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# Influence of planting dates and mulching treatments on marigold productivity and soil quality in the North-western Himalayan region

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## Abstract

Marigold is an economically important floricultural crop grown extensively for its ornamental and commercial value. However, the successful production of quality flowers depends on appropriate planting schedules and crop management practices. Accordingly, the present investigation was conducted to evaluate the effects of different planting dates and mulching methods on soil health and the productivity of Bidhan Marigold-2. The experiment included 20 treatment combinations of four planting dates:15$^{th}$ April, 15$^{th}$ May, 15$^{th}$ June and 15$^{th}$ July (2024) and five mulching treatments (unweeded control, weeded control, weed mulch, silver-black plastic mulch and grass mulch), laid out in a factorial randomised block design (FRBD) and replicated thrice. Findings revealed that 15$^{th}$ June planting combined with silver-black plastic mulch resulted in the maximum flower weight (10.57 g) and flower yield per plant (1311.66 g), whereas 15$^{th}$ April planting under the same mulch treatment recorded the highest number of flowers per plant (154.03) and the earliest flowering (56.13 days). The highest available soil nitrogen (N), phosphