7	68.3	70.0	96.4	107.8	114.4	118.9
SE(m)±	0.53	0.44	1.58	1.43	2.08	1.06	2.81	2.73
C.D. (5%)	1.85	1.41	5.56	4.63	7.35	3.44	9.90	8.85
Sub-plots (Nutrition levels)								
25 kg N ha ⁻¹	31.0	32.0	80.3	85.3	122.0	147.1	152.7	156.6
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	35.8	35.6	89.1	92.2	137.9	153.1	159.5	169.7
50 kg N ha ⁻¹	33.5	34.4	87.5	88.9	130.5	149.0	155.7	163.0
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	37.2	37.7	92.4	96.8	140.7	156.5	164.5	175.0
SE(m)±	0.59	0.41	0.76	0.94	1.02	1.53	2.22	1.38
C.D. (5%)	1.74	1.18	2.23	2.69	3.00	4.40	6.51	3.99
Interaction C.D. (5%)								
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS

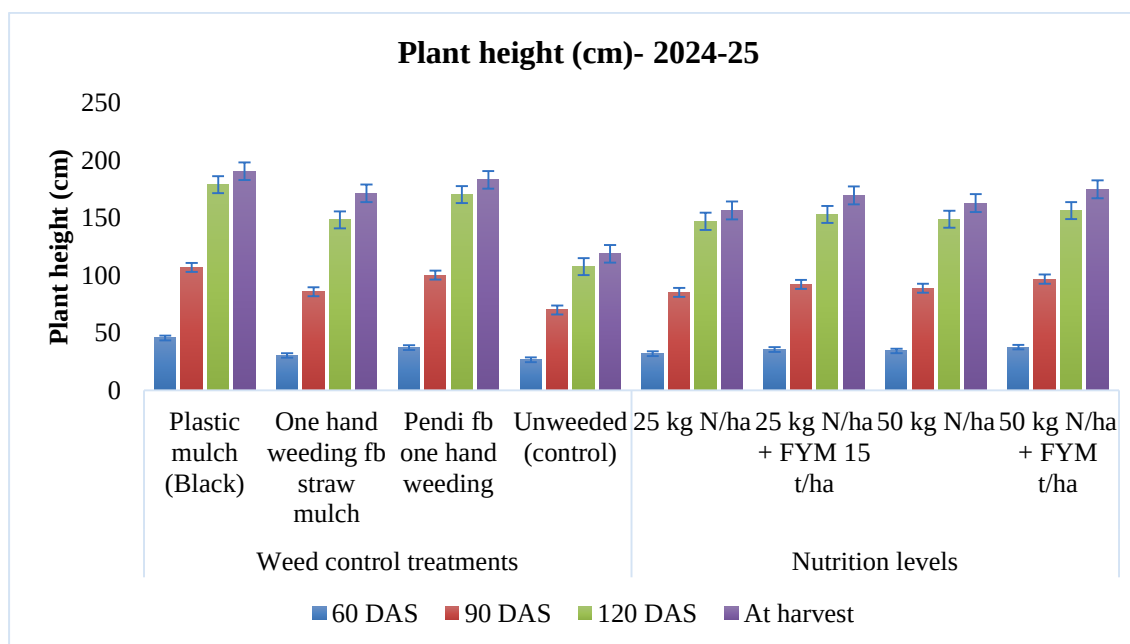
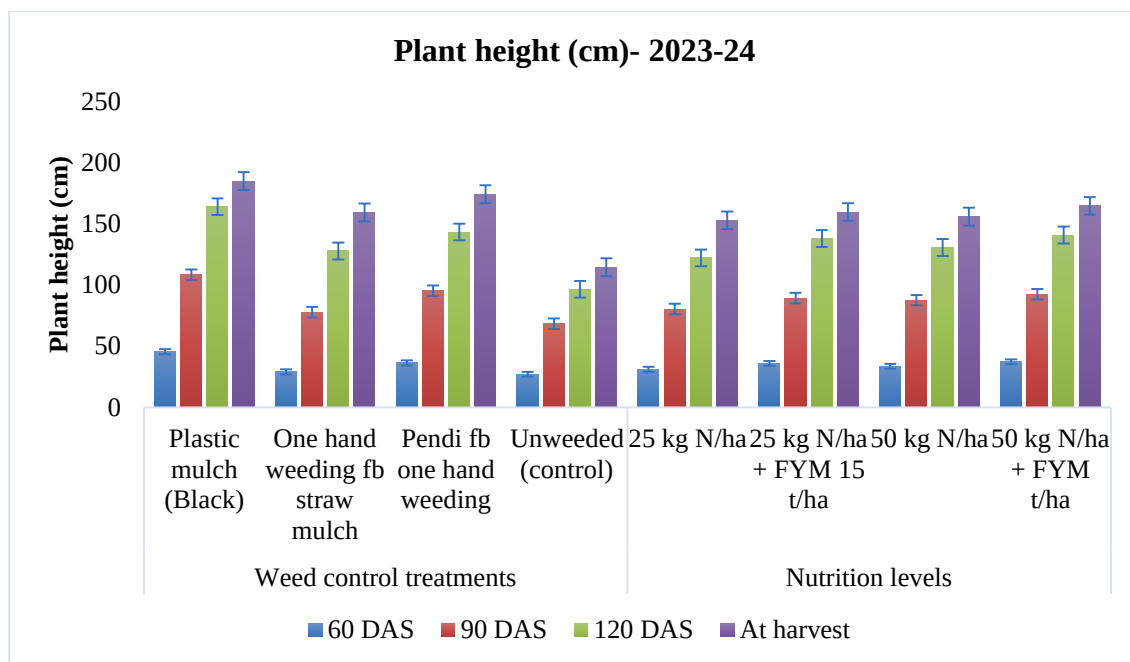


Figure 4.2.1 Effect of weed control and nutrition level treatments on plant height (cm) at 60, 90, 120 DAS and at harvest.

4.2.2 Plant dry matter (g plant⁻¹)

The data presented in Table 4.2.2 indicates that differences in plant dry matter (g plant⁻¹) due to weed control treatments and nutrition levels recorded at 60, 90, 120 DAS and at harvest were found to be significant during both the years (Table 4.2.2). Data pertaining to dry matter (g plant⁻¹) has been graphically depicted in Figure 4.2.2.

The differences in plant dry matter (g plant⁻¹) due to weed control treatments and nutrition levels at 60 DAS were found to be significant during 2023-24 (Table 4.2.2). Among weed control treatments, the plant dry matter (g plant⁻¹) in black plastic mulch, was found to be significantly more than all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly more plant dry matter as compared to one hand weeding *fb* straw mulch. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more plant dry matter as compared to alone application of 25 kg N ha⁻¹. Plant dry matter in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹, 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ treatments were statistically at par with each other. Significantly less plant dry matter (g plant⁻¹) was recorded in 25 kg N ha⁻¹ as compared to integrated treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. During 2024-25, the differences in plant dry matter (g plant⁻¹) were found to be significant among the various weed control and nutrition level treatments (Table 4.2.2). Among weed control treatments, plant dry matter in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter as compared to one hand weeding *fb* straw mulch treatment. The plant dry matter (g plant⁻¹) was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant dry matter (g plant⁻¹) as compared to all other treatments. Application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more plant dry matter as compared to the treatments of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The plant dry matter was significantly less in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

At 90 DAS, the differences in plant dry matter (g plant^{-1}) due to weed control and nutrition level treatments were found to be significant during 2023-24 (Table 4.2.2). Among weed control treatments, the plant dry matter (g plant^{-1}) in black plastic mulch, was found to be significantly higher than all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter (g plant^{-1}) as compared to one hand weeding *fb* straw mulch treatment. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly more plant dry matter as compared to all other nutritional treatments. Plant dry matter in 50 kg N ha^{-1} was statistically at par with the treatment of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$. Significantly less plant dry matter was found in 25 kg N ha^{-1} as compared to all other nutrition levels. During 2024-25, the differences in plant dry matter (g plant^{-1}) were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.2). Among weed control treatments, plant dry matter in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter as compared to one hand weeding *fb* straw mulch treatment. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition level treatments, application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher plant dry matter (g plant^{-1}) as compared to all other treatments. The application of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly more plant dry matter as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . The plant dry matter was significantly less in 25 kg N ha^{-1} as compared to all other nutrition level treatments.

At 120 DAS, the differences in plant dry matter (g plant^{-1}) due to weed control and nutrition level treatments were found to be significant during 2023-24 (Table 4.2.2). Among weed control treatments, the plant dry matter in black plastic mulch, was found to be significantly higher than all other treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter (g plant^{-1}) as compared to one hand weeding *fb* straw mulch treatment. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among

nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant dry matter as compared to all other treatments. Plant dry matter recorded in the treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The plant dry matter (g plant⁻¹) was significantly less in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in plant dry matter (g plant⁻¹) were found to be significant among the various weed control and nutrition level treatments (Table 4.2.2). Among weed control treatments, plant dry matter in black plastic mulch was found to be significantly higher as compared to one hand weeding *fb* straw mulch. Plant dry matter in pendimethalin *fb* one hand weeding was statistically at par with black plastic mulch. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition level treatments, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant dry matter as compared to all other treatments. Integrated application of 5 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more plant dry matter as compared to the treatment of alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The plant dry matter was significantly less in 25 kg N ha⁻¹ as compared to all other nutrition levels.

At harvest, the differences in plant dry matter (g plant⁻¹) due to weed control treatments and nutrition levels were found to be significant during 2023-24 (Table 4.2.2). Among weed control treatments, the plant dry matter in black plastic mulch was found to be significantly higher than all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter as compared to one hand weeding *fb* straw mulch. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more plant dry matter as compared to 25 kg N ha⁻¹. Plant dry matter in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ was statistically at par with each other. Application of 25 kg N ha⁻¹ recorded significantly less plant dry matter as compared to 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments. During 2024-25, the differences in plant dry matter (g plant⁻¹) were significant among the various weed control and nutrition level treatments (Table

4.2.2). Among weed control treatments, the plant dry matter in black plastic mulch was found to be significantly higher than all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher plant dry matter as compared to one hand weeding *fb* straw mulch. The plant dry matter was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher plant dry matter (g plant⁻¹) as compared to application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Plant dry matter in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with 50 kg N ha⁻¹. The plant dry matter was significantly less in 25 kg N ha⁻¹ as compared to all other nutrition levels.

The higher dry matter of the crop in black plastic mulch treatment might be due to less crop weed competition which enhances the root activity and nutrient uptake of crop. Better growth conditions are provided to the crop under black mulch, which lead to improved photosynthesis and more photosynthates are formed which are then converted into dry matter (Chaudhary, 2000). Higher dose of nitrogen integrated with FYM, directly increases the photosynthetic activity and enhances the biomass production of the crop. These findings were similar to those of Javiya *et al.* (2017).

The interactive effect of weed control treatments and nutrition levels on plant dry matter (g plant⁻¹) was non-significant at 60, 90, 120 DAS and at harvest during both years except 60 DAS and 90 DAS during 2024-25 (Table 4.2.3).

The interactive effect of weed control treatments and nutrition levels on plant dry matter (g plant⁻¹) was significant at 60 and 90 DAS during 2024-25 (Table 4.2.3). At 60 DAS, plant dry matter in the combination of black plastic mulch with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher as compared to treatment combination of pendimethalin *fb* hand weeding with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (Table 4.2.3). Plant dry matter in black plastic mulch with 25 kg N ha⁻¹ was found to be at par with application of pendimethalin *fb* hand weeding with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The combination of one hand weeding *fb* straw mulch and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded statistically at par plant dry matter (g plant⁻¹) with pendimethalin *fb* hand weeding with 25 kg N ha⁻¹. At 90 DAS, black plastic mulch applied with 50 kg N ha⁻¹

+ FYM 15.0 t ha⁻¹ recorded statistically at par plant dry matter with pendimethalin *fb* hand weeding under same nutrition level (Table 4.2.3). The plant dry matter in pendimethalin *fb* hand weeding applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher as compared to hand weeding *fb* straw mulch and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Pendimethalin *fb* one hand weeding applied with 25 kg N ha⁻¹ recorded statistically at par plant dry matter with one hand weeding *fb* straw mulch and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Crop applied with black plastic mulch and 25 kg N ha⁻¹ recorded significantly more plant dry matter as compared to pre-emergence application of pendimethalin *fb* hand weeding but supplied with 50 kg N ha⁻¹.

Table 4.2.2 Effect of weed control and nutrition level treatments on plant dry matter (g plant⁻¹) at 60, 90, 120 DAS and at harvest

Treatment details	Plant dry matter (g plant ⁻¹)							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)								
Plastic mulch (Black)	1.9	1.8	28.3	33.4	125.3	145.7	243.4	346.7
One hand weeding <i>fb</i> straw mulch	0.7	0.8	18.5	18.1	72.3	76.1	205.0	266.0
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1.4	1.4	20.6	27.7	102.3	139.3	228.9	309.1
Unweeded (control)	0.4	0.4	8.0	12.5	20.5	43.1	50.9	55.7
SE(m)±	0.03	0.04	0.35	0.34	1.52	2.25	3.91	6.50
C.D. (5%)	0.12	0.12	1.22	1.10	5.38	7.31	13.80	21.09
Sub-plots (Nutrition levels)								
25 kg N ha ⁻¹	1.0	0.9	14.0	17.0	64.1	87.5	154.9	209.7
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.2	1.2	20.3	23.8	85.3	106.0	187.7	254.1
50 kg N ha ⁻¹	1.1	1.0	18.7	21.1	75.3	98.2	185.9	236.3
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.2	1.3	22.4	29.8	95.8	112.6	199.7	277.5
SE(m)±	0.04	0.02	0.60	0.44	2.55	2.25	6.10	8.65
C.D. (5%)	0.11	0.06	1.76	1.26	7.48	6.49	17.90	24.90
Interaction C.D. (5%)	NS	0.13	NS	2.57	NS	NS	NS	NS

Table 4.2.3 Interactive effect of weed control and nutrition level treatments on plant dry matter (g plant⁻¹) at 60 and 90 DAS during 2024-25

Dry matter (g plant⁻¹) - 60 DAS (2024-25)

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	1.7	1.9	1.8	1.9	1.8
One hand weeding <i>fb</i> straw mulch	0.6	0.9	0.6	1.1	0.8
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1.1	1.5	1.2	1.8	1.4
Unweeded (control)	0.4	0.4	0.4	0.5	0.4
Mean B	0.9	1.2	1.0	1.3	
SE(m)±	0.07				
C.D. (5%)	0.13				

Dry matter (g plant⁻¹) - 90 DAS (2024-25)

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	27.7	35.2	29.9	40.8	33.4
One hand weeding <i>fb</i> straw mulch	13.2	18.7	17.5	23.2	18.1
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	18.7	28.1	24.9	39.3	27.7
Unweeded (control)	8.6	13.1	12.2	16.1	12.5
Mean B	17.0	23.8	21.1	29.8	
SE(m)±	0.68				
C.D. (5%)	2.57				

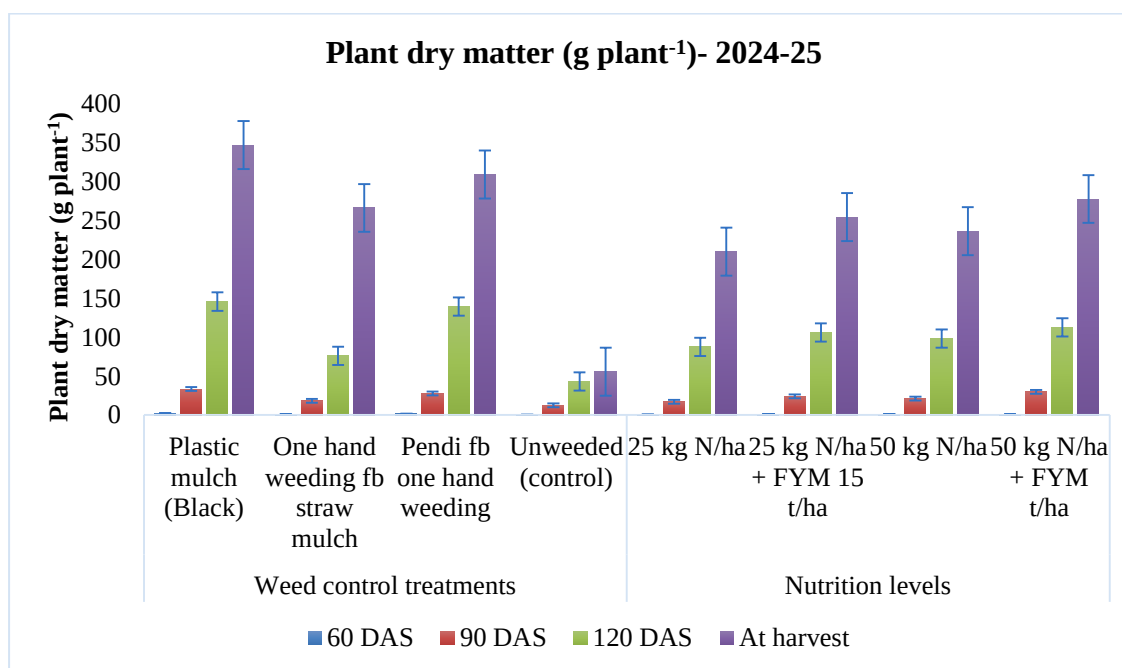
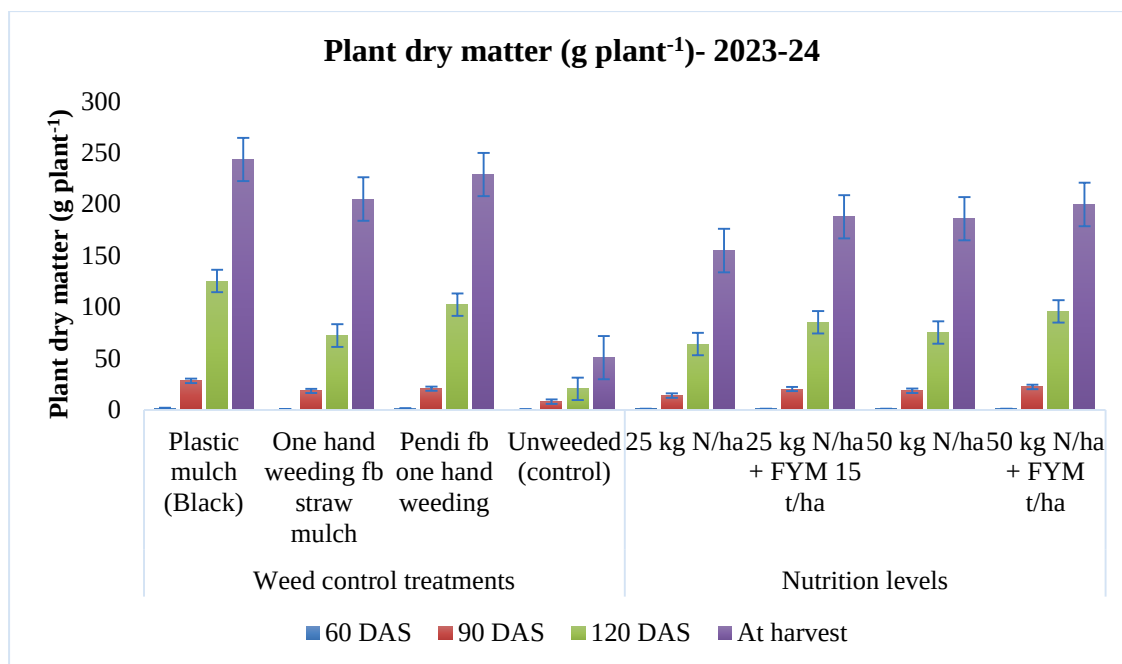


Figure 4.2.2 Effect of weed control and nutrition level treatments on plant dry matter (q ha⁻¹) at 60, 90, 120 DAS and at harvest.

4.2.3 Number of plants per meter row length

The data presented in Table 4.2.4 indicated that differences in number of plants per meter row length due to weed control treatments were significant at 60, 90, 120 DAS and at harvest during both years except 60 and 90 DAS during 2023-24 (Table 4.2.4).

The differences in number of plants per meter row length due to weed control treatments and nutrition levels at 60 DAS were found to be non-significant during 2023-24 (Table 4.2.4). During 2024-25, the differences in number of plants per meter row were found to be significant among the various weed control treatments. Among weed control treatments, number of plants per meter row length in black plastic mulch was found to be significantly more as compared to all other treatments. Number of plants per meter row length in pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch were found to be statistically at par with each other. Number of plants per meter row length was significantly less in unweeded (control) as compared to all other weed control treatments. The differences in number of plants per meter row length due to nutrition levels were non-significant during both the years.

At 90 DAS, the differences in number of plants per meter row length due to weed control treatments were found to be non-significant during 2023-24 (Table 4.2.4). During 2024-25, the differences in number of plants per meter row were found to be significant among the various weed control treatments. Among weed control treatments, number of plants per meter row length in black plastic mulch was found to be significantly more as compared to unweeded (control). Number of plants per meter row in black plastic mulch, pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch were found to be statistically at par with each other. The number of plants per meter row length were found to be non-significant among nutrition levels during both years.

At 120 DAS, the differences in number of plants per meter row length were found to be significant among various weed control treatments during 2023-24 (Table 4.2.4). Among the weed control treatments, number of plants per meter row length in black plastic mulch were statistically at par with pendimethalin *fb* one hand weeding and

one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly lower number of plants per meter row as compared to black plastic mulch. Number of plants per meter row length in black plastic mulch, one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding were found to be at par among each other. Similar findings were obtained during 2024-25 also. During both years, the number of plants per meter row length were found to be non-significant due to nutrition level treatments.

At harvest, the differences in number of plants per meter row length were found to be significant among various weed control treatments during both years (Table 4.2.4). Among the weed control treatments, number of plants per meter row length in black plastic mulch were statistically at par with pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of plants per meter row as compared to black plastic mulch. Similar findings were obtained during 2024-25 also. The differences in number of plants per meter row length due to nutrition levels were found to be non-significant during both years.

It can be concluded that number of plants per meter row were found to be more in black plastic mulch treatment. This might be due to less crop weed competition and suppression of weeds from the very start of the crop growth. This allowed the crop to grow freely without competing for any resources like light, moisture or nutrients. Whereas, in unweeded (control) the weeds had altered the crop growth by more competition for resources, which led to death of crop and reduced the overall crop stand and hence yield was also reduced (Kaur *et al.*, 2022; Patil *et al.*, 2020).

The interactive effect of weed control treatments and nutrition levels on number of plants per meter row length was found to be non-significant during 2023-24 and 2024-25 (Table 4.2.4).

Table 4.2.4 Effect of weed control and nutrition level treatments on number of plants per meter row length at 60, 90, 120 DAS and at harvest

	Number of plants per meter row length							
	60 DAS		90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)								
Plastic mulch (Black)	5.38	5.46	5.33	5.46	5.38	5.50	5.29	5.50
One hand weeding <i>fb</i> straw mulch	5.25	5.29	5.29	5.29	5.29	5.29	5.29	5.29
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	5.21	5.25	5.21	5.29	5.29	5.33	5.25	5.33
Unweeded (control)	5.17	5.17	5.08	5.04	3.23	3.19	2.71	2.69
SE(m)±	0.05	0.05	0.06	0.08	0.06	0.10	0.11	0.13
C.D. (5%)	NS	0.18	NS	0.27	0.21	0.37	0.37	0.45
Sub-plots (Nutrition levels)								
25 kg N ha ⁻¹	5.08	5.17	5.04	5.08	4.63	4.75	4.46	4.54
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	5.29	5.29	5.29	5.38	4.81	4.85	4.71	4.81
50 kg N ha ⁻¹	5.21	5.25	5.17	5.21	4.71	4.71	4.50	4.58
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	5.42	5.46	5.42	5.42	5.04	5.00	4.88	4.88
SE(m)±	0.09	0.09	0.10	0.10	0.12	0.13	0.12	0.13
C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS	NS	NS

4.2.4 Number of primary branches (plant⁻¹)

The data presented in Table 4.2.5 indicates that differences in number of primary branches plant⁻¹ due to weed control treatments and nutrition levels recorded at 90, 120 DAS and at harvest were found to be significant during both the years (Table 4.2.5).

The differences in number of primary branches plant⁻¹ due to weed control treatments and nutrition levels at 90 DAS were found to be significant during 2023-24 (Table 4.2.5). Among weed control treatments, number of primary branches in black plastic mulch, were found to be significantly higher than all other weed control treatments. Number of primary branches in pendimethalin *fb* one hand weeding was found to be statistically at par with one hand weeding *fb* straw mulch. Number of primary branches was significantly lower in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of primary branches as compared to all other treatments. Number of primary branches in both integrated treatments i.e. 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹, 50 kg N ha⁻¹ and 25 kg N ha⁻¹ were statistically at par with each other. Significantly less number of primary branches was recorded in 25 kg N ha⁻¹ as compared to 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. During 2024-25, the differences in number of primary branches plant⁻¹ were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.5). Among weed control treatments, number of primary branches in black plastic mulch were found to be significantly more as compared to one hand weeding *fb* straw mulch. Number of primary branches in pendimethalin *fb* one hand weeding were found to be statistically at par with black plastic mulch. Number of primary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary branches as compared to all other treatments. Number of primary branches in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ were statistically at par with each other. Number of primary branches were significantly less in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments.

At 120 DAS, the differences in number of primary branches plant⁻¹ due to weed control treatments were found to be significant during 2023-24 (Table 4.2.5). Among weed control treatments, number of primary branches in black plastic mulch and pendimethalin *fb* one hand weeding were found to be significantly higher as compared to one hand weeding *fb* straw mulch. Number of primary branches in pendimethalin *fb* one hand weeding was found to be statistically at par with black plastic mulch. Number of primary branches was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary branches plant⁻¹ as compared to all other treatments. Number of primary branches in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ were statistically at par with each other. Number of primary branches were significantly less in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments. During 2024-25, the differences in number of primary branches plant⁻¹ were found to be significant among the various weed control and nutrition level treatments (Table 4.2.5). Among weed control treatments, number of primary branches in black plastic mulch were found to be significantly higher as compared to all other treatments. Pendimethalin *fb* one hand weeding recorded significantly higher number of primary branches as compared to one hand weeding *fb* straw mulch. Number of primary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary branches as compared to all other treatments. Number of primary branches in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ was statistically at par with each other. Number of primary branches were significantly less in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments.

At harvest, the differences in number of primary branches plant⁻¹ due to weed control treatments and nutrition levels were found to be significant during 2023-24 (Table 4.2.5). Among weed control treatments, number of primary branches in unweeded (control) were found to be significantly less as compared to all weed control treatments. Number of primary branches in black plastic mulch, pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch was found to be statistically at

par with each other. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary branches as compared to 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of primary branches in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with each other. Number of primary branches were significantly less in 25 kg N ha⁻¹ as compared to all other nutrition levels. During 2024-2025, the differences in number of primary branches were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.5). Among weed control treatments, number of primary branches in black plastic mulch were found to be significantly higher as compared to all other treatments. Pendimethalin *fb* one hand weeding recorded significantly higher number of primary branches as compared to one hand weeding *fb* straw mulch treatment. Number of primary branches was significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary branches as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of primary branches in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were statistically at par with each other. Number of primary branches were significantly less in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

Higher number of primary branches plant⁻¹ in black mulch treatment might be due to better control of weeds as well as continuous availability of moisture and nutrients under this treatment, which encouraged more branching of the crop. Moreover, the higher dose of nitrogen and organic manure (FYM) promotes vegetative growth and branching in crop as compared to lower dose of nitrogen and without application of FYM. These findings were similar to Meena *et al.* (2023) and Kumar *et al.* (2023).

The interactive effect of weed control treatments and nutrition levels on number of primary branches plant⁻¹ was found to be non-significant during 2023-24 and 2024-25 (Table 4.2.5).

Table 4.2.5 Effect of weed control and nutrition level treatments on number of primary branches plant⁻¹ at 90, 120 DAS and at harvest

Treatment details	Number of primary branches plant ⁻¹					
	90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	6.4	7.5	9.5	11.5	11.1	11.5
One hand weeding <i>fb</i> straw mulch	5.5	6.5	8.1	10.1	10.6	9.6
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	5.7	7.2	9.4	10.9	10.6	10.1
Unweeded (control)	3.8	4.5	5.21	6.7	6.0	6.8
SE(m)±	0.17	0.12	0.25	0.15	0.19	0.13
C.D. (5%)	0.60	0.37	0.89	0.48	0.67	0.42
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	5.1	5.9	7.4	9.3	8.7	8.8
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	5.2	6.5	8.1	9.9	10.0	9.8
50 kg N ha ⁻¹	5.2	6.1	7.7	9.5	9.3	9.3
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	5.8	7.4	8.9	10.6	10.2	10.1
SE(m)±	0.14	0.11	0.12	0.13	0.20	0.13
C.D. (5%)	0.40	0.31	0.35	0.38	0.58	0.36
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.2.5 Number of secondary branches (plant^{-1})

The data presented in Table 4.2.6 indicates that differences in number of secondary branches plant^{-1} due to weed control treatments and nutrition levels recorded at 90, 120 DAS and at harvest were found to be significant during both the years.

The differences in number of secondary branches plant^{-1} due to weed control treatments and nutrition levels at 90 DAS were found to be significant during 2023-24 (Table 4.2.6). Among weed control treatments, number of secondary branches plant^{-1} in black plastic mulch were found to be significantly higher than all other treatments. Number of secondary branches in pendimethalin *fb* one hand weeding were found to be statistically at par with one hand weeding *fb* straw mulch. Number of secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly more number of secondary branches as compared to all other nutrition level treatments. Number of secondary branches in $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and 50 kg N ha^{-1} were found to be statistically at par with each other. Application of 25 kg N ha^{-1} recorded significantly less number of secondary branches as compared to $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$. During 2024-25, the differences in number of secondary branches plant^{-1} were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.6). Among weed control treatments, number of secondary branches in black plastic mulch were found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher number of secondary branches as compared to one hand weeding *fb* straw mulch. Number of secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher number of secondary branches as compared to all other nutrition level treatments. Number of secondary branches in $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ were significantly higher than 50 kg N ha^{-1} and 25 kg N ha^{-1} . Number of secondary branches were significantly less in 25 kg N ha^{-1} as compared to all other nutrition level treatments.

At 120 DAS, the differences in number of secondary branches plant⁻¹ due to weed control treatments and nutrition levels were found to be significant during 2023-24 (Table 4.2.6). Among weed control treatments, number of secondary branches in black plastic mulch were found to be significantly higher than all other weed control treatments. Number of secondary branches in pendimethalin *fb* one hand weeding were found to be significantly higher as compared to one hand weeding *fb* straw mulch. Number of secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of secondary branches as compared to 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of secondary branches in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ was found to be statistically at par with each other. Significantly less number of secondary branches were recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels. During 2024-25, the differences in number of secondary branches plant⁻¹ were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.6). Among weed control treatments, number of secondary branches in black plastic mulch were found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher number of secondary branches as compared to one hand weeding *fb* straw mulch. Number of secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of secondary branches as compared to all other treatments. Number of secondary branches in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of secondary branches were significantly lower in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

At harvest, the differences in number of secondary branches plant⁻¹ due to weed control treatments and nutrition levels were found to be significant during 2023-24 (Table 4.2.6). Among weed control treatments, number of secondary branches in black plastic mulch were found to be significantly higher than all other treatments. Number of secondary branches in pendimethalin *fb* one hand weeding were found to be significantly more than one hand weeding *fb* straw mulch treatment. Number of

secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of secondary branches as compared to all other nutrition levels. Number of secondary branches in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were found to be significantly higher as compared to 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of secondary branches were observed in 25 kg N ha⁻¹ as compared to all other nutrition levels. During 2024-25, the differences in number of secondary branches plant⁻¹ were found to be significant among the various weed control treatments and nutrition levels (Table 4.2.6). Among weed control treatments, number of secondary branches in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Number of secondary branches in pendimethalin *fb* one hand weeding were statistically at par with one hand weeding *fb* straw mulch. Number of secondary branches were significantly less in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of secondary branches as compared to all other nutrition levels. Number of secondary branches in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were found to be significantly more than the treatments of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of secondary branches were recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels.

The interactive effect of weed control treatments and nutrition levels on number of secondary branches plant⁻¹ were found to be significant at harvest during both the years (Table 4.2.6). During 2023-24, number of secondary branches were significantly higher in black plastic mulch applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ as compared to pendimethalin *fb* one hand weeding under same nutrition level. Number of secondary branches plant⁻¹ in pendimethalin *fb* one hand weeding applied in combination with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly higher as compared to black plastic mulch applied with 50 kg N ha⁻¹. One hand weeding *fb* straw mulch applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded statistically at par number of secondary branches with pendimethalin *fb* one hand weeding applied with 50 kg N ha⁻¹. The number of secondary branches plant⁻¹ were significantly less in

alone application of nitrogen (25 kg N ha^{-1} and 50 kg N ha^{-1}) as compared to integration with FYM under black mulching. During 2024-25, combination of black plastic mulch with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher number of secondary branches as compared to application of 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} under the same weed control treatment (Table 4.2.6). Pendimethalin *fb* one hand weeding applied with 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher number of secondary branches as compared to combination of one hand weeding *fb* straw mulch applied with 50 kg N ha^{-1} . One hand weeding *fb* straw mulch applied with 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded statistically at par number of secondary branches as compared to pendimethalin *fb* one hand weeding applied with 50 kg N ha^{-1} .

It can be concluded that more number of secondary branches plant^{-1} in black plastic mulch might be due to suppression of weeds very effectively which enhanced efficient utilization of nutrients and moisture which promoted more vegetative growth, thus secondary branches were higher. Nitrogen, being an essential constituent of chlorophyll, enhances photosynthetic activity and more shoot growth. Thus, higher number of secondary branches were found in the integrated use of nitrogen and FYM. These findings were in conformity with Choudhary *et al.* (2022) and Naher *et al.* (2016).

The interactive effect of weed control treatments and nutrition levels on number of secondary branches plant^{-1} were found to be non-significant at 90 and 120 DAS during 2023-24 and 2024-25 (Table 4.2.6).

Table 4.2.6 Effect of weed control and nutrition level treatments on number of secondary branches plant⁻¹ at 90, 120 DAS and at harvest

Treatment details	Number of secondary branches plant ⁻¹					
	90 DAS		120 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	5.5	7.7	12.6	17.2	48.2	36.8
One hand weeding <i>fb</i> straw mulch	4.0	6.0	10.6	14.5	37.1	30.9
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	4.1	7.3	11.7	16.3	44.1	32.7
Unweeded (control)	0.6	2.0	5.0	6.5	6.5	12.0
SE(m)±	0.16	0.11	0.25	0.27	0.71	0.77
C.D. (5%)	0.56	0.36	0.89	0.88	2.51	2.51
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	3.2	4.8	7.9	11.9	29.0	23.6
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	3.6	6.0	10.7	14.4	35.7	29.3
50 kg N ha ⁻¹	3.3	5.1	9.8	13.0	31.4	25.6
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	4.1	7.0	11.5	15.2	39.8	33.9
SE(m)±	0.12	0.10	0.41	0.20	0.80	0.48
C.D. (5%)	0.35	0.28	1.20	0.58	2.36	1.38
Interaction C.D. (5%)	NS	NS	NS	NS	4.92	2.92

Table 4.2.7 Interactive effect of weed control and nutrition level treatments on number of secondary branches plant⁻¹ at harvest

Number of secondary branches plant⁻¹ - 2023-24

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	41.8	50.3	44.8	56.1	48.2
One hand weeding <i>fb</i> straw mulch	30.8	38.5	34.0	45.0	37.1
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	38.0	47.3	41.1	50.3	44.1
Unweeded (control)	5.3	6.8	5.9	7.9	6.5
Mean B	29.0	35.7	31.4	39.8	
SE(m)±	1.42				
C.D. (5%)	4.92				

Number of secondary branches plant⁻¹ - 2024-25

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	29.9	39.9	32.9	44.4	36.8
One hand weeding <i>fb</i> straw mulch	27.1	32.4	27.9	36.4	30.9
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	28.8	32.0	30.3	39.6	32.7
Unweeded (control)	8.6	12.9	11.4	15.1	12.0
Mean B	23.6	29.3	25.6	33.9	
SE(m)±	1.54				
C.D. (5%)	2.92				

4.3 Yield parameters

The yield attributes are the important factors that influence the final seed yield and productive efficiency in fennel. These parameters include the number of umbels per plant, the number of umbellets per umbel, the number of seeds per umbel, 1000-seed weight, etc. The seed yield act as integrative indicators of the physiological performance of the plant as well as determines the effectiveness of agronomic practices. The yield attributes viz. number of umbels plant⁻¹, diameter of umbel (cm), number of umbellets per umbel, number of seeds per umbellet, seed weight per umbel (g), 1000 seed weight per main, primary and secondary umbel respectively, were recorded at harvest.

4.3.1 Number of primary and secondary umbels plant⁻¹

The number of primary and secondary umbels plant⁻¹ (recorded at harvest) as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.1 and graphically depicted in Figure 4.3.1.

The differences in number of primary umbels plant⁻¹ were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.1). Among weed control treatments, the number of primary umbels plant⁻¹ recorded in black plastic mulch, one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding were found to be statistically at par with each other. Significantly less number of primary umbels plant⁻¹ were recorded in unweeded (control) as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ produced statistically at par number of primary umbels plant⁻¹ with each other. Number of primary umbels plant⁻¹ in 25 kg N ha⁻¹ were significantly less than integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments. During 2024-25, among the weed control treatments, number of primary umbels in black plastic mulch were significantly higher than one hand weeding *fb* straw mulch (Table 4.3.1). Number of primary umbels plant⁻¹ in black plastic mulch and pendimethalin *fb* one hand weeding were statistically at par with each other. Unweeded (control) recorded

significantly less number of primary umbels plant⁻¹ as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of primary umbels plant⁻¹ as compared to all other nutrition level treatments. Number of primary umbels plant⁻¹ in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be significantly higher than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Treatment of 25 kg N ha⁻¹ recorded significantly less number of umbels plant⁻¹ as compared to all other nutrition levels.

The differences in number of secondary umbels plant⁻¹ were significant among the weed control treatments and nutrition levels during 2023-24 (Table 4.3.1). Among weed control treatments, the number of secondary umbels plant⁻¹ recorded in black plastic mulch were found to be significantly higher as compared to all other treatments. Significantly higher number of secondary umbels plant⁻¹ were recorded in black plastic mulch as compared to all other treatments. Number of secondary umbels plant⁻¹ in one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding were found to be statistically at par with each other. Significantly less number of secondary umbels plant⁻¹ were recorded in unweeded (control) as compared to other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of secondary umbels as compared to all other nutrition level treatments. Both integrated treatments i.e. of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ recorded statistically at par number of secondary umbels plant⁻¹ with each other. Application of 25 kg N ha⁻¹ produced significantly less number of secondary umbels per plant as compared to all other nutrition level treatments. During 2024-25, the differences in number of secondary umbels plant⁻¹ were significant among the weed control and nutrition level treatments (Table 4.3.1). Among weed control treatments, the number of secondary umbels plant⁻¹ recorded in black plastic mulch were found to be significantly higher as compared to all other treatments. Number of secondary umbels in one hand weeding *fb* straw mulch and pendimethalin (0.45 kg ha⁻¹) *fb* one hand weeding were found to be statistically at par with each other. Significantly less number of secondary umbels plant⁻¹ were recorded in unweeded (control) as compared to other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of

secondary umbels as compared to all other treatments. Number of secondary umbels in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than 50 kg N ha⁻¹. The application of 25 kg N ha⁻¹ produced significantly less number of secondary umbels per plant as compared to all other nutrition level treatments.

The higher number of primary and secondary umbels plant⁻¹ in black plastic mulch treatment might be due to improved nutrient availability and soil microclimate due to which more vegetative and reproductive growth was found in this treatment. The weed free condition provided from the initial stages improved the crop growth and yield. The synergistic effect of nitrogen and FYM also ensures continuous growth and reproductive development. These findings were confirmed by Yadav and Sharma (2004) and Yadav *et al.* (2016).

The interactive effect of weed control treatments and nutrition levels on number of primary and secondary umbels plant⁻¹ was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.1).

Table 4.3.1 Effect of weed control and nutrition level treatments on number of primary and secondary umbels plant⁻¹

	Number of primary umbels plant ⁻¹		Number secondary umbels plant ⁻¹	
	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)				
Plastic mulch (Black)	9.3	10.6	27.9	26.4
One hand weeding <i>fb</i> straw mulch	9.1	9.7	24.7	24.8
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	8.9	9.9	25.6	24.5
Unweeded (control)	6.5	6.2	11.1	9.7
SE(m)±	0.22	0.23	0.52	0.32
C.D. (5%)	0.76	0.74	1.84	1.04
Sub-plots (Nutrition levels)				
25 kg N ha ⁻¹	7.9	8.3	19.2	17.1
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	8.9	9.4	23.1	22.6
50 kg N ha ⁻¹	8.2	8.8	22.3	20.2
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	9.0	9.8	24.8	25.5
SE(m)±	0.16	0.10	0.49	0.72
C.D. (5%)	0.47	0.29	1.45	2.06
Interaction C.D. (5%)	NS	NS	NS	NS

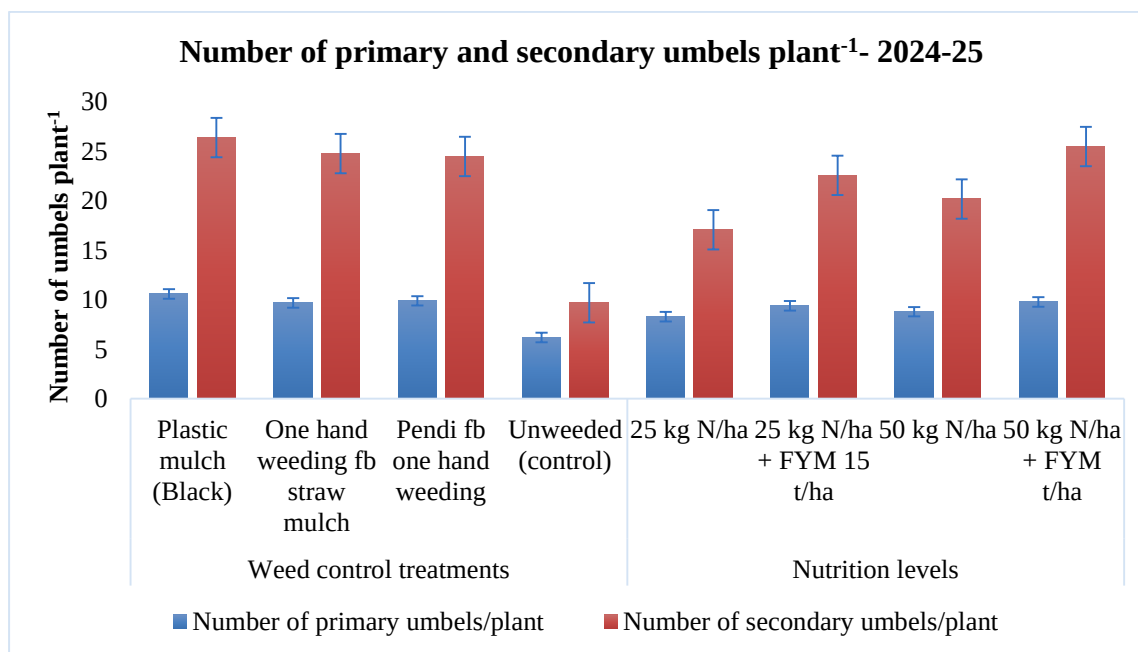
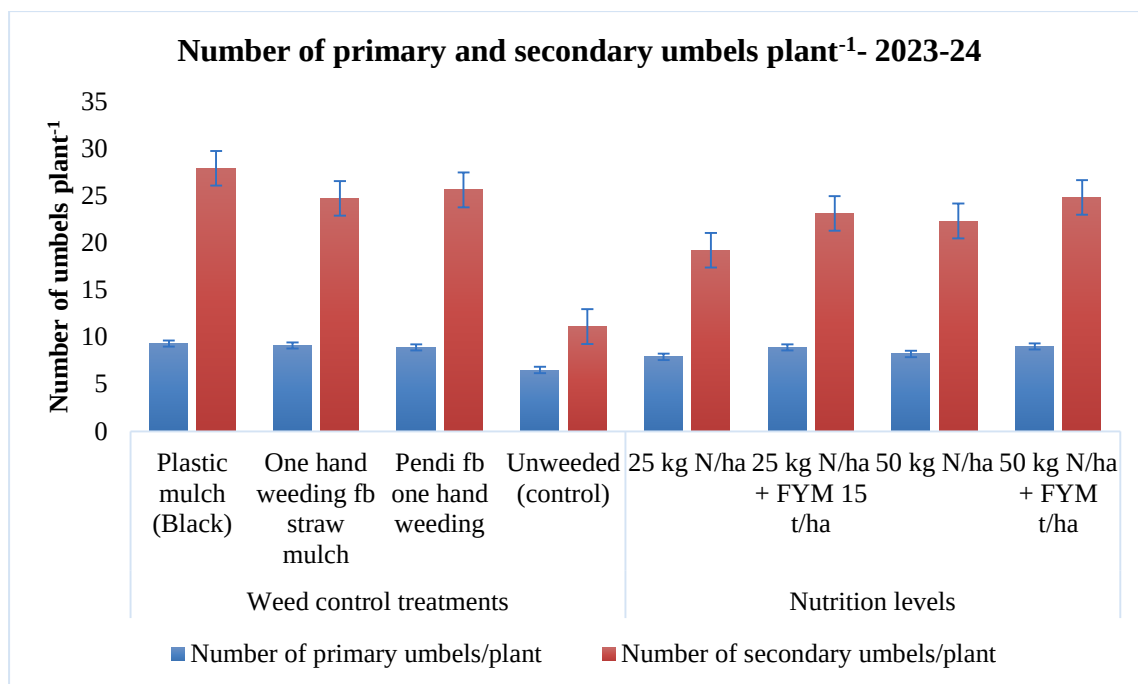


Figure 4.3.1 Effect of weed control and nutrition level treatments on number of primary and secondary umbels plant⁻¹

4.3.2 Diameter of main, primary and secondary umbel (cm)

The diameter of main, primary and secondary umbel (cm) as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.2 and graphically depicted in Figure 4.3.2.

The differences in diameter of main umbel (cm) were significant among the weed control treatments and nutrition levels during 2023-24 (Table 4.3.2). Among weed control treatments, diameter of main umbel in black plastic mulch, one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Unweeded (control) recorded significantly less diameter of main umbel as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more diameter of main umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Diameter of main umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ was statistically at par with each other. Significantly less diameter of main umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in diameter of main umbel (cm) were significant among the weed control and nutrition level treatments (Table 4.3.2). Among weed control treatments, black plastic mulch recorded significantly more diameter of main umbel than one hand weeding *fb* straw mulch. Diameter of main umbel in black plastic mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Unweeded (control) recorded significantly less diameter of main umbel as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more diameter of main umbel as compared to all other treatments. Diameter of main umbel in integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less diameter of main umbel was recorded in 25 kg N ha⁻¹ as compared to integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹.

The differences in diameter of primary umbel (cm) was significant at harvest among the weed control and nutrition level treatments during 2023-24 (Table 4.3.2). Among weed control treatments, the diameter of primary umbel in black plastic mulch and

pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Unweeded (control) recorded significantly less diameter of primary umbel as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more diameter of primary umbel as compared to 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Diameter of primary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with each other. Significantly lower diameter of primary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in diameter of primary umbel (cm) were significant among the weed control and nutrition level treatments (Table 4.3.2). Among weed control treatments, black plastic mulch recorded significantly more diameter of primary umbel as compared to all other weed control treatments. Diameter of primary umbel in pendimethalin *fb* one hand weeding was significantly more as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less diameter of primary umbel as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more diameter of primary umbel as compared to all other treatments. Diameter of primary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with 50 kg N ha⁻¹ treatment. Significantly less diameter of primary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

At harvest, the differences in diameter of secondary umbel (cm) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.2). Among weed control treatments, diameter of secondary umbel in black plastic mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other and both these treatments recorded significantly higher diameter of secondary umbel as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less diameter of secondary umbel as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more diameter of secondary umbel as compared to all other nutrition level treatments. Diameter of secondary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹.

Significantly less diameter of secondary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. Similar findings were observed during 2024-25 also.

It can be concluded that among weed control methods, the diameter of main, primary and secondary umbels (cm) was higher in black mulch and pendimethalin *fb* hand weeding due to less crop weed competition for inputs like nutrients, moisture, space, sunlight, etc. in these treatments. Similar findings were reported by Choudhary *et al.* (2022). The combination of higher dose of nitrogen with FYM enhanced the vegetative as well as reproductive growth of the crop leading to larger diameter of umbels (Yadav *et al.*, 2016).

The interactive effect of weed control treatments and nutrition levels on diameter of main, primary and secondary umbels (cm) was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.2).

Table 4.3.2 Effect of weed control and nutrition level treatments on diameter of main, primary and secondary umbel (cm)

	Diameter of main umbel (cm)		Diameter of primary umbel (cm)		Diameter of secondary umbel (cm)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	16.5	14.9	13.6	13.3	8.6	8.5
One hand weeding <i>fb</i> straw mulch	16.0	14.1	12.0	12.0	8.1	7.6
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	16.1	14.4	13.6	12.6	8.9	8.3
Unweeded (control)	12.5	9.7	9.8	9.0	5.8	5.9
SE(m)±	0.22	0.24	0.19	0.09	0.12	0.13
C.D. (5%)	0.78	0.77	0.65	0.30	0.40	0.43
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	14.4	12.6	11.0	11.1	7.1	7.0
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	15.6	13.4	12.7	11.8	8.0	7.8
50 kg N ha ⁻¹	15.2	12.9	12.0	11.6	7.5	7.4
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	15.9	14.1	13.2	12.5	8.7	8.2
SE(m)±	0.18	0.17	0.18	0.11	0.13	0.12
C.D. (5%)	0.54	0.49	0.53	0.33	0.39	0.33
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

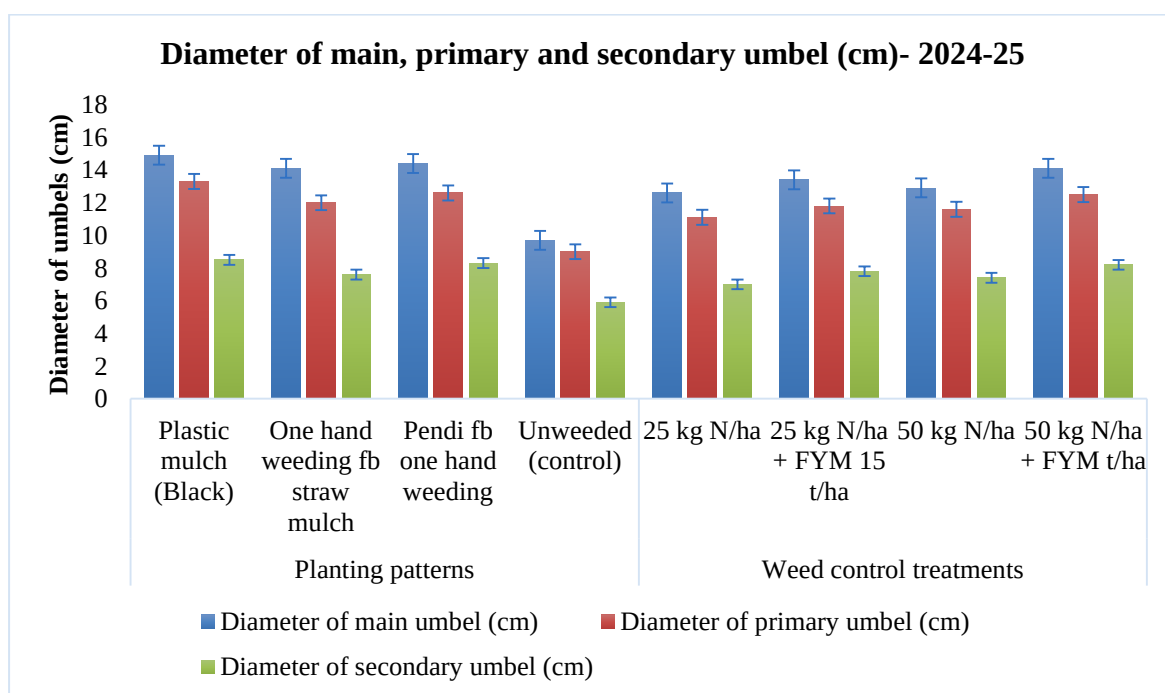
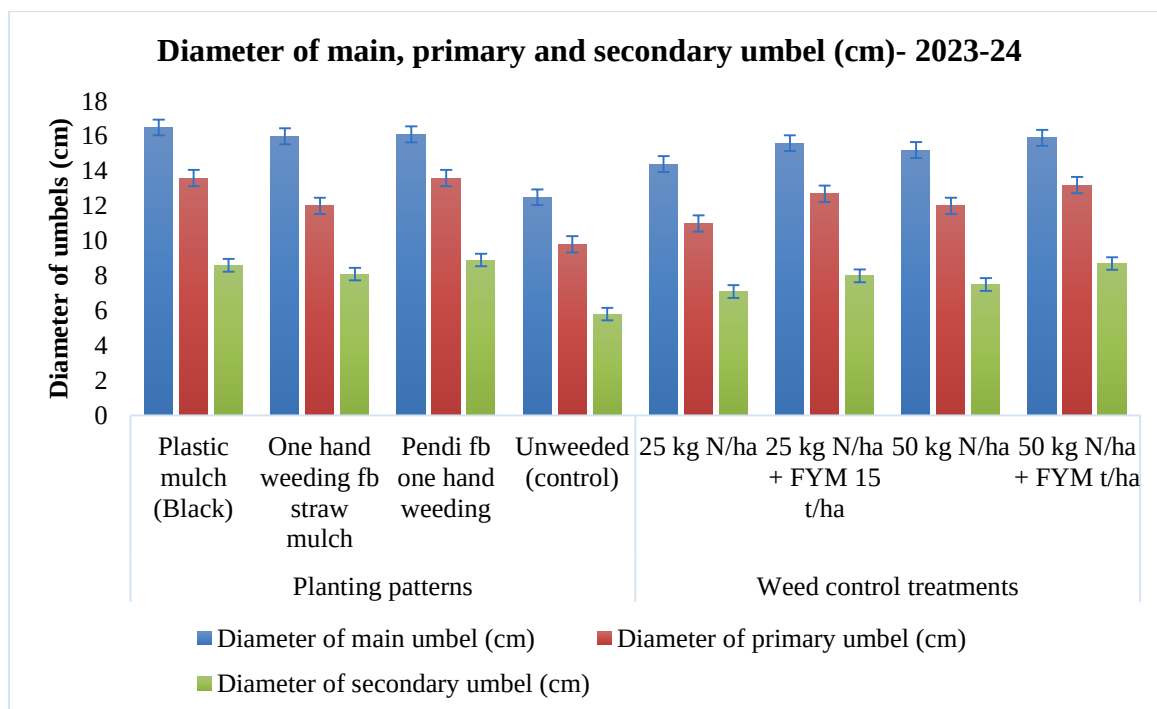


Figure 4.3.2 Effect of weed control and nutrition level treatments on diameter of main, primary and secondary umbels (cm)

4.3.3 Number of umbellets per main, primary and secondary umbel

The number of umbellets per main, primary and secondary umbel as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.3.

The differences in number of umbellets per umbel (main) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.3). Among weed control treatments, application of black plastic mulch recorded significantly more number of umbellets per umbel (main) as compared to one hand weeding *fb* straw mulch. Number of umbellets per umbel (main) in black plastic mulch and pendimethalin *fb* one hand weeding were statistically at par with each other. Unweeded (control) recorded significantly less number of umbellets per umbel (main) as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per umbel (main) as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of umbellets per umbel (main) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with each other. Application of 25 kg N ha⁻¹ recorded significantly less number of umbellets per umbel (main) as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. During 2024-25, the differences in number of umbellets per umbel (main) were significant among the weed control and nutrition level treatments (Table 4.3.3). Among weed control treatments, black plastic mulch recorded significantly more number of umbellets per umbel (main) as compared to all other weed control treatments. Number of umbellets per umbel (main) in pendimethalin *fb* one hand weeding was found to be significantly higher as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of umbellets per umbel (main) as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per umbel (main) as compared to all other nutrition level treatments. Number of umbellets per umbel (main) in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ were found to be statistically at par with each other. The application of 25 kg N ha⁻¹

recorded significantly less number of umbellets per umbel (main) as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹.

The differences in number of umbellets per primary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.3). Among weed control treatments, application of black plastic mulch recorded significantly more number of umbellets per primary umbel as compared to all other treatments. Number of umbellets per primary umbel in pendimethalin *fb* one hand weeding was found to be significantly higher as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less number of umbellets per primary umbel as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per primary umbel as compared to all other nutrition level treatments. Number of umbellets per primary umbel in 50 kg N ha⁻¹ and 25 kg N ha⁻¹ were found to be statistically at par with each other. Application of 25 kg N ha⁻¹ recorded significantly lower number of umbellets per primary umbel as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments. During 2024-25, the differences in number of umbellets per primary umbel were significant among the weed control and nutrition level treatments (Table 4.3.3). Among weed control treatments, application of black plastic mulch recorded significantly more number of umbellets per primary umbel as compared to all other treatments. Number of umbellets per primary umbel in pendimethalin *fb* one hand weeding were found to be significantly higher as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of umbellets per primary umbel as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per primary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of umbellets per primary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ were found to be statistically at par with each other. Application of 25 kg N ha⁻¹ recorded significantly less number of umbellets per primary umbel as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹.

The differences in number of umbellets per secondary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.3). Among weed control treatments, application of black plastic mulch recorded significantly more number of umbellets per secondary umbel as compared to all other treatments. Number of umbellets per secondary umbel in pendimethalin *fb* one hand weeding were found to be significantly higher as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of umbellets per secondary umbel as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of umbellets per secondary umbel in both integrated treatments i.e. 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were found to be statistically at par with each other. Significantly less number of umbellets per secondary umbel were recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in number of umbellets per secondary umbel were significant among the weed control and nutrition level treatments (Table 4.3.3). Among weed control treatments, black plastic mulch recorded significantly more number of umbellets per secondary umbel as compared to all other weed control treatments. Number of umbellets per secondary umbel in pendimethalin *fb* one hand weeding were found to be significantly more as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of umbellets per secondary umbel as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of umbellets per secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of umbellets per secondary umbel in both integrated treatments of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were found to be statistically at par with each other. Significantly lower number of umbellets per secondary umbel were recorded in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹.

The higher number of umbellets per main, primary and secondary umbel in black mulch treatment might be due to conservation of soil moisture and temperature moderation which provides favourable environment for root growth and overall vegetative growth which led to more number of umbellets per umbel. Higher dose of nitrogen with FYM provides favourable conditions for vegetative growth and the assimilates produced are translocated to reproductive parts which promotes more number of umbellets. These findings were similar to Siddika (2021) and Meena *et al.* (2014).

The interactive effect of weed control treatments and nutrition levels on number of umbellets per main, primary and secondary umbel was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.3).

Table 4.3.3 Effect of weed control and nutrition level treatments on number of umbellets per main, primary and secondary umbel

	Number of umbellets per umbel					
	Main umbel		Primary Umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	43.1	44.3	37.2	38.3	23.4	24.3
One hand weeding <i>fb</i> straw mulch	38.0	39.1	32.0	33.0	20.0	20.2
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	41.3	42.2	34.6	35.7	21.5	22.7
Unweeded (control)	30.7	31.5	28.6	29.3	16.1	16.6
SE(m)±	0.55	0.49	0.59	0.41	0.27	0.32
C.D. (5%)	1.95	1.72	2.06	1.46	0.96	1.13
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	36.3	37.3	31.5	32.3	18.8	19.6
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	39.0	39.6	33.5	34.5	20.9	21.6
50 kg N ha ⁻¹	37.3	38.6	32.3	33.5	19.8	20.4
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	40.4	41.5	34.9	35.9	21.5	22.2
SE(m)±	0.53	0.59	0.40	0.50	0.32	0.39
C.D. (5%)	1.56	1.74	1.17	1.45	0.92	1.14
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.4 Number of seeds per umbellet (main, primary and secondary umbel)

The number of seeds per umbellet (main, primary and secondary umbels) as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.4.

The differences in number of seeds per umbellet (main umbel) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.4). Among weed control treatments, black plastic mulch recorded significantly more number of seeds per umbellet (main umbel) as compared to one hand weeding *fb* straw mulch. Number of seeds per umbellet (main umbel) in black plastic mulch and pendimethalin *fb* one hand weeding were found to be statistically at par with each other. Unweeded (control) recorded significantly less number of seeds per umbellet (main umbel) as compared to all other weed control treatments. Among nutrition levels, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per umbellet (main umbel) as compared to all other treatments. Number of seeds per umbellet (main umbel) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of seeds per umbellet (main umbel) recorded in 25 kg N ha⁻¹ were significantly less as compared to all other nutrition level treatments. During 2024-25, the differences in number of seeds per umbellet (main umbel) were significant among the weed control treatments and nutrition levels (Table 4.3.4). Among weed control treatments, black plastic mulch treatment recorded significantly more number of seeds per umbellet (main umbel) as compared to one hand weeding *fb* straw mulch. Number of seeds per umbellet (main umbel) in pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch were found to be statistically at par with each other. Unweeded (control) recorded significantly less number of seeds per umbellet (main umbel) as compared to all other weed control treatments. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher number of seeds per umbellet (main umbel) as compared to all other treatments. Number of seeds per umbellet (main umbel) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Number of seeds per umbellet (main umbel) recorded in 25 kg N ha⁻¹ were significantly less as compared to all other nutrition level treatments.

The differences in number of seeds per umbellet (primary umbel) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.4). Among weed control treatments, black plastic mulch recorded significantly more number of seeds per umbellet (primary umbel) as compared to one hand weeding *fb* straw mulch. Number of seeds per umbellet (primary umbel) in black plastic mulch and pendimethalin *fb* one hand weeding were found to be statistically at par with each other. Unweeded (control) recorded significantly less number of seeds per umbellet (primary umbel) as compared to all other weed control treatments. Among nutrition level treatments, integration of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per umbellet (primary umbel) as compared to all other treatments. Number of seeds per umbellet (primary umbel) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds per umbellet (primary umbel) were recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in number of seeds per umbellet (primary umbel) were significant among the weed control treatments and nutrition level treatments (Table 4.3.4). Among weed control treatments, application of black plastic mulch recorded significantly more number of seeds per umbellet (primary umbel) as compared to all other treatments. Number of seeds per umbellet (primary umbel) in pendimethalin *fb* one hand weeding were found to be significantly more as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of seeds per umbellet (primary umbel) as compared to all other weed control treatments. Among nutrition levels, the treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per umbellet (primary umbel) as compared to all other treatments. Number of seeds per umbellet (primary umbel) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than the treatments of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds per umbellet (primary umbel) were recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

The differences in number of seeds per umbellet (secondary umbel) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.4). Among weed control treatments, black plastic mulch recorded significantly more

number of seeds per umbellet (secondary umbel) as compared to one hand weeding *fb* straw mulch. Number of seeds per umbellet (secondary umbel) in black plastic mulch and pendimethalin *fb* one hand weeding treatments were found to be statistically at par with each other. Unweeded (control) recorded significantly less number of seeds per umbellet (secondary umbel) as compared to all other weed control treatments. Among nutrition levels, the treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per umbellet (secondary umbel) as compared to all other treatments. Number of seeds per umbellet (secondary umbel) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds per umbellet (secondary umbel) were recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. Similar findings were observed during 2024-25 also.

The higher number of seeds per umbellet (main, primary and secondary) in black plastic mulch treatment might be due to improved canopy cover and enhanced photosynthetic activity under weed free condition which is a critical factor for seed setting in umbel and umbellets. Similar findings were reported by Meena *et al.* (2014). Higher dose of nitrogen with FYM enhanced the vegetative and reproductive growth and seed setting in umbels. Similar findings were reported by Yeul (2018) and Mahendra (2020) in their studies.

The interactive effect of weed control treatments and nutrition levels on number of seeds per umbellet (main, primary and secondary) was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.4).

Table 4.3.4 Effect of weed control and nutrition level treatments on number of seeds per umbellet (main, primary and secondary umbel)

	Number of seeds per umbellet					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	34.8	35.5	28.0	29.0	22.6	23.8
One hand weeding <i>fb</i> straw mulch	31.5	32.1	25.2	26.3	19.9	20.4
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	33.8	33.6	27.3	27.8	22.0	22.7
Unweeded (control)	24.6	24.7	22.9	23.8	18.0	18.4
SE(m)±	0.60	0.54	0.48	0.32	0.35	0.39
C.D. (5%)	2.11	1.91	1.71	1.13	1.24	1.39
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	27.3	27.6	20.7	21.8	17.2	18.0
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	32.3	32.5	28.1	28.8	22.0	22.7
50 kg N ha ⁻¹	30.6	30.6	24.9	25.9	19.1	20.1
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	34.6	35.2	29.8	30.4	24.2	24.5
SE(m)±	0.48	0.46	0.44	0.40	0.45	0.44
C.D. (5%)	1.41	1.36	1.28	1.18	1.31	1.30
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.5 Number of seeds per main, primary and secondary umbel

The number of seeds per main, primary and secondary umbels as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.5. and graphically depicted in Figure 4.3.3.

The differences in number of seeds per main umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.5). Among weed control treatments, black plastic mulch recorded significantly more number of seeds per main umbel as compared to all other weed control treatments. Number of seeds per main umbel in pendimethalin *fb* one hand weeding were found to be significantly more as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of seeds per main umbel as compared to all other weed control treatments. Among nutrition levels, the integrated treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per main umbel as compared to all other nutrition level treatments. Number of seeds per main umbel in the integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds per main umbel were recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels. Similar results were obtained during 2024-25 also.

The differences in number of seeds per primary umbel were significant among the weed control treatments and nutrition levels during 2023-24 (Table 4.3.5). Among weed control treatments, application of black plastic mulch recorded significantly more number of seeds per primary umbel as compared to all other treatments. Number of seeds per primary umbel in pendimethalin *fb* one hand weeding was found to be significantly more as compared to one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less number of seeds per primary umbel as compared to all other weed control treatments. Among nutrition levels, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per primary umbel as compared to all other treatments. Number of seeds per primary umbel in integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds

per primary umbel were recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels. Similar findings were observed during 2024-25 also.

The differences in number of seeds per secondary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.5). Among weed control treatments, application of black plastic mulch recorded significantly more number of seeds per secondary umbel as compared to all other treatments. Number of seeds per secondary umbel in pendimethalin *fb* one hand weeding were significantly more as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less number of seeds per secondary umbel as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more number of seeds per secondary umbel as compared to all other treatments. Number of seeds per secondary umbel in integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ were significantly higher than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less number of seeds per secondary umbel were recorded in 25 kg N ha⁻¹ as compared to all other nutrition levels. Similar findings were observed during 2024-25 also.

Number of seeds per main, primary and secondary umbel were significantly higher under black mulch than other treatments due to less crop weed competition from the initial crop growth stage upto harvest which led to better utilization of resources and better soil physical conditions which promotes more reproductive growth. Moreover, the higher nitrogen level with FYM promotes vegetative growth and more assimilates production towards reproductive growth which results in increased number of seeds per umbel. Similar findings were observed by Mahendra (2020) and Dodamani (2021).

The interactive effect of weed control treatments and nutrition levels on number of seeds per main, primary and secondary umbels were non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.5).

Table 4.3.5 Effect of weed control and nutrition level treatments on number of seeds per main, primary and secondary umbel

	Number of seeds per umbel					
	Main umbel		Primary umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	1,276	1,290	946	1,019	529	565
One hand weeding <i>fb</i> straw mulch	989	1,021	768	797	397	417
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1,159	1,166	879	904	476	509
Unweeded (control)	546	545	559	574	281	297
SE(m)±	14.46	14.56	11.12	14.16	10.68	8.11
C.D. (5%)	51.01	51.36	39.22	49.95	37.68	28.61
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	786	808	640	661	327	356
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1,061	1,072	855	892	460	487
50 kg N ha ⁻¹	929	952	707	768	379	408
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1194	1,191	949	974	517	537
SE(m)±	14.86	13.22	10.77	15.15	10.51	10.85
C.D.(5%)	43.64	38.83	31.62	44.49	30.87	31.86
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

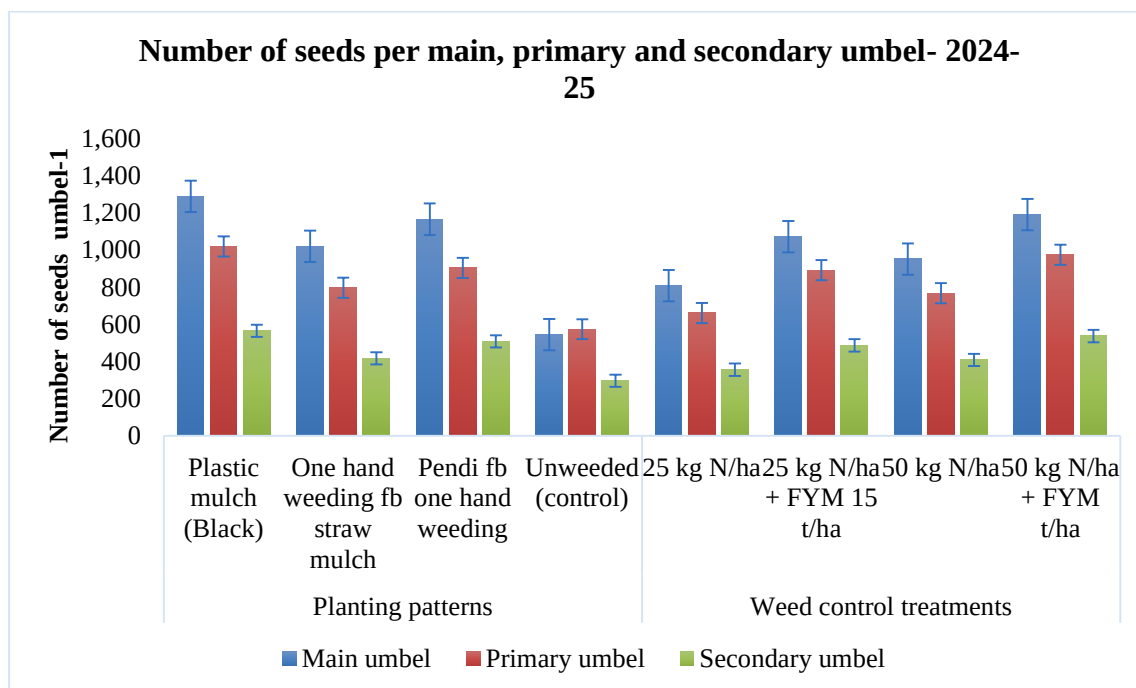
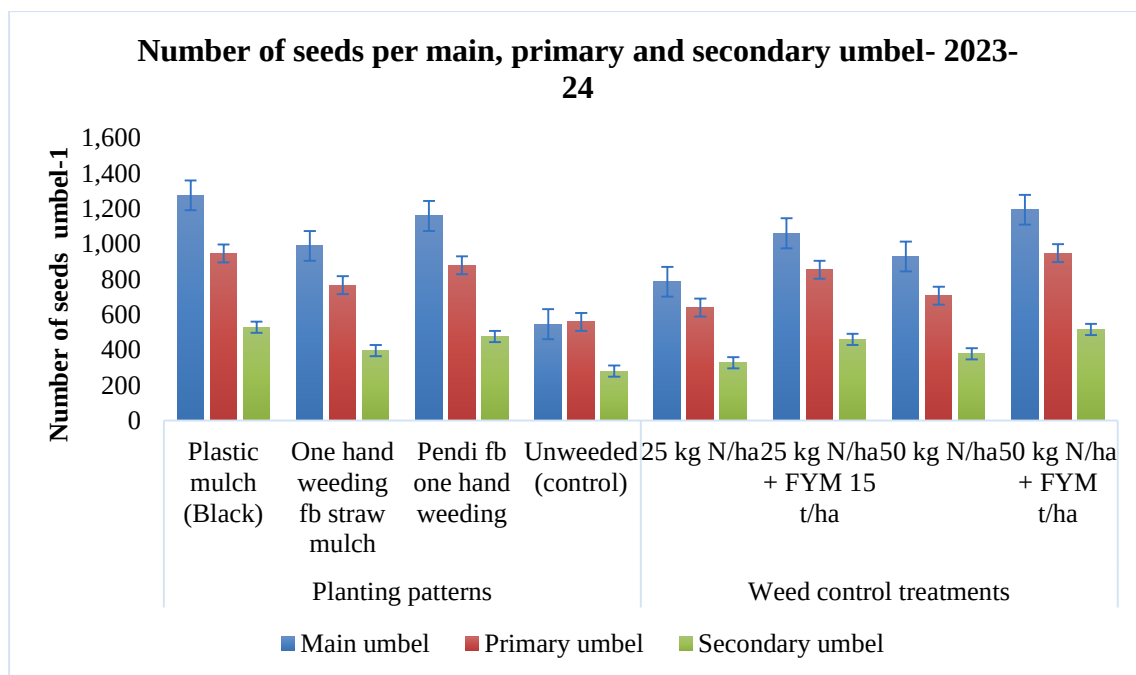


Figure 4.3.3 Effect of weed control and nutrition level treatments on number of seeds per main, primary and secondary umbel

4.3.6 Seed weight (g) of main, primary and secondary umbel

The impact on seed weight of main, primary and secondary umbel as influenced by various weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.6 and graphically depicted in Figure 4.3.4.

The differences in seed weight per main umbel were significant among the weed control treatments and nutrition levels during 2023-24 (Table 4.3.6). Among weed control treatments, black plastic mulch recorded significantly higher seed weight per main umbel (g) as compared to one hand weeding *fb* straw mulch treatment. Seed weight of main umbel in pendimethalin *fb* one hand weeding treatment was found to be statistically at par with black mulch. Unweeded (control) recorded significantly less seed weight of main umbel as compared to all other weed control treatments. Among nutrition level treatments, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight of main umbel (g) as compared to all other treatments. Seed weight per main umbel in integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Application of 25 kg N ha⁻¹ recorded significantly less seed weight of main umbel as compared to all other nutrition level treatments. During 2024-25, the differences in seed weight of main umbel (g) were significant among the weed control and nutrition level treatments. Among weed control treatments, black plastic mulch recorded significantly higher seed weight of main umbel (g) as compared to all other treatments. Seed weight of main umbel in pendimethalin *fb* one hand weeding was significantly higher than one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less seed weight of main umbel as compared to all other weed control treatments. Among nutrition levels, the treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight of main umbel as compared to all other treatments. Seed weight of main umbel in integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less seed weight of main umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

The differences in seed weight of primary umbel (g) were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.6). Among weed

control treatments, application of black plastic mulch recorded significantly more seed weight of primary umbel (g) as compared to one hand weeding *fb* straw mulch. Seed weight of primary umbel in pendimethalin *fb* one hand weeding was found to be statistically at par with black mulch. Unweeded (control) recorded significantly less seed weight of primary umbel (g) as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight per primary umbel (g) as compared to all other treatments. Seed weight of primary umbel (g) in integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less seed weight of primary umbel (g) was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in seed weight of primary umbel (g) were significant among the weed control and nutrition level treatments (Table 4.3.6). Among weed control treatments, black plastic mulch recorded significantly more seed weight of primary umbel (g) as compared to all other weed control treatments. Seed weight of primary umbel (g) in pendimethalin *fb* one hand weeding was significantly higher than one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less seed weight of primary umbel as compared to all other weed control treatments. Among nutrition levels, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight of primary umbel as compared to all other treatments. Similarly, seed weight of primary umbel in integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less seed weight of primary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

The differences in seed weight of secondary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.6). Among weed control treatments, black plastic mulch recorded significantly higher seed weight of secondary umbel (g) as compared to one hand weeding *fb* straw mulch. Seed weight of secondary umbel in pendimethalin *fb* one hand weeding was found to be statistically at par with black mulch treatment. Unweeded (control) recorded significantly less seed weight of secondary umbel as compared to all other weed

control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight of secondary umbel (g) as compared to all other treatments. Seed weight of secondary umbel in the integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly more than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less seed weight of secondary umbel (g) was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in seed weight of secondary umbel were significant among the weed control and nutrition level treatments (Table 4.3.6). Among weed control treatments, application of black plastic mulch recorded significantly higher seed weight of secondary umbel (g) as compared to all other treatments. Seed weight of secondary umbel in pendimethalin *fb* one hand weeding was significantly higher than one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less seed weight of secondary umbel as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more seed weight of secondary umbel (g) as compared to all other treatments. Seed weight of secondary umbel in integrated treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher than alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. Significantly less seed weight of secondary umbel (g) was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

Application of black mulch treatment and integrated application of higher nitrogen dose with FYM (50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹) increased the seed yield which may be due to favourable growth conditions provided by these treatments. The better utilization of resources under weed free conditions and improved soil physical conditions by combination of fertilizer and FYM leads to higher reproductive growth and hence seed weight of umbel was increased (Meena *et al.*, 2024; Mamatha *et al.*, 2021).

The interactive effect of weed control treatments and nutrition levels on seed weight of main, primary and secondary umbel (g) was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.6).

Table 4.3.6 Effect of weed control and nutrition level treatments on seed weight (g) of main, primary and secondary umbel

	Seed weight (g)					
	Main Umbel		Primary Umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	6.8	9.0	6.9	7.9	1.3	1.6
One hand weeding <i>fb</i> straw mulch	5.7	6.7	6.3	5.8	1.2	1.1
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	6.6	7.9	6.7	6.8	1.3	1.4
Unweeded (control)	3.0	2.9	3.2	3.3	0.8	0.7
SE(m)±	0.07	0.11	0.07	0.16	0.02	0.02
C.D. (5%)	0.26	0.39	0.25	0.57	0.07	0.07
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	4.5	5.1	4.9	4.5	0.9	0.9
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	5.8	7.1	6.0	6.5	1.2	1.3
50 kg N ha ⁻¹	5.2	6.1	5.5	5.4	1.0	1.1
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	6.5	8.1	6.5	7.4	1.4	1.5
SE(m)±	0.10	0.17	0.10	0.16	0.02	0.03
C.D.(5%)	0.29	0.50	0.31	0.48	0.07	0.10
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

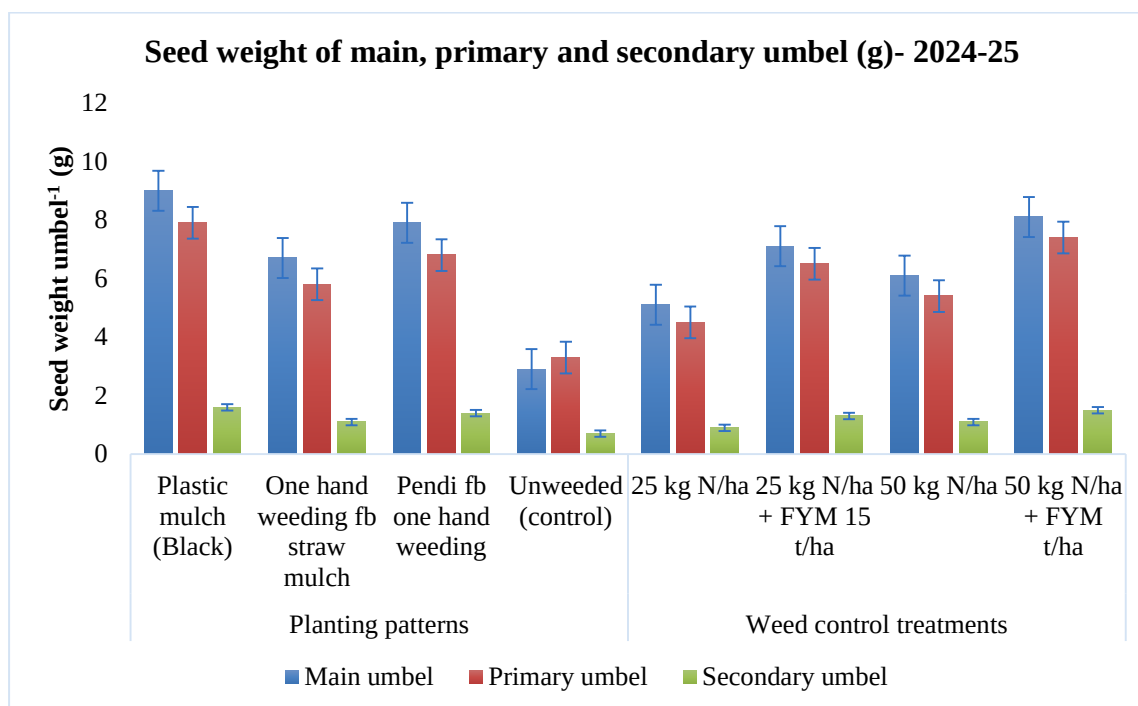
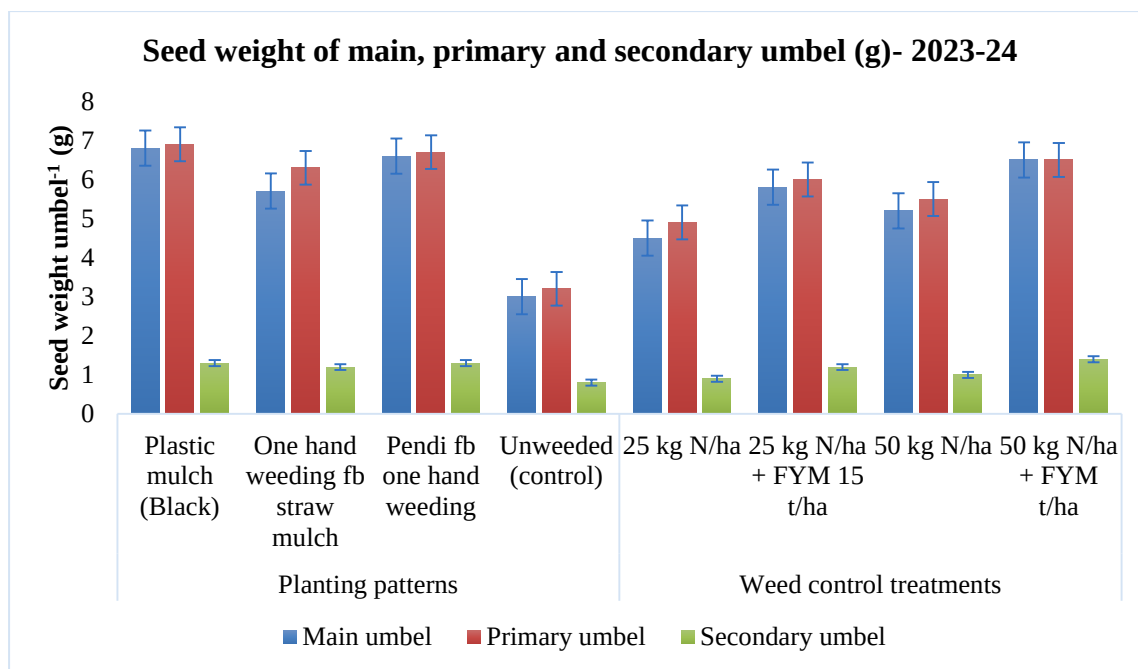


Figure 4.3.4 Effect of weed control and nutrition level treatments on seed weight of main, primary and secondary umbel (g)

4.3.7 1000 seed weight of main, primary and secondary umbels (g)

The impact on 1000 seed weight of main, primary and secondary umbel as influenced by variable weed control treatments and nutrition levels at harvest during 2023-24 and 2024-25 has been presented in Table 4.3.7.

The differences in 1000 seed weight (g) of main umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.7). Among weed control treatments, the 1000 seed weight of main umbel in black plastic mulch, one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Unweeded (control) recorded significantly less 1000 seed weight of main umbel as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of main umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ treatments. The 1000 seed weight of main umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹. Significantly less 1000 seed weight of main umbel was recorded in 25 kg N ha⁻¹ as compared to 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatment. During 2024-25, the differences in 1000 seed weight of main umbel (g) were significant among the weed control and nutrition level treatments (Table 4.3.7). Among weed control treatments, black plastic mulch recorded significantly higher 1000 seed weight of main umbel (g) as compared to all other weed control treatments. The 1000 seed weight of main umbel in pendimethalin *fb* one hand weeding was significantly higher than one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less 1000 seed weight (g) of main umbel as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of main umbel (g) as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The 1000 seed weight of main umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹. Significantly less 1000 seed weight (g) of main umbel was recorded in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments.

The differences in 1000 seed weight of primary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.7). Among weed control treatments, application of black plastic mulch recorded significantly higher 1000 seed weight of primary umbel (g) as compared to one hand weeding *fb* straw mulch. The 1000 seed weight of primary umbel in pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch was found to be statistically at par with each other. Unweeded (control) recorded significantly less 1000 seed weight of primary umbel as compared to all other weed control treatments. Among nutrition levels, integrated treatment of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of primary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The 1000 seed weight of primary umbel (g) in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with the treatment of 50 kg N ha⁻¹. Significantly less 1000 seed weight of primary umbel was recorded in 25 kg N ha⁻¹ as compared to both integrated treatments i.e. 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatment. During 2024-25, the differences in 1000 seed weight of primary umbel were significant among the weed control and nutrition level treatments (Table 4.3.7). Among weed control treatments, black plastic mulch recorded significantly higher 1000 seed weight of primary umbel as compared to all other weed control treatments. Thousand seed weight of primary umbel in pendimethalin *fb* one hand weeding was significantly higher than one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less 1000 seed weight (g) of primary umbel as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of primary umbel as compared to all other nutrition treatments. Thousand seed weight of primary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹. Significantly less 1000 seed weight of primary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments.

The differences in 1000 seed weight (g) of secondary umbel were significant among the weed control and nutrition level treatments during 2023-24 (Table 4.3.7). Among weed control treatments, application of black plastic mulch recorded significantly

higher 1000 seed weight of secondary umbel as compared to one hand weeding *fb* straw mulch treatment. Thousand seed weight (g) of secondary umbel in pendimethalin *fb* one hand weeding was found to be statistically at par with black plastic mulch treatment. Unweeded (control) recorded significantly less 1000 seed weight (g) of secondary umbel as compared to pendimethalin *fb* one hand weeding and black plastic mulch treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of secondary umbel (g) as compared to all other nutrition level treatments. The 1000 seed weight (g) of secondary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹. Significantly less 1000 seed weight of secondary umbel was recorded in 25 kg N ha⁻¹ as compared to all other nutrition level treatments. During 2024-25, the differences in 1000 seed weight of secondary umbel were significant among the weed control and nutrition level treatments (Table 4.3.7). Among weed control treatments, application of black plastic mulch recorded significantly higher 1000 seed weight of secondary umbel as compared to one hand weeding *fb* straw mulch treatment. Thousand seed weight of secondary umbel (g) in pendimethalin *fb* one hand weeding was statistically at par with one hand weeding *fb* straw mulch. Unweeded (control) recorded significantly less 1000 seed weight (g) of secondary umbel as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more 1000 seed weight of secondary umbel as compared to all other nutrition level treatments. Thousand seed weight of secondary umbel in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹. Significantly less 1000 seed weight of secondary umbel was recorded in 25 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatments.

Thousand seed weight of main, primary and secondary umbel under black mulch was significantly higher than all other weed control treatments, which may be due to less crop weed competition throughout the crop growth period and better growth conditions provided by this treatment which enhanced yield attributes of the crop. Integrated application of higher nitrogen dose with FYM enhanced the nutrient uptake

of the crop which promoted development of bolder and heavier seeds. These findings were in conformity with Gholami & Madandoust (2024) and Bhattarai *et al.* (2021).

The interactive effect of weed control treatments and nutrition levels on 1000 seed weight (g) of main, primary and secondary umbel was found to be non-significant at harvest during 2023-24 and 2024-25 (Table 4.3.7).

Table 4.3.7 Effect of weed control and nutrition level treatments on 1000 seed weight of main, primary and secondary umbel (g)

	1000 seed weight (g)					
	Main umbel		Primary Umbel		Secondary umbel	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	6.7	6.9	7.6	7.7	3.0	2.8
One hand weeding <i>fb</i> straw mulch	6.4	6.5	7.1	7.2	2.5	2.6
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	6.5	6.7	7.4	7.5	2.8	2.7
Unweeded (control)	5.0	5.2	5.6	5.7	2.4	2.4
SE(m)±	0.14	0.05	0.10	0.05	0.06	0.05
C.D. (5%)	0.48	0.17	0.36	0.19	0.21	0.17
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	6.0	6.1	6.6	6.7	2.4	2.4
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	6.2	6.5	7.0	7.1	2.7	2.6
50 kg N ha ⁻¹	6.1	6.2	6.8	7.0	2.7	2.5
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	6.4	6.6	7.2	7.4	2.9	2.8
SE(m)±	0.10	0.11	0.08	0.08	0.06	0.07
C.D. (5%)	0.28	0.32	0.24	0.23	0.17	0.19
Interaction C.D. (5%)						
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.3.8 Seed yield and stover yield (q ha^{-1})

The seed yield is the economic part of the crop which is ultimate product of crop growth factors and yield attributes. The treatment with higher seed yield is considered to be the best treatment. The data on the effect of weed control treatments and nutrition levels on seed yield (q ha^{-1}) and stover yield (q ha^{-1}) during 2023-24 and 2024-25 has been presented in Table 4.3.8 and graphically depicted in Figure 4.3.5.

The seed yield (q ha^{-1}) was influenced significantly by various weed control and nutrition level treatments during 2023-24 (Table 4.3.8). Among weed control treatments, application of black plastic mulch recorded significantly higher seed yield as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding produced significantly more seed yield (q ha^{-1}) as compared to one hand weeding *fb* straw mulch treatment. Seed yield in unweeded (control) was significantly less as compared to all other weed control treatments. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher seed yield as compared to all other nutrition level treatments. The treatment of integrated application of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher seed yield as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . Significantly less seed yield was recorded in 25 kg N ha^{-1} as compared to all other nutrition level treatments. During 2024-25, the differences in seed yield (q ha^{-1}) due to weed control and nutrition level treatments were found to be significant (Table 4.3.8). Among weed control treatments, application of black plastic mulch recorded significantly higher seed yield (q ha^{-1}) as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding produced statistically at par seed yield with one hand weeding *fb* straw mulch treatment. The seed yield in unweeded (control) was found to be significantly less as compared to all other weed control treatments. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher seed yield (q ha^{-1}) as compared to all other nutrition level treatments. Seed yield in the treatment of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was significantly higher as compared to 50 kg N ha^{-1} . Significantly less seed yield was recorded in 25 kg N ha^{-1} as compared to all other nutrition level treatments.

Among main plots, significantly higher seed yield of fennel (q ha^{-1}) under the weed control treatment of black plastic mulch and pendimethalin *fb* one hand weeding as compared to one hand weeding *fb* straw mulch and unweeded (control) may be due to effective weed control in the former treatments (Table 4.1.1 to 4.1.4), increased growth factors (Table 4.2.1 to 4.2.7) and better yield attributes (Table 4.3.1 to 4.3.7). Higher yields under these treatments may be attributed to better weed control due to more suppression of weeds as well as availability of better soil physical conditions which favoured the crop growth. Similar results were reported by Meena *et al.* (2024). Among sub plots, significantly more seed yield (q ha^{-1}) was recorded in application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ treatment as compared to all other nutrition level treatments which may be due to increased crop growth factors (Table 4.2.1 to 4.2.7) and better yield attributes (Table 4.3.1 to 4.3.7) in this treatment. Higher yield in $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ treatment may be due to the availability of more amount of nutrients to the crop and improvement in soil physical conditions which improved the growth of crop in this treatment as compared to others. Similar results were reported by Kaur *et al.* (2022). On an average of two years data, seed yield under black plastic mulch, pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch treatment was increased by 1005.88, 841.18 and 794.11 percent, respectively as compared to unweeded (control) treatment. Among nutrition levels, application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$, $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ and 50 kg N ha^{-1} increased the seed yield of fennel by 39.25, 27.10 and 17.76 percent, respectively as compared to 25 kg N ha^{-1} .

The interactive effect of weed control treatments and nutrition levels for seed yield (q ha^{-1}) of fennel was found to be significant during both the years (Table 4.3.9). During 2023-24, seed yield in the combination of black plastic mulch applied with $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was found to be significantly higher as compared to pre-emergence application of pendimethalin *fb* one hand weeding under same nutrition level. Pendimethalin *fb* one hand weeding applied with $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher seed yield (q ha^{-1}) as compared to one hand weeding *fb* straw mulch applied with 50 kg N ha^{-1} . One hand weeding *fb* straw mulch applied with $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher seed yield as

compared to pendimethalin *fb* one hand weeding applied with 50 kg N ha⁻¹. During 2024-25, application of black plastic mulch with 50 kg N ha⁻¹ recorded statistically at par seed yield (q ha⁻¹) with pendimethalin *fb* one hand weeding applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (Table 4.3.9). Pre-emergence application of pendimethalin *fb* one hand weeding in combination with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher seed yield as compared to one hand weeding *fb* straw mulch applied with 50 kg N ha⁻¹. One hand weeding *fb* straw mulch supplied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded statistically at par seed yield (q ha⁻¹) with the combination of pendimethalin *fb* one hand weeding and application of 50 kg N ha⁻¹ to the crop.

The stover yield (q ha⁻¹) was influenced significantly by various weed control and nutrition level treatments during 2023-24 (Table 4.3.8). Among weed control treatments, black plastic mulch recorded significantly higher stover yield (q ha⁻¹) as compared to all other treatments. Pendimethalin *fb* one hand weeding produced significantly higher stover yield (q ha⁻¹) as compared to one hand weeding *fb* straw mulch treatment. The stover yield (q ha⁻¹) in unweeded (control) was found to be significantly less as compared to all other weed control treatments. Among nutrition level treatments, the stover yield of crop supplied with in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The stover yield in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher as compared to 50 kg N ha⁻¹. Application of 25 kg N ha⁻¹ produced significantly lower stover yield (q ha⁻¹) as compared to all other nutrition level treatments. During 2024-25, the stover yield was influenced significantly by various weed control and nutrition level treatments (Table 4.3.8). Among weed control treatments, black plastic mulch recorded significantly higher stover yield (q ha⁻¹) as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding produced significantly higher stover yield as compared to one hand weeding *fb* straw mulch treatment. The stover yield (q ha⁻¹) in unweeded (control) was found to be significantly less as compared to all other weed control treatments. Among nutrition levels, the stover yield in 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The stover yield in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatment was

statistically at par with 50 kg N ha⁻¹. Application of 25 kg N ha⁻¹ produced significantly lower stover yield (q ha⁻¹) as compared to all other nutrition level treatments.

The higher seed and stover yield (q ha⁻¹) with the application of black plastic mulch might be due to effective weed control from the initial growth stages to maturity of the crop which led to less crop weed competition for resources. Therefore, higher yield was found under this treatment. Similar results were reported by Meena *et al.* (2024). The integrated treatment of fertilizer and FYM ensured prolonged availability of nutrients throughout the crop growth period. The increased and balanced supply of nutrients to the crop promotes flowering and fruiting and better partitioning of assimilates to the sink. These findings were in conformity with Kaur *et al.* (2022) and Datta *et al.* (2008).

The interactive effect of weed control treatments and nutrition levels on stover yield (q ha⁻¹) was found to be non-significant during both the years (Table 4.3.9).

Table 4.3.8 Effect of weed control and nutrition level treatments on seed and stover yield (q ha⁻¹) of fennel

Treatment details	Seed yield (q ha ⁻¹)			Stover yield (q ha ⁻¹)	
	2023-24	2024-25	Average of two years	2023-24	2024-25
Main plots (Weed control treatments)					
Plastic mulch (Black)	18.4	19.2	18.8	90.5	92.0
One hand weeding <i>fb</i> straw mulch	12.5	17.9	15.2	70.1	79.0
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	14.1	18.0	16.0	78.3	85.8
Unweeded (control)	1.2	2.2	1.7	4.6	9.6
SE(m)±	0.32	0.38	-	1.75	0.87
C.D. (5%)	1.12	1.23	-	6.18	2.83
Sub-plots (Nutrition levels)					
25 kg N ha ⁻¹	9.8	11.5	10.7	51.9	59.5
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	12.3	15.0	13.6	65.3	69.0
50 kg N ha ⁻¹	11.2	14.0	12.6	59.3	67.3
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	13.0	16.8	14.9	67.0	70.6
SE(m)±	0.22	0.32	-	1.62	0.89
C.D. (5%)	0.64	0.93	-	4.75	2.56
Interaction C.D. (5%)	1.39	1.94	-	NS	NS

Table 4.3.9 Interactive effect of weed control and nutrition level treatments on seed yield (q ha^{-1}) during 2023-24 and 2024-25

Seed yield (q ha^{-1}) - 2023-24

	25 kg N ha^{-1}	25 kg N ha^{-1} + FYM 15.0 t ha^{-1}	50 kg N ha^{-1}	50 kg N ha^{-1} + FYM 15.0 t ha^{-1}	Mean A
Plastic mulch (Black)	17.1	18.8	18.8	19.1	18.4
One hand weeding <i>fb</i> straw mulch	9.7	13.6	12.9	13.8	12.5
Pendimethalin (0.45 kg ha^{-1}) <i>fb</i> one hand weeding	11.2	15.6	12.2	17.4	14.1
Unweeded (control)	1.0	1.3	0.9	1.8	1.2
Mean B	9.8	12.3	11.2	13.0	
SE(m)±	0.63				
C.D. (5%)	1.39				

Seed yield (q ha^{-1}) - 2024-25

	25 kg N ha^{-1}	25 kg N ha^{-1} + FYM 15.0 t ha^{-1}	50 kg N ha^{-1}	50 kg N ha^{-1} + FYM 15.0 t ha^{-1}	Mean A
Plastic mulch (Black)	14.6	20.6	19.3	22.4	19.2
One hand weeding <i>fb</i> straw mulch	14.1	18.8	16.2	22.5	17.9
Pendimethalin (0.45 kg ha^{-1}) <i>fb</i> one hand weeding	15.5	18.3	18.2	19.9	18.0
Unweeded (control)	1.9	2.2	2.2	2.6	2.2
Mean B	11.5	15.0	14.0	16.8	
SE(m)±	0.76				
C.D. (5%)	1.94				

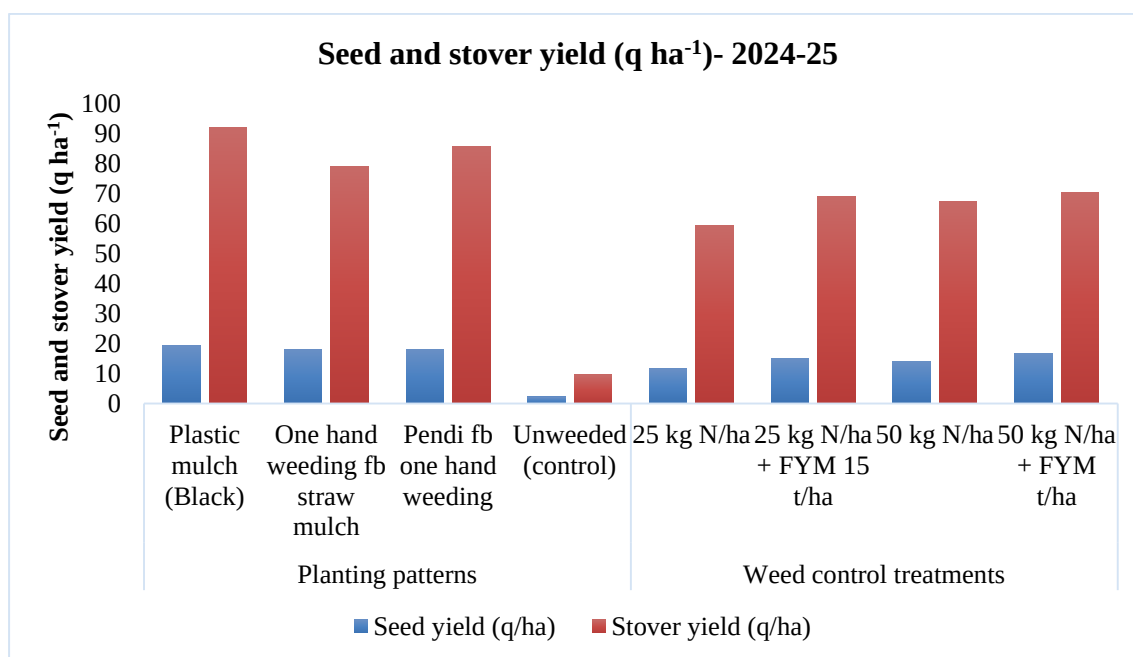
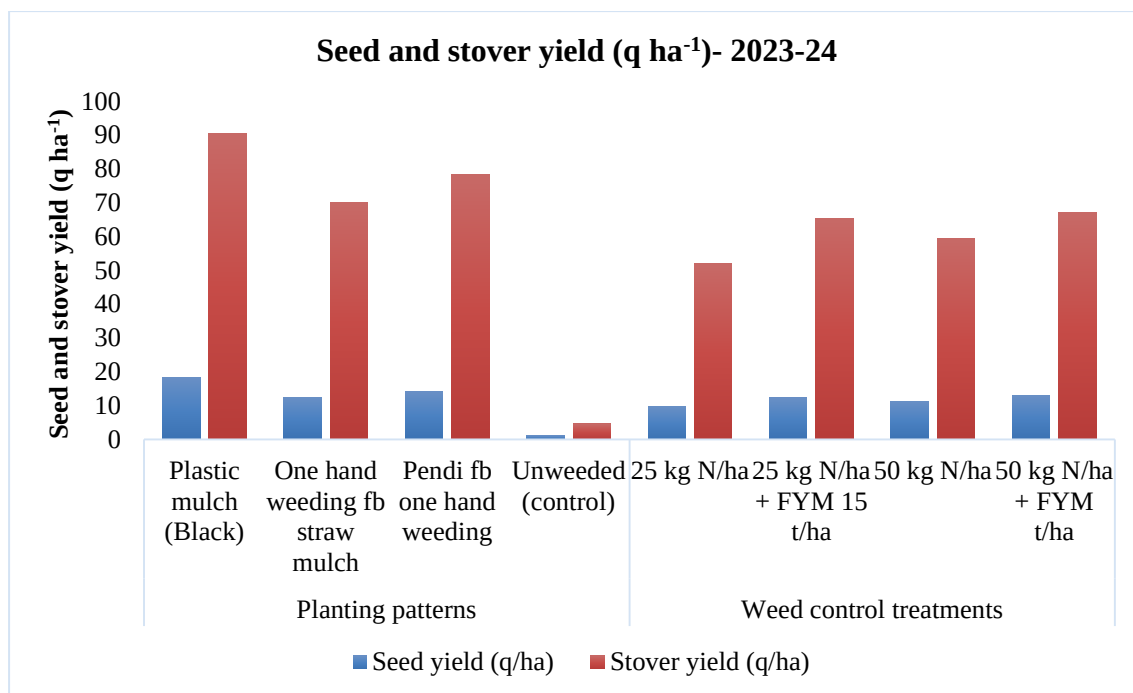


Figure 4.3.5 Effect of weed control and nutrition level treatments on seed and stover yield (q ha⁻¹)

4.3.9 Biological yield (q ha^{-1}) and harvest index (%)

The data on effect of weed control and nutrition level treatments on biological yield (q ha^{-1}) and harvest index (%) during 2023-2024 and 2024-2025 has been presented in Table 4.3.10.

The biological yield (q ha^{-1}) was influenced significantly by various weed control and nutrition level treatments during 2023-24 (Table 4.3.10). Among weed control treatments, the biological yield in black plastic mulch treated crop was found to be significantly higher as compared to all other treatments. Pre-emergence application of pendimethalin *fb* one hand weeding recorded significantly higher biological yield as compared to one hand weeding *fb* straw mulch treatment. The biological yield (q ha^{-1}) in unweeded (control) was found to be significantly less as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher biological yield as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . The biological yield in 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} was found to be statistically at par with 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} . Application of 25 kg N ha^{-1} recorded significantly less biological yield as compared to all other nutrition level treatments. During 2024-25, the biological yield (q ha^{-1}) was influenced significantly by various weed control and nutrition level treatments (Table 4.3.10). Among weed control treatments, biological yield (q ha^{-1}) in black plastic mulch was found to be significantly higher as compared to all other weed control treatments. Pendimethalin *fb* one hand weeding recorded significantly higher biological yield as compared to one hand weeding *fb* straw mulch treatment. Biological yield in unweeded (control) treatment was found to be significantly less as compared to all other weed control treatments. Among nutrition levels, integrated application of 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher biological yield (q ha^{-1}) as compared to all other treatments. The biological yield in 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} was found to be significantly higher than 50 kg N ha^{-1} and 25 kg N ha^{-1} . Significantly less biological yield was recorded in 25 kg N ha^{-1} application as compared to all other nutrition level treatments.

The harvest index (%) was influenced significantly by various weed control and nutrition level treatments during 2023-24 (Table 4.3.10). Among weed control treatments, the harvest index in unweeded (control) was found to be significantly higher as compared to all other treatments. Black plastic mulch recorded significantly higher harvest index (%) as compared to one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding. The harvest index in one hand weeding *fb* straw mulch and pendimethalin *fb* one hand weeding was found to be statistically at par with each other. Among nutrition levels, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher harvest index as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The harvest index in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. Significantly lower harvest index (%) was found in application of 50 kg N ha⁻¹ as compared to 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. During 2024-25, the harvest index (%) was influenced significantly by various weed control and nutrition level treatments (Table 4.3.10). Among weed control treatments, the harvest index (%) in unweeded (control) was found to be significantly higher as compared to black plastic mulch and pendimethalin *fb* one hand weeding treatments. Harvest index was found to be statistically at par in one hand weeding *fb* straw mulch with pendimethalin *fb* one hand weeding treatments. The harvest index in black plastic mulch was significantly less than one hand weeding *fb* straw mulch. Among nutrition levels, 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher harvest index as compared to 25 kg N ha⁻¹. The harvest index in 50 kg N ha⁻¹, 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with each other. Significantly less harvest index was observed in 25 kg N ha⁻¹ application as compared to 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹.

The higher biological yield (q ha⁻¹) and harvest index (%) in black plastic mulch might be due to less crop weed competition and suppression of weeds effectively which leads to better utilization of nutrients, moisture and light which enhanced the vegetative growth of crop. Similar results were reported by Kumar *et al.* (2023). There was a synergistic effect of higher dose of fertilizer with organic manure (FYM) on the growth and yield of crop. Nitrogen boosts vegetative growth and FYM

enhances soil health and moisture retention. Therefore, these treatments enhance photosynthesis process and biomass production. These findings were similar to that of Błazewicz-Wozniak (2010) and Pariari *et al.* (2015).

The interactive effect of weed control treatments and nutrition levels on biological yield ($q\ ha^{-1}$) and harvest index (%) was found to be non-significant during 2023-24 and 2024-25 (Table 4.3.10).

Table 4.3.10 Effect of weed control and nutrition level treatments on biological yield (q ha^{-1}) and harvest index (%)

	Biological yield (q ha^{-1})		Harvest index (%)	
	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)				
Plastic mulch (Black)	108.9	111.2	16.9	17.2
One hand weeding <i>fb</i> straw mulch	82.6	96.9	15.3	18.3
Pendimethalin (0.45 kg ha^{-1}) <i>fb</i> one hand weeding	92.4	103.7	15.2	17.3
Unweeded (control)	5.9	11.8	20.6	19.0
SE(m)±	2.05	1.02	0.40	0.34
C.D. (5%)	7.23	3.31	1.40	1.09
Sub-plots (Nutrition levels)				
25 kg N ha^{-1}	61.6	71.0	16.7	17.0
$25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$	77.7	84.0	17.2	18.0
50 kg N ha^{-1}	70.5	81.3	16.3	18.1
$50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$	80.0	87.4	17.7	18.7
SE(m)±	1.79	0.85	0.28	0.39
C.D. (5%)	5.26	2.43	0.82	1.13
Interaction C.D. (5%)	NS	NS	NS	NS

4.4 Economics

Data on economics of fennel was presented in Table 4.4.1. On the basis of average of two years data (2023-24 and 2024-25), among all the treatment combinations, black plastic mulch applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ gave higher net returns (181107.6 ₹ ha⁻¹) as well as benefit cost ratio as compared to treatment combination of hand weeding *fb* straw mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (136880.0 ₹ ha⁻¹). The highest net return of fennel (181107.6 ₹ ha⁻¹) was recorded with the application of black plastic mulch treatment with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The benefit cost ratio recorded in pendimethalin *fb* hand weeding applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (2.76) was better than one hand weeding *fb* straw mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (2.42). Unweeded (control) treatment recorded negative net returns when combined with all the nutrition levels because of more weed infestation leading to significant losses in seed yield. The treatment combination of pendimethalin *fb* hand weeding applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ gave higher net returns (149846.2 ₹ ha⁻¹) and benefit cost ratio as compared to hand weeding *fb* straw mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ (136880.0 ₹ ha⁻¹).

Table 4.4.1 Effect of weed control and nutrition level treatments on economics of fennel crop

Treatments	Cost of cultivation (₹ ha⁻¹)	Gross returns (₹ ha⁻¹)	Net returns (₹ ha⁻¹)	B:C ratio
Black plastic mulch + 25 kg N ha ⁻¹	59526.0	197945.0	138418.9	2.33
Black plastic mulch + 25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	77526.0	246294.8	168768.8	2.18
Black plastic mulch + 50 kg N ha ⁻¹	59852.1	237619.9	177767.9	2.97
Black plastic mulch + 50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	77852.1	258959.7	181107.6	2.33
Hand weeding <i>fb</i> straw mulch + 25 kg N ha ⁻¹	47976.0	148837.7	100861.6	2.10
Hand weeding <i>fb</i> straw mulch + 25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	65976.0	202856.0	136880.0	2.07
Hand weeding <i>fb</i> straw mulch + 50 kg N ha ⁻¹	48302.1	182282.6	133980.5	2.77
Hand weeding <i>fb</i> straw mulch + 50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	66302.1	226481.5	160179.4	2.42
Pendimethalin <i>fb</i> Hand weeding + 25 kg N ha ⁻¹	43651.0	167031.8	123380.7	2.83
Pendimethalin <i>fb</i> Hand weeding + 25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	61651.0	211497.3	149846.2	2.43
Pendimethalin <i>fb</i> Hand weeding + 50 kg N ha ⁻¹	43977.1	189745.7	145768.6	3.31
Pendimethalin <i>fb</i> Hand weeding + 50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	61977.1	233047.8	171070.8	2.76
Unweeded (control) + 25 kg N ha ⁻¹	37726.0	18438.4	-19287.7	-0.51
Unweeded (control) + 25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	55726.0	21524.6	-34201.4	-0.61
Unweeded (control) + 50 kg N ha ⁻¹	38052.1	18830.3	-19221.8	-0.51
Unweeded (control) + 50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	56052.1	27092.4	-28959.7	-0.52

4.5 Quality parameters

4.5.1 N content (%), protein content (%) and oil content in seed (%)

N content in seeds is one of the important quality parameter and protein content of seeds depends on N content in seeds. The data on effect of weed control and nutrition level treatments on N content, protein content and oil content in seed during 2023-24 and 2024-25 has been presented in Table 4.5.1.

The differences in N content in seed (%) as influenced by various weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among nutrition level treatments, the N content in seed (%) was found to be non-significant during both the years.

The differences in protein content in seed (%) as influenced by weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among nutrition level treatments, the protein content in seed (%) was found to be non-significant during both the years.

The differences in oil content in seed (%) as influenced by various weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Among nutrition level treatments, oil content in seed (%) was found to be non-significant during both the years.

The interactive effect of weed control and nutrition level treatments on N content (%), protein content (%) and oil content in seed (%) was found to be non-significant during 2023-24 and 2024-25 (Table 4.5.1). Similar results were obtained by Khalili *et al.* (2025) and Mamatha (2021).

**Table 4.5.1 Effect of weed control and nutrition level treatments on N content
(%), protein content (%) and oil content (%) in seed**

	N content (%)		Protein content (%)		Oil content (%)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)						
Plastic mulch (Black)	1.45	1.41	9.04	8.81	1.63	1.64
One hand weeding <i>fb</i> straw mulch	1.46	1.43	9.13	8.92	1.61	1.63
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1.43	1.41	8.96	8.81	1.62	1.62
Unweeded (control)	1.48	1.43	9.24	8.96	1.58	1.62
SE(m)±	0.01	0.01	0.08	0.04	0.01	0.01
C.D. (5%)	NS	NS	NS	NS	NS	NS
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	1.43	1.40	8.94	8.75	1.60	1.61
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.45	1.43	9.09	8.93	1.62	1.63
50 kg N ha ⁻¹	1.47	1.43	9.19	8.93	1.60	1.62
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.46	1.42	9.14	8.89	1.63	1.63
SE(m)±	0.01	0.01	0.07	0.05	0.01	0.01
C.D. (5%)	NS	NS	NS	NS	NS	NS
Interaction C.D. (5%)						
Interaction C.D. (5%)	NS	NS	NS	NS	NS	NS

4.5.2 Periodic N content (%) in crop at 90 DAS and at harvest

The data on effect of weed control and nutrition level treatments on periodic N content (%) of the crop at 90 DAS and at harvest during 2023-24 and 2024-25 has been presented in Table 4.5.2.

The differences in N content in crop (%) at 90 DAS as influenced by various weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.2). Among nutrition level treatments, the N content in crop (%) at 90 DAS was also found to be non-significant during both the years.

The differences in N content in crop (%) at harvest as influenced by various weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.2). Among nutrition level treatments, the N content in crop (%) at harvest was also found to be non-significant during both the years.

The interactive effects of weed control and nutrition level treatments on periodic N content in crop (%) at 90 DAS and at harvest were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.2). Similar findings were reported by Khalili *et al.*, 2025.

Table 4.5.2 Effect of weed control and nutrition level treatments on periodic N content in crop (%) at 90 DAS and at harvest

	N content in crop (%)		N content in stover (%)	
	At 90 DAS		At harvest	
	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)				
Plastic mulch (Black)	1.23	1.16	0.39	0.37
One hand weeding <i>fb</i> straw mulch	1.25	1.18	0.40	0.39
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	1.21	1.16	0.39	0.38
Unweeded (control)	1.27	1.19	0.40	0.39
SE(m)±	0.02	0.01	0.004	0.004
C.D. (5%)	NS	NS	NS	NS
Sub-plots (Nutrition levels)				
25 kg N ha ⁻¹	1.21	1.16	0.39	0.38
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.24	1.18	0.39	0.38
50 kg N ha ⁻¹	1.26	1.19	0.40	0.39
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	1.25	1.18	0.40	0.38
SE(m)±	0.01	0.01	0.004	0.003
C.D. (5%)	NS	NS	NS	NS
Interaction C.D. (5%)				
Interaction C.D. (5%)	NS	NS	NS	NS

4.5.3 N uptake by seeds (kg ha^{-1}), N uptake by stover (kg ha^{-1}) and total N uptake by crop (kg ha^{-1})

The impact of various weed control and nutrition level treatments on N uptake by seeds (kg ha^{-1}), N uptake by stover (kg ha^{-1}) and total N uptake by crop (kg ha^{-1}) recorded at harvest during 2023-24 and 2024-25 has been presented in Table 4.5.3 and graphically depicted in Figure 4.5.1.

The differences in N uptake by seed (kg ha^{-1}) were significant among weed control and nutrition level treatments during 2023-24 (Table 4.5.3). Among weed control treatments, application of black plastic mulch recorded significantly more N uptake by seed (kg ha^{-1}) as compared to all other weed control treatments. The N uptake by seed with the application of pendimethalin *fb* one hand weeding was significantly higher than in one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly less N uptake by seed (kg ha^{-1}) as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher N uptake by seed as compared to all other nutrition level treatments. The integrated application of 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher N uptake by seed as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . The application of 25 kg N ha^{-1} recorded significantly less N uptake by seed as compared to all other nutrition level treatments. During 2024-25, the differences in N uptake by seed (kg ha^{-1}) were significant among various weed control and nutrition level treatments (Table 4.5.3). Among weed control treatments, black plastic mulch recorded significantly higher N uptake by seed (kg ha^{-1}) as compared to all other weed control treatments. The uptake of nitrogen by seed (kg ha^{-1}) in pendimethalin *fb* one hand weeding was found to be statistically at par with one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly less N uptake by seed as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly more N uptake by seed as compared to all other nutrition level treatments. The integrated application of 25 kg N ha^{-1} + FYM 15.0 t ha^{-1} recorded significantly higher N uptake by seed as compared to alone application of 50

kg N ha⁻¹ and 25 kg N ha⁻¹. The application of 25 kg N ha⁻¹ recorded significantly less N uptake by seed as compared to all other nutrition levels.

The differences in N uptake by stover (kg ha⁻¹) were significant among weed control and nutrition level treatments during 2023-24 (Table 4.5.3). Among weed control treatments, application of black plastic mulch recorded significantly higher N uptake by stover (kg ha⁻¹) as compared to all other weed control treatments. The N uptake by stover with the application of pendimethalin *fb* one hand weeding was significantly higher than in one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly less N uptake by stover (kg ha⁻¹) as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded statistically at par N uptake by stover with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The N uptake by stover with integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was significantly higher as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. The application of 25 kg N ha⁻¹ recorded significantly less N uptake by stover as compared to all other nutrition level treatments. During 2024-25, the differences in N uptake by stover (kg ha⁻¹) were significant among various weed control and nutrition level treatments. Among weed control treatments, black plastic mulch recorded significantly higher N uptake by stover (kg ha⁻¹) as compared to all other weed control treatments. The N uptake by stover with the application of pendimethalin *fb* one hand weeding was significantly higher than in one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly less N uptake by stover (kg ha⁻¹) as compared to all other weed control treatments. Among nutrition level treatments, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded statistically at par N uptake by stover (kg ha⁻¹) with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The N uptake by stover with integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with alone application of 50 kg N ha⁻¹. The application of 25 kg N ha⁻¹ recorded significantly less N uptake by stover (kg ha⁻¹) as compared to all other nutrition level treatments.

The differences in total N uptake by crop (kg ha⁻¹) were significant among weed control and nutrition level treatments during 2023-24 (Table 4.5.3). Among weed control treatments, application of black plastic mulch recorded significantly more

total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments. The total N uptake by crop with the application of pendimethalin *fb* one hand weeding was significantly more than one hand weeding *fb* straw mulch treatment. Unweeded (control) treatment recorded significantly less total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments. Among nutrition level treatments, total N uptake by crop with the application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was statistically at par with $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$. The total N uptake by crop with integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was significantly more as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . The application of 25 kg N ha^{-1} recorded significantly less total N uptake by crop as compared to all other nutrition levels. During 2024-25, the differences in total N uptake by crop (kg ha^{-1}) were significant among various weed control and nutrition level treatments. Among weed control treatments, application of black plastic mulch recorded significantly higher total N uptake by crop (kg ha^{-1}) as compared to all other weed control treatments. The total N uptake by crop with the application of pendimethalin *fb* one hand weeding was significantly more than one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly less total N uptake by crop as compared to all other weed control treatments. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ recorded significantly higher N uptake by crop (kg ha^{-1}) as compared to all other nutrition level treatments. The total N uptake by crop (kg ha^{-1}) with integrated application of $25 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was significantly more than alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} . The application of 25 kg N ha^{-1} recorded significantly lower total uptake of N by crop (kg ha^{-1}) as compared to all other nutrition levels.

The interactive effects of weed control and nutrition level treatments on N uptake by stover (kg ha^{-1}) and total N uptake by crop (kg ha^{-1}) were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.3). However, the interactive effects of weed control treatments and nutrition level treatments for N uptake by seed was found to be significant during both years.

During 2023-24, the N uptake by seed (kg ha^{-1}) in the treatment of black plastic mulch applied with $50 \text{ kg N ha}^{-1} + \text{FYM } 15.0 \text{ t ha}^{-1}$ was found to be significantly higher than

application of 25 kg N ha⁻¹ under same weed control treatment (Table 4.5.4). The N uptake by seed (kg ha⁻¹) in the treatment combination of pendimethalin *fb* one hand weeding applied with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be significantly more as compared to one hand weeding *fb* straw mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The uptake of N by seed (kg ha⁻¹) in the treatment combination of black plastic mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was found to be statistically at par with 50 kg N ha⁻¹ under same weed control method. During 2024-25, the integration of black plastic mulch with 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more uptake of N by seed (kg ha⁻¹) as compared to pendimethalin *fb* hand weeding under same nutrition level (Table 4.5.4). The uptake of N by seeds in pendimethalin *fb* hand weeding applied with 50 kg N ha⁻¹ was statistically at par with one hand weeding *fb* straw mulch applied with 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹. The uptake of nitrogen by seed (kg ha⁻¹) in the treatment of black plastic mulch applied with 25 kg N ha⁻¹ was statistically at par with one hand weeding *fb* straw mulch applied with 50 kg N ha⁻¹.

Higher uptake of N by seeds and stover in black plastic mulch might be due to less crop- weed competition and better growth conditions for crop which resulted in better utilization of resources and nutrients. The integrated use of organic and inorganic fertilizers enhanced the nitrogen uptake by the crop. Similar findings were reported by Meena *et al.* (2023) and Choudhary *et al.* (2022).

Table 4.5.3 Effect of weed control and nutrition level treatments on N uptake by seed, stover and total N uptake by crop (kg ha⁻¹)

	N uptake by seed (kg ha ⁻¹)		N uptake by stover (kg ha ⁻¹)		Total N uptake by crop(kg ha ⁻¹)	
	2023- 24	2024- 25	2023- 24	2024- 25	2023- 24	2024- 25
Main plots (Weed control treatments)						
Plastic mulch (Black)	26.6	27.0	35.5	34.4	62.1	61.4
One hand weeding <i>fb</i> straw mulch	18.3	24.5	28.1	30.9	46.4	55.3
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	20.2	24.9	30.4	32.1	50.6	57.0
Unweeded (control)	1.8	3.2	1.9	3.7	3.7	6.9
SE(m)±	0.31	0.20	0.53	0.22	0.81	0.29
C.D. (5%)	1.08	0.70	1.88	0.78	2.87	1.04
Sub-plots (Nutrition levels)						
25 kg N ha ⁻¹	13.8	15.8	19.9	22.7	33.7	38.5
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	17.9	21.1	25.8	26.1	43.6	47.2
50 kg N ha ⁻¹	16.4	18.9	23.7	25.7	40.1	44.6
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	18.9	23.7	26.5	26.6	45.4	50.4
SE(m)±	0.22	0.39	0.55	0.28	0.72	0.49
C.D. (5%)	0.64	1.15	1.63	0.81	2.11	1.43
Interaction C.D. (5%)						
Interaction C.D. (5%)	1.38	2.33	NS	NS	NS	NS

**Table 4.5.4 Interactive effect of weed control and nutrition level treatments on
N uptake by seed (kg ha⁻¹) at harvest during 2023-24 and 2024-25**

N uptake by seed (kg ha⁻¹) - 2023-24

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	23.9	27.1	27.4	28.2	26.6
One hand weeding <i>fb</i> straw mulch	13.9	20.0	19.2	20.2	18.3
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	15.9	22.5	17.6	24.7	20.2
Unweeded (control)	1.5	1.9	1.3	2.6	1.8
Mean B	13.8	17.9	16.4	18.9	
SE(m)±	0.61				
C.D. (5%)	1.38				

N uptake by seed (kg ha⁻¹) - 2024-25

	25 kg N ha ⁻¹	25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	50 kg N ha ⁻¹	50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	Mean A
Plastic mulch (Black)	20.5	29.8	26.7	31.0	27.0
One hand weeding <i>fb</i> straw mulch	18.8	25.6	21.2	32.2	24.5
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	21.0	25.8	24.7	28.1	24.9
Unweeded (control)	2.8	3.2	3.0	3.7	3.2
Mean B	15.8	21.1	18.9	23.7	
SE(m)±	0.40				
C.D. (5%)	2.33				

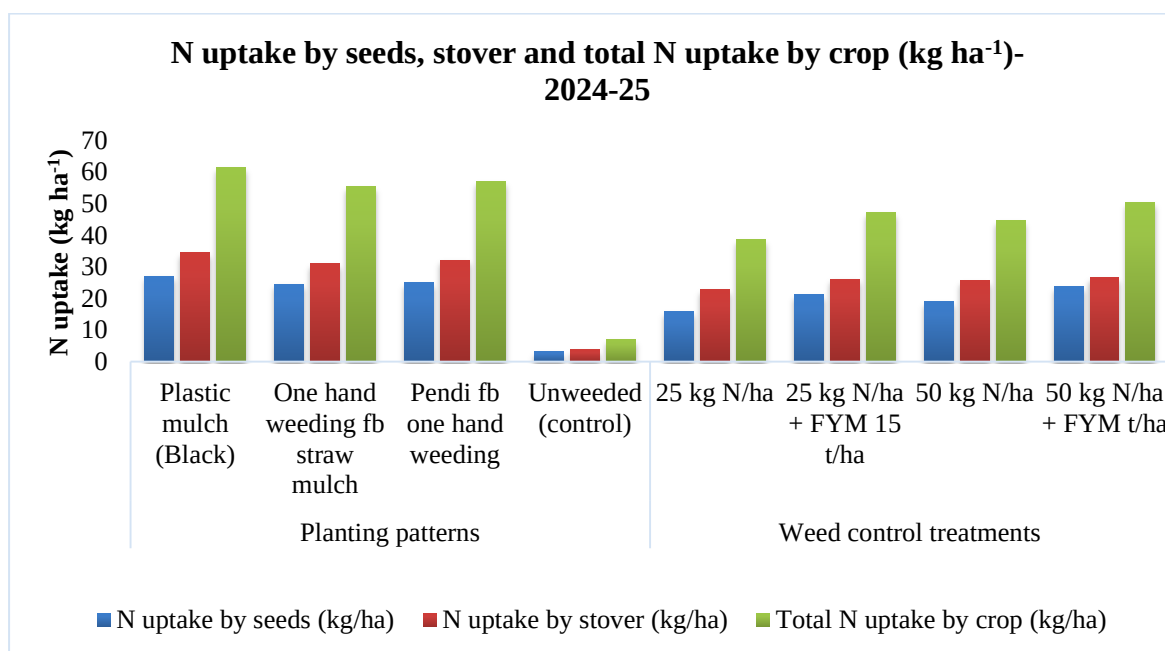
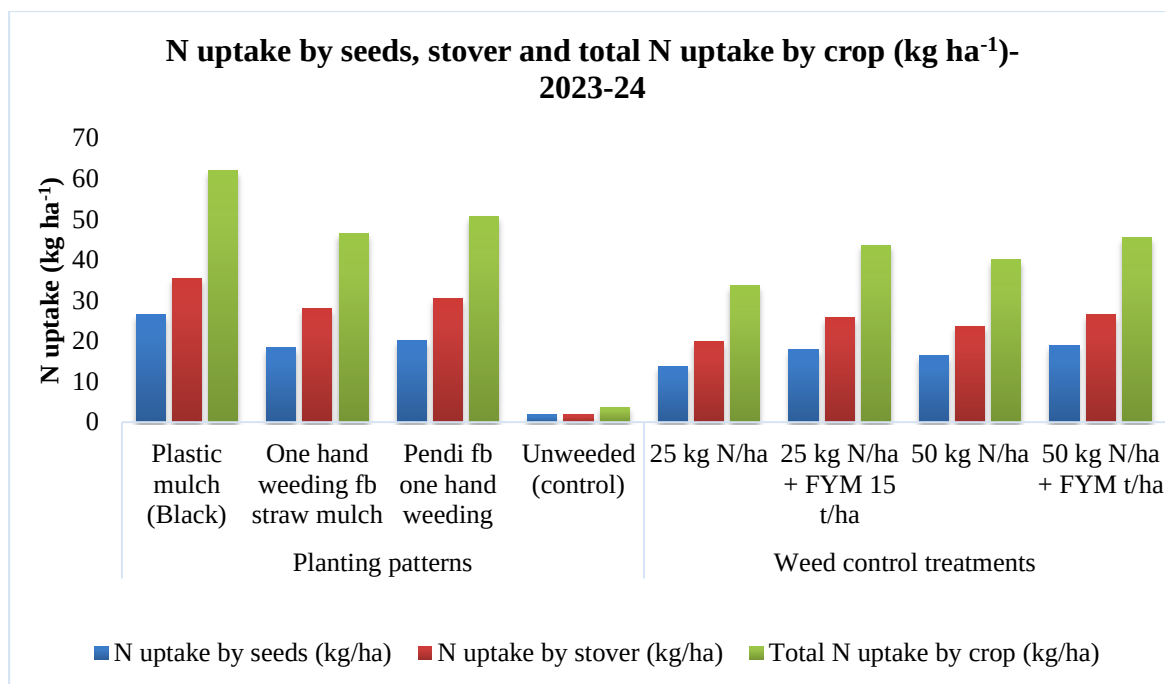


**Figure 4.5.1 Effect of weed control and nutrition level treatments on N uptake
by seeds, stover and total N uptake by crop (kg ha⁻¹)**

4.5.4 N content (%) and N uptake by weeds (kg ha⁻¹)

The impact of various weed control and nutrition level treatments on N content (%) and N uptake by weeds (kg ha⁻¹) at harvest during 2023-24 and 2024-25 has been presented in Table 4.5.4.

The differences in N content in weeds (%) as influenced by weed control treatments were found to be non-significant during 2023-24 and 2024-25 (Table 4.5.4). Among nutrition level treatments, the differences in N content in weeds (%) were found to be non-significant during both the years.

The differences in N uptake by weeds (kg ha⁻¹) were significant among weed control and nutrition level treatments during 2023-24 (Table 4.5.4). Among weed control treatments, application of black plastic mulch recorded significantly less uptake of N by weeds (kg ha⁻¹) as compared to all other weed control treatments. The application of pendimethalin *fb* one hand weeding recorded significantly less uptake of N weeds as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly higher uptake of N by weeds (kg ha⁻¹) as compared to all other weed control treatments. Among nutrition level treatments, application of 25 kg N ha⁻¹ recorded significantly less uptake of N by weeds as compared to all other nutrition level treatments. The N uptake by weeds (kg ha⁻¹) in the treatment of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was statistically at par with 50 kg N ha⁻¹ treatment. The integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more uptake of N by weeds (kg ha⁻¹) as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹. During 2024-25, the differences in N uptake by weeds (kg ha⁻¹) were significant among weed control and nutrition level treatments (Table 4.5.4). Among weed control treatments, application of black plastic mulch recorded significantly less uptake of N by weeds (kg ha⁻¹) as compared to all other weed control treatments. The application of pendimethalin *fb* one hand weeding recorded significantly less uptake of N weeds as compared to one hand weeding *fb* straw mulch treatment. Unweeded (control) recorded significantly higher uptake of N by weeds (kg ha⁻¹) as compared to all other weed control treatments. Among nutrition level treatments, the uptake of nitrogen by weeds with the application of 25 kg N ha⁻¹ was statistically at par with the application of 50 kg N ha⁻¹. The N uptake by weeds (kg ha⁻¹) in 50 kg N ha⁻¹ was significantly

less as compared to integrated application of 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ treatment. The integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly higher uptake of N by weeds as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹.

The interactive effect of weed control and nutrition level treatments on N content in weeds (%) and N uptake by weeds (kg ha⁻¹) was found to be non-significant during 2023-24 and 2024-25 (Table 4.5.4).

Higher uptake of N by weeds in unweeded (control) treatment was due to unrestricted growth of weeds and less crop growth. Weed control treatments improved the crop growth conditions and reduced the crop weed competition. The N uptake by weeds (kg ha⁻¹) in integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ was higher due to long term availability of nitrogen to weeds. Similar results were reported by Patel *et al.* (2018) and Wang *et al.* (2019).

Table 4.5.5 Effect of weed control and nutrition level treatments on N content in weeds (%) and N uptake by weeds (kg ha⁻¹)

	N content in weeds (%)		N uptake by weeds (kg ha ⁻¹)	
	2023-24	2024-25	2023-24	2024-25
Main plots (Weed control treatments)				
Plastic mulch (Black)	0.89	0.88	5.6	6.7
One hand weeding <i>fb</i> straw mulch	0.90	0.89	16.6	22.6
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	0.92	0.90	11.7	17.1
Unweeded (control)	0.88	0.87	76.7	78.9
SE(m)±	0.01	0.01	0.87	0.46
C.D. (5%)	NS	NS	3.06	1.62
Sub-plots (Nutrition levels)				
25 kg N ha ⁻¹	0.91	0.88	23.4	27.9
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	0.91	0.89	28.7	33.1
50 kg N ha ⁻¹	0.89	0.88	27.4	29.5
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	0.89	0.89	31.1	34.9
SE(m)±	0.01	0.01	1.10	0.66
C.D. (5%)	NS	NS	3.23	1.93
Interaction C.D. (5%)				
Interaction C.D. (5%)	NS	NS	NS	NS

4.6 Soil parameters

The important soil properties that influence crop growth and yield are soil pH, EC, OC (%) and available soil N. The most important factor of the soil is its capacity to provide nutrition to the crop.

4.6.1 Soil pH, EC (dS m^{-1}), OC (%) and available soil N (kg ha^{-1})

Soil pH shows the nature of the soil, which can be acidic, basic or neutral. Most of the crops require neutral soil pH for better growth and production. Soil EC indicates the nature of soil health which provides information on soil salinity, nutrient availability and fertility of the soil. Soil OC (%) is also an indicator of soil health. It acts as reservoir for carbon sequestration and supports microbial activity. The data on soil pH, EC and OC (%) after harvest has been presented in Table 4.6.1.

The differences in soil pH after harvest was found to be non-significant among the weed control treatments (Table 4.6.1). Among nutrition level treatments, the soil pH was non-significant in soil samples collected after harvest. The soil pH varied from 7.37 to 7.43.

The soil electrical conductivity (EC) after harvest was found to be non-significant among various weed control treatments (Table 4.6.1). Among the nutrition level treatments, soil EC did not differ significantly after harvest. The soil EC of the experiment ranged from 0.32 to 0.34 dS m^{-1} .

The soil OC (%) was found to be non-significant among various weed control treatments after harvest of the crop (Table 4.6.1). The nutrition level treatments did not influenced soil OC (%) significantly after harvest of the crop. The soil organic carbon ranged from 0.42 to 0.44%.

The differences in available soil nitrogen (kg ha^{-1}) were found to be significant among various weed control and nutrition level treatments after harvest of the crop (Table 4.6.1). Among weed control treatments, the available soil nitrogen (kg ha^{-1}) in black plastic mulch and one hand weeding *fb* straw mulch treatments was found to be statistically at par with each other. The available soil nitrogen in pendimethalin *fb* straw mulch was statistically at par with black plastic mulch. Unweeded (control)

recorded significantly low available soil N as compared to all other weed control treatments. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ recorded significantly more soil available nitrogen (kg ha⁻¹) as compared to all other nutrition level treatments. The available soil nitrogen in 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ were found to be statistically at par with each other. The treatment of 25 kg N ha⁻¹ recorded significantly less available soil nitrogen as compared to all other nutrition level treatments.

The interactive effect of weed control and nutrition level treatments on soil pH, EC, OC (%) and available soil nitrogen (kg ha⁻¹) were found to be non-significant after harvest of the crop (Table 4.6.1).

Higher available nitrogen in soil under the integrated application of organic (FYM) and inorganic fertilizers might be due to more nutrient retention in soil and less nitrogen losses. Further, by adopting weed control measures there is less removal of nitrogen by weeds which results in higher residual N in soil. Similar findings were obtained by Shivran and Jat (2015) and Bashir *et al.* (2012).

Table 4.6.1 Effect of weed control and nutrition level treatments on soil pH, EC (dS m⁻¹), OC (%) and available soil N (kg ha⁻¹) after harvest

	Soil pH	Soil EC (dS m ⁻¹)	Soil OC (%)	Available soil N (kg ha ⁻¹)
Main plots (Weed control treatments)				
Plastic mulch (Black)	7.39	0.34	0.44	227.2
One hand weeding <i>fb</i> straw mulch	7.40	0.32	0.43	229.0
Pendimethalin (0.45 kg ha ⁻¹) <i>fb</i> one hand weeding	7.41	0.32	0.43	227.0
Unweeded (control)	7.42	0.33	0.43	222.8
SE(m)±	0.02	0.004	0.003	0.52
C.D. (5%)	NS	NS	NS	1.83
Sub-plots (Nutrition levels)				
25 kg N ha ⁻¹	7.40	0.32	0.43	223.3
25 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	7.37	0.33	0.44	226.8
50 kg N ha ⁻¹	7.43	0.33	0.44	226.4
50 kg N ha ⁻¹ + FYM 15.0 t ha ⁻¹	7.43	0.33	0.42	229.5
SE(m)±	0.02	0.004	0.012	0.91
C.D. (5%)	NS	NS	NS	2.66
Interaction C.D. (5%)				
Initial values	7.40	0.31	0.43	224.3

The research trial entitled “**Impact of planting patterns, nitrogen and FYM on growth and development of Fennel (*Foeniculum vulgare* Mill.) under variable weed control methods**” was conducted during *rabi* season of 2023-24 and 2024-25 at the Research Farm of Department of Agronomy, Lovely Professional University, Phagwara. The two experiments, each were conducted in Split Plot Design with four replications during 2023-24 and 2024-25. The conclusion of research work is presented in the following pages experiment wise.

Experiment 1 - Role of planting patterns and weed control methods on growth and development of Fennel (*Foeniculum vulgare* Mill.)

5.1 Weed parameters

- Weed count (m^{-2}) was significantly less in flat sowing *fb* earthing up and bed sowing as compared to ridge sowing and flat sowing methods at all periodic intervals *i.e.* 60, 90, 120 DAS and at harvest during both the years due to burial of weed seeds deep into the soil. Among sub-plots, weed population in black and white plastic mulch was significantly less as compared to one hand weeding *fb* straw mulch and unweeded (control) treatments at all periodic intervals during both years.
- Weed dry matter ($q\ ha^{-1}$) was significantly less in flat sowing *fb* earthing up and bed sowing techniques as compared to ridge sowing and flat sowing at all periodic intervals *i.e.* 60, 90, 120 DAS and at harvest during both the years due to burial of weed seeds deep into the soil with the formal sowing methods. Among sub-plots, weed dry matter ($q\ ha^{-1}$) in black and white plastic mulch treatments was significantly less due to prevention of weed seeds germination and growth as compared to one hand weeding *fb* straw mulch and unweeded (control) treatments at all periodic intervals during both years.
- Weed control efficiency (%) was higher in flat sowing *fb* earthing up followed by bed sowing method during both the years. Among the weed control treatments, the highest weed control efficiency was recorded in black plastic mulch which was followed by white plastic mulch during both the years.

5.2 Crop growth parameters

- Plant height (cm) recorded at 60, 90, 120 DAS and at harvest was significantly more in flat sowing *fb* earthing up and bed sowing treatments as compared to ridge sowing and flat sown crop during both the years. Among weed control treatments, plant height (cm) in black and white plastic mulch was significantly more as compared to hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- Plant dry matter (g plant^{-1}) recorded at 60, 90, 120 DAS and at harvest was significantly more in flat sowing *fb* earthing up method as compared to ridge sowing and flat sown crop during both the years. Among weed control treatments, plant dry matter (g plant^{-1}) in black plastic mulch was significantly higher as compared to hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- Number of plants per meter row length were non-significant among planting patterns at all periodic intervals during both the years. Among weed control treatments, black and white plastic mulch recorded significantly higher number of plants per meter row length as compared to one hand weeding *fb* straw mulch and unweeded (control) treatments at all periodic intervals during both the years.
- Number of primary branches plant^{-1} recorded at 60, 90, 120 DAS and at harvest were found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge sowing and flat sowing, during both the years. Among weed control treatments, black plastic mulch and white plastic mulch recorded significantly higher number of primary branches plant^{-1} as compared to hand weeding *fb* straw mulch and unweeded (control) treatment at all periodic intervals, during both the years.
- Number of secondary branches plant^{-1} recorded at 60, 90, 120 DAS and at harvest were found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge sowing and flat sowing methods, during both the years. Among weed control treatments, application of black plastic mulch recorded significantly higher number of

secondary branches as compared to hand weeding *fb* straw mulch and unweeded (control) treatments at all periodic intervals, during both the years.

5.3 Yield parameters

- Number of primary and secondary umbels plant⁻¹ at harvest in flat sowing *fb* earthing up method were significantly higher than ridge and flat sowing planting methods during both the years. Among weed control treatments, application of black and white plastic mulch recorded significantly higher number of primary umbels plant⁻¹ as compared to hand weeding *fb* straw mulch and unweeded (control) treatments, during both the years.
- Diameter of main, primary and secondary umbel (cm) was found to be significantly higher in the planting patterns of flat sowing *fb* earthing up as compared to ridge and flat sowing methods during both the years. Among weed control treatments, the diameter of main, primary and secondary umbel (cm) was found to be significantly higher in black and white plastic mulch as compared to one hand weeding *fb* straw mulch and unweeded (control), during both the years.
- Number of umbellets per main, primary and secondary umbel were found to be significantly more in flat sowing *fb* earthing up as compared to ridge sowing and flat sowing planting method during both the years. Among weed control treatments black and white plastic mulch recorded significantly higher number of umbellets per main, primary and secondary umbel as compared to one hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- Number of seeds per umbellet of main, primary and secondary umbel were found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge and flat sowing methods during both the years. Among weed control treatments, black plastic mulch recorded significantly higher number of seeds per umbellet of main, primary and secondary umbel as compared to one hand weeding *fb* straw mulch and unweeded (control) during both the years.

- Number of seeds per main, primary and secondary umbel were significantly higher in the planting patterns of flat sowing *fb* earthing up as compared to ridge and flat sowing methods during both the years. Among weed control treatments, number of seeds per main umbel in black plastic mulch were significantly higher than hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- Seed weight (g) of main, primary and secondary umbel were significantly more in the planting pattern of flat sowing *fb* earthing up as compared to ridge and flat sowing methods during both the years. Among weed control treatments, black plastic mulch recorded significantly more seed weight of main, primary and secondary umbel as compared to hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- 1000 seed weight (g) of main, primary and secondary umbel were significantly more in the planting patterns of flat sowing *fb* earthing up as compared to ridge and flat sowing methods during both the years. Among weed control treatments, black plastic mulch recorded significantly more 1000 seed weight of main, primary and secondary umbel as compared to hand weeding *fb* straw mulch and unweeded (control) treatments during both the years.
- Seed yield (q ha^{-1}) was found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge and flat sowing during both the years. On the basis of average of two years, flat sowing *fb* earthing up, two rows per bed and ridge sowing increased seed yield of fennel by 40.20, 30.93 and 9.28 percent respectively as compared to conventional method i.e. flat sowing. Among weed control treatments, application of black plastic mulch, white plastic mulch and hand weeding *fb* straw mulch increased the seed yield of fennel by 458.06, 390.32 and 254.84 percent, respectively as compared to unweeded (control) treatment.
- Stover yield (q ha^{-1}) was found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge and flat sowing during both the years. Among weed control treatments, black plastic mulch recorded significantly higher stover yield as compared to all other treatments during both the years.

- Biological yield (q ha^{-1}) was found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge and flat sowing methods during both the years. Among weed control treatments, black plastic mulch recorded significantly higher biological yield as compared to all other weed control treatments during both the years.
- Harvest index (%) was found to be significantly higher in the planting patterns of flat sowing *fb* earthing up and bed sowing as compared to ridge and flat sowing during both the years. Among weed control treatments, application of black and white plastic mulch recorded significantly higher harvest index as compared to all one hand weeding *fb* straw mulch during both the years.

5.4 Economics

- Net returns ($173261.9 \text{ ₹ ha}^{-1}$) were highest in the treatment combination of bed sowing method applied with black plastic mulch followed by flat sowing *fb* earthing up applied with black plastic mulch and the lower net returns were found in all the planting patterns with unweeded (control).
- B:C ratio (2.52) was highest in the treatment combination of bed sowing method applied with black plastic mulch followed by flat sowing *fb* earthing up applied with black plastic mulch (2.41) and the lower net returns were found in all the planting patterns with unweeded (control).

5.5 Quality parameters

- The differences in N content in seeds (%) among various planting patterns and weed control treatments during 2023-24 and 2024-25 were found to be non-significant.
- Protein content in seeds (%) was non-significant among various planting patterns and weed control treatments during 2023-24 and 2024-25.
- Oil content in seeds (%) was non-significant among various planting patterns and weed control treatments during 2023-24 and 2024-25.
- N content in stover (%) was non-significant among various planting patterns and weed control treatments during 2023-24 and 2024-25.
- N uptake by seeds (kg ha^{-1}) recorded at harvest was significantly higher in flat sowing *fb* earthing up as compared to all other planting patterns during both

the years. Among weed control treatments, application of black plastic mulch recorded significantly higher N uptake by seeds as compared to all other weed control treatments during both the years.

- N uptake by stover (kg ha^{-1}) recorded at harvest was significantly higher in flat sowing *fb* earthing up as compared to all other planting patterns during both the years. Among weed control treatments, application of black plastic mulch recorded significantly higher N uptake by stover as compared to all other weed control treatments during both the years.
- Total N uptake by crop (kg ha^{-1}) recorded at harvest was significantly higher in flat sowing *fb* earthing up as compared to all other planting patterns during both the years. Among weed control treatments, application of black plastic mulch recorded significantly higher total N uptake by crop as compared to all other weed control treatments during both the years.
- N content in weeds (%) was non-significant among various planting patterns and weed control treatments during 2023-24 and 2024-25.
- N uptake by weeds (kg ha^{-1}) recorded at harvest was significantly higher in flat sowing and ridge sowing as compared to planting pattern of bed sowing and flat sowing *fb* earthing up during both the years. Among weed control treatments, unweeded (control) recorded significantly higher N uptake by weeds as compared to all other weed control treatments during both the years.

5.6 Soil properties

- Soil pH, EC (dS m^{-1}), OC (%) and available soil N (kg ha^{-1}) at harvest was non-significant among various planting patterns and weed control treatments during 2023-24 and 2024-25.

Experiment 2 - Response of Fennel (*Foeniculum vulgare* Mill.) to nitrogen and FYM in relation to weed control strategies

5.1 Weed parameters

- Weed count (m^{-2}) recorded at 90, 120 DAS, and at harvest was significantly lower in black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition levels significantly less weed count (m^{-2}) was found with the application of 25 kg N ha^{-1} and 50 kg N ha^{-1} as compared to integrated application of 25 kg N ha^{-1} + FYM 15 t ha^{-1} and 50 kg N ha^{-1} + FYM 15 t ha^{-1} treatments at all the periodic intervals during both years.
- Weed dry matter (q ha^{-1}) recorded at 90, 120 DAS, and at harvest was significantly less with the application of black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition level treatments, significantly less weed dry matter (q ha^{-1}) was found with the application of 25 kg N ha^{-1} and 50 kg N ha^{-1} as compared to integrated application of 25 kg N ha^{-1} + FYM 15 t ha^{-1} and 50 kg N ha^{-1} + FYM 15 t ha^{-1} at all the periodic intervals during both years.
- Highest weed control efficiency (%) recorded at harvest was found in black plastic mulch followed by pendimethalin *fb* hand weeding treatment and lowest was recorded in hand weeding *fb* straw mulch. Among nutrition levels, highest WCE (%) was recorded in application of 25 kg N ha^{-1} followed by 50 kg N ha^{-1} whereas, lowest WCE was found with application of 25 kg N ha^{-1} + FYM 15 t ha^{-1} during both the years.

5.2 Crop growth parameters

- Plant height (cm) recorded at 60, 90, 120 DAS and at harvest was significantly higher with the application of black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition level treatments, significantly higher plant height (cm) was recorded with integrated application of 50 kg N ha^{-1} + FYM 15 t ha^{-1} as compared to alone application of 50 kg N ha^{-1} and 50 kg N ha^{-1} during both the years.

- Plant dry matter (q ha^{-1}) recorded at 60, 90, 120 DAS and at harvest was significantly higher with the application of black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition level treatments, significantly higher plant dry matter was recorded with integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ as compared to alone application of 50 kg N ha^{-1} and 50 kg N ha^{-1} during both the years.
- Number of plants per meter row length recorded at 60, 90, 120 DAS and at harvest were significantly more with the application of black plastic mulch and pendimethalin *fb* hand weeding treatments as compared to unweeded (control) during both the years. Number of plants per meter row length did not differ significantly due to nutrition level treatments during both the years.
- Number of primary branches plant^{-1} with the application of black plastic mulch were significantly higher than one hand weeding *fb* straw mulch treatment at all periodic intervals during both the years. Among nutrition level treatments, number of primary branches in integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ were significantly higher as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} at all periodic intervals during both the years.
- Number of secondary branches plant^{-1} with the application of black plastic mulch were significantly higher than all other weed control treatments at all periodic intervals during both the years. Among nutrition level treatments, number of secondary branches in integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ were significantly higher as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} at all periodic intervals during both the years.

5.3 Yield parameters

- Number of primary and secondary umbels plant^{-1} were significantly higher with the application of black plastic mulch and pendimethalin *fb* hand weeding treatments as compared to one hand weeding *fb* straw mulch during both the years. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ recorded significantly higher number of primary umbels plant^{-1} as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} during both the years.

- Diameter of main umbel (cm) recorded in black plastic mulch treatment was significantly more than unweeded (control) treatment during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly more diameter of main umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Diameter of primary and secondary umbel (cm) recorded in black plastic mulch and pendimethalin *fb* hand weeding treatments was significantly more than one hand weeding *fb* straw mulch treatment during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly more diameter of primary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Number of umbellets per main, primary and secondary umbel recorded in black plastic mulch and pendimethalin *fb* hand weeding treatments were significantly higher than one hand weeding *fb* straw mulch treatment during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly higher number of umbellets per main, primary and secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Number of seeds per umbellet of main, primary and secondary umbel in black plastic mulch were significantly higher as compared to hand weeding *fb* straw mulch treatment during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly higher number of seeds per umbellet of main, primary and secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Number of seeds per main, primary and secondary umbel in black plastic mulch application were significantly higher than one hand weeding *fb* straw mulch during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly higher

number of seeds per main, primary and secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.

- Seed weight per main, primary and secondary umbel (g) in black plastic mulch treatment was significantly more than one hand weeding *fb* straw mulch during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly more seed weight (g) per main, primary and secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Significantly higher 1000 seed weight of main, primary and secondary umbel (g) was recorded in black plastic mulch application than unweeded (control) treatment during both the years. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly more 1000 seed weight of main, primary and secondary umbel as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.
- Seed yield (q ha⁻¹) recorded at harvest was significantly higher in black plastic mulch application and pendimethalin *fb* hand weeding as compared to hand weeding *fb* straw mulch treatment. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly higher seed yield (q ha⁻¹) as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years. On an average of two years data, seed yield under black plastic mulch, pendimethalin *fb* one hand weeding and one hand weeding *fb* straw mulch treatment increased by 1005.88, 841.18 and 794.11 percent, respectively as compared to unweeded (control) treatment. Among nutrition levels, application of 50 kg N ha⁻¹ + FYM 15.0 t ha⁻¹, 25 kg N ha⁻¹ + FYM 15.0 t ha⁻¹ and 50 kg N ha⁻¹ increased the seed yield of fennel by 39.25, 27.10 and 17.76 percent, respectively as compared to 25 kg N ha⁻¹.
- Stover yield (q ha⁻¹) recorded at harvest was significantly higher in black plastic mulch application and pendimethalin *fb* hand weeding as compared to hand weeding *fb* straw mulch treatment. Among nutrition level treatments, integrated application of 50 kg N ha⁻¹ + FYM 15 t ha⁻¹ recorded significantly higher stover yield (q ha⁻¹) as compared to alone application of 50 kg N ha⁻¹ and 25 kg N ha⁻¹ during both the years.

- Biological yield (q ha^{-1}) recorded at harvest was significantly higher in black plastic mulch application than hand weeding *fb* straw mulch treatment. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ recorded significantly higher biological yield (q ha^{-1}) as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} during both the years.
- Harvest index (%) recorded at harvest in unweeded (control) was significantly higher as compared to black plastic mulch application during both the years. Among nutrition level treatments, harvest index (%) in the treatment of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ was significantly more as compared to application of 25 kg N ha^{-1} during both the years.

5.4 Economics

- Highest net returns ($181107.6 \text{ ₹ ha}^{-1}$) was found in the treatment of black plastic mulch applied with $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ which was followed by black plastic mulch applied with 50 kg N ha^{-1} ($177767.9 \text{ ₹ ha}^{-1}$) and lowest net returns were found in unweeded (control) applied with all the nutrition levels during both the years.
- B:C ratio in the combined application of pendimethalin *fb* hand weeding with $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ (2.76) treatment and hand weeding *fb* straw mulch applied with $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ (2.42) was higher as compared to black plastic mulch applied with $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ (2.33). The lowest B:C ratio was recorded in unweeded (control) combined with all the nutrition level treatments.

5.5 Quality parameters

- N content in seeds and crop at 90 DAS (%) was non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.
- Protein content in seeds (%) was non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.
- Oil content in seeds (%) was non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.
- N content in stover (%) at harvest was non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.

- N uptake by seeds and stover (kg ha^{-1}) at harvest was significantly higher with application of black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition level treatments, the N uptake by seeds in integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ was significantly higher as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} during both the years.
- Total N uptake by crop (kg ha^{-1}) at harvest was significantly higher with application of black plastic mulch as compared to all other weed control treatments during both the years. Among nutrition level treatments, total N uptake by crop in integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ was significantly higher as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} during both the years.
- N content in weeds (%) was non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.
- N uptake by weeds (kg ha^{-1}) recorded at harvest was found to be significantly higher in unweeded (control) and one hand weeding *fb* straw mulch as compared to black plastic mulch and pendimethalin *fb* hand weeding treatments during both the years. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ recorded significantly higher uptake of N by weeds as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} during both the years.

5.6 Soil properties

- Soil pH, EC (dS m^{-1}) and OC (%) were non-significant among various weed control and nutrition level treatments during 2023-24 and 2024-25.
- Available soil N (kg ha^{-1}) at harvest was more in application of black plastic mulch as compared to unweeded (control) treatment. Among nutrition level treatments, integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ recorded significantly higher available soil N as compared to alone application of 50 kg N ha^{-1} and 25 kg N ha^{-1} .

Conclusion:

In first experiment, the combination of flat sowing *fb* earthing up along with application of black plastic mulch reduced the weed count (m^{-2}) and weed dry weight (q ha^{-1}), improved the growth parameters such as plant height (cm), plant dry matter (g plant^{-1}), number of primary and secondary branches plant^{-1} , enhanced the yield parameters like number of primary and secondary umbels plant^{-1} , diameter of main, primary and secondary umbels (cm), number of umbellets per umbel, number of seeds per umbellet, number of seeds per umbel, seed weight per umbel (g) and 1000 seed weight per umbel (g), and produced better seed yield (q ha^{-1}) as compared to all other treatment combinations. Higher net returns were obtained in the combined application of bed sowing method applied with black plastic mulch ($173261.9 \text{ ₹ ha}^{-1}$) as compared to all other planting patterns.

In second experiment, the combination of black plastic mulch along with application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ improved the growth parameters such as plant height (cm), plant dry matter (g plant^{-1}), number of primary and secondary branches plant^{-1} , enhanced the yield parameters like number of primary and secondary umbels plant^{-1} , diameter of main, primary and secondary umbels (cm), number of umbellets per umbel, number of seeds per umbellet, number of seeds per umbel, seed weight per umbel (g) and 1000 seed weight per umbel (g), and produced better seed yield (q ha^{-1}) as compared to all other treatment combinations. Higher net returns of $181107.6 \text{ ₹ ha}^{-1}$ were obtained with application of black plastic mulch along with $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$ as compared to all other treatment combinations.

From this study, it can be concluded that the overall seed yield of fennel can be improved by adopting the planting pattern of flat sowing *fb* earthing up with application of black plastic mulch and integrated application of $50 \text{ kg N ha}^{-1} + \text{FYM } 15 \text{ t ha}^{-1}$.

The findings of the present study provide valuable insights about the optimization of planting patterns, nutrition levels and weed management strategies for improving the growth, productivity and profitability of fennel. However, further research is required to enhance the sustainability and wider applicability of these production practices.

Long term experiments are also needed to assess the residual effects of FYM and different weed management practices on weed species, soil fertility, microbial activity and crop productivity. Further investigations under different agro-climatic conditions and soil types are essential to validate the recommendations given from the present study.

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APPENDICES

Table 1. Meteorological weather data during crop season of 2023-24

Week no.	Date (2023-24)	Max. temp (°C)	Min. temp (°C)	Average humidity (%)	Rainfall (mm)	Windspeed (km/hr)	Sunshine hours (hrs/day)
43	22 Oct - 28 Oct	30.27	13.71	69.83	0.00	5.40	8.0
44	29 Oct- 4 Nov	30.02	14.14	70.05	0.00	0.09	7.0
45	5 Nov - 11 Nov	26.90	12.94	73.05	0.00	5.50	4.5
46	12 Nov - 18 Nov	27.11	10.03	71.85	0.00	5.00	8.8
47	19 Nov - 25 Nov	26.19	9.89	70.00	0.00	4.80	5.9
48	26 Nov - 02 Dec	23.52	11.17	75.60	0.94	4.53	3.6
49	03 Dec - 09 Dec	23.55	7.97	73.54	0.00	4.63	7.8
50	10 Dec - 16 Dec	22.02	4.46	72.08	0.00	3.75	7.3
51	17 Dec - 23 Dec	21.23	4.33	74.96	0.00	4.22	6.9
52	24 Dec - 31 Dec	18.00	7.45	82.45	0.00	2.68	2.6
1	01 Jan - 07 Jan	12.40	6.59	90.43	0.00	3.08	5.7
2	08 Jan - 14 Jan	11.76	6.43	86.29	0.00	2.92	7.4
3	15 Jan - 21 Jan	13.14	5.57	86.72	0.00	3.19	7.0
4	22 Jan - 28 Jan	14.14	5.57	84.29	0.00	4.91	3.5
5	29 Jan - 04 Feb	17.71	9.00	83.15	1.26	5.06	1.9
6	05 Feb - 11 Feb	20.23	3.48	73.93	0.00	5.33	8.7
7	12 Feb - 18 Feb	23.30	5.56	74.05	0.00	4.37	7.1
8	19 Feb - 25 Feb	22.84	7.53	68.15	0.14	10.08	9.6
9	26 Feb - 04 Mar	21.95	9.92	70.04	8.00	8.40	6.4
10	05 Mar - 11 Mar	23.22	7.52	73.35	0.00	5.97	9.1
11	12 Mar - 18 Mar	26.86	8.94	72.34	0.00	6.43	9.4
12	19 Mar - 25 Mar	29.71	13.75	70.42	0.00	7.41	9.8
13	26 Mar - 01 April	30.54	16.49	69.61	2.00	6.54	5.3
14	02 April - 8 April	32.86	12.85	61.72	0.00	7.56	10.0
15	09 April - 15 April	34.16	16.46	56.68	0.00	5.50	10.1
16	16 April - 22 April	34.59	17.27	59.08	5.11	8.64	11.1
17	23 April - 29 April	34.44	17.33	57.50	0.54	1.61	9.7
18	30 April - 06 May	35.80	16.96	50.43	0.76	9.03	7.6

Table 2. Meteorological weather data during crop season of 2024-25

Week no.	Date (2024-25)	Max. temp (°C)	Min. temp (°C)	Average humidity (%)	Rainfall (mm)	Windspeed (km/hr)	Sunshine hours (hrs/day)
43	22 Oct - 28 Oct	32.77	16.42	73.10	0.00	4.47	9.1
44	29 Oct- 4 Nov	32.61	15.27	70.18	0.00	3.29	8.8
45	5 Nov - 11 Nov	29.24	15.73	81.16	0.00	2.21	8.4
46	12 Nov - 18 Nov	24.16	15.33	82.35	0.00	2.26	8.4
47	19 Nov - 25 Nov	26.93	9.09	69.15	0.00	3.14	7.6
48	26 Nov - 02 Dec	26.48	7.68	68.72	0.00	3.14	7.9
49	03 Dec - 09 Dec	16.34	7.22	80.53	0.00	4.06	8.3
50	10 Dec - 16 Dec	20.73	2.73	69.07	0.00	5.15	8.4
51	17 Dec - 23 Dec	20.35	5.71	69.20	0.00	3.25	3.8
52	24 Dec - 31 Dec	17.16	8.25	80.39	0.25	4.43	2.0
1	01 Jan - 07 Jan	15.26	8.70	87.29	0.14	3.43	2.0
2	08 Jan - 14 Jan	17.10	7.77	80.43	0.83	2.96	5.0
3	15 Jan - 21 Jan	19.29	8.31	73.57	0.00	4.09	4.3
4	22 Jan - 28 Jan	21.66	6.14	67.07	0.00	9.04	9.2
5	29 Jan - 04 Feb	20.77	9.26	82.34	0.00	4.05	2.7
6	05 Feb - 11 Feb	23.50	5.80	72.62	0.29	5.71	8.8
7	12 Feb - 18 Feb	23.71	9.86	65.29	0.86	4.30	8.4
8	19 Feb - 25 Feb	23.23	12.43	70.64	1.57	3.59	6.8
9	26 Feb - 04 Mar	23.06	14.00	74.07	2.77	8.60	7.1
10	05 Mar - 11 Mar	25.86	12.14	71.28	0.00	14.00	8.9
11	12 Mar - 18 Mar	27.43	14.00	72.50	0.14	14.63	9.0
12	19 Mar - 25 Mar	30.84	12.34	64.22	0.57	5.09	9.1
13	26 Mar - 01 April	30.81	11.64	58.31	0.00	4.66	7.6
14	02 April - 8 April	35.50	13.87	58.96	0.00	4.36	9.5
15	09 April - 15 April	34.86	18.29	59.54	0.00	5.25	9.8
16	16 April - 22 April	36.42	20.26	58.68	0.00	5.75	10.0
17	23 April - 29 April	37.57	22.14	59.38	0.00	4.94	9.0
18	30 April - 06 May	35.25	19.29	56.25	0.00	5.33	9.2

Table 3. Fixed cost for Experiment 1

S.no	Particular/input	Frequency	Cost (₹ ha ⁻¹)
1	Rotavator	2 @3750₹ / ha	7500
2	Planking	₹1000 / ha	1000
3	Layout preparation	10 workers	4500
4	Sowing	15 workers	6750
5	Seed price	10 kg @ ₹ 280/ kg	2800
6	Fertilizer (Urea)	₹ 6 / kg	652.08
7	Thinning/ gap filling	3 workers	1350
8	Harvesting	15 workers	6750
9	Threshing and cleaning	15 workers	6750
Total			38052.08

Table 4. Fixed cost for Experiment 2

S.no	Particular/input	Frequency	Cost (₹ ha ⁻¹)
1	Rotavator	2 @3750₹ / ha	7500
2	Planking	₹1000 / ha	1000
3	Layout preparation	10 workers	4500
4	Sowing	15 workers	6750
5	Seed price	10 kg @ ₹ 280/ kg	2800
6	Thinning/ gap filling	3 workers	1350
7	Harvesting	15 workers	6750
8	Threshing and cleaning	15 workers	6750
Total			37400

Table 5. Variable cost for experiment 1

	Black mulch	White mulch	Hand Weeding	Straw mulch	Mulch application cost	Bed preparation	Ridge preparation	Earthing up	Total
	₹ 20000 ha ⁻¹	₹ 18000 ha ⁻¹	₹ 450 /worker/day	₹ 3500 ha ⁻¹	₹ 450 /worker/day	₹ 450 /worker/day	₹ 450 /worker/day	₹ 450 /worker/day	₹ ha ⁻¹
T1N1	20000	-	-	-	1800	9000	-	-	30800
T1N2	-	18000	-	-	1800	9000	-	-	28800
T1N3	-	-	4500	3500	2250	9000	-	-	19250
T1N4	-	-	-	-	-	9000	-	-	9000
T2N1	20000	-	-	-	1800	-	9000	-	30800
T2N2	-	18000	-	-	1800	-	9000	-	28800
T2N3	-	-	4500	3500	2250	-	9000	-	19250
T2N4	-	-	-	-	-	-	9000	-	9000
T3N1	20000	-	-	-	1800	-	-	6750	28550
T3N2	-	18000	-	-	1800	-	-	6750	26550
T3N3	-	-	4500	3500	2250	-	-	6750	17000
T3N4	-	-	-	-	-	-	-	6750	6750
T4N1	20000	-	-	-	1800	-	-	-	21800
T4N2	-	18000	-	-	1800	-	-	-	19800
T4N3	-	-	4500	3500	2250	-	-	-	10250
T4N4	-	-	-	-	-	-	-	-	0

Table 6. Variable cost for experiment 2

	Black mulch	Straw mulch	Mulch/ pendi application cost	Hand weeding	Pendimethalin	Urea	FYM	Total
	₹ 20000 ha ⁻¹	₹ 3500 ha ⁻¹	₹ 450 /worker/day	₹ 450 /worker/day	₹ 525 ha ⁻¹	₹ 6/kg	₹ 18000/ha	₹ ha ⁻¹
T1N1	20000	-	1800	-	-	326.04	-	22126.04
T1N2	20000	-	1800	-	-	326.04	18000	40126.04
T1N3	20000	-	1800	-	-	652.08	-	22452.08
T1N4	20000	-	1800	-	-	652.08	18000	40452.08
T2N1	-	3500	2250	4500	-	326.04	-	10576.04
T2N2	-	3500	2250	4500	-	326.04	18000	28576.04
T2N3	-	3500	2250	4500	-	652.08	-	10902.08
T2N4	-	3500	2250	4500	-	652.08	18000	28902.08
T3N1	-	-	900	4500	525	326.04	-	6251.04
T3N2	-	-	900	4500	525	326.04	18000	24251.04
T3N3	-	-	900	4500	525	652.08	-	6577.08
T3N4	-	-	900	4500	525	652.08	18000	24577.08
T4N1	-	-	-	-	-	326.04	-	326.04
T4N2	-	-	-	-	-	326.04	18000	18326.04
T4N3	-	-	-	-	-	652.08	-	652.08
T4N4	-	-	-	-	-	652.08	18000	18652.08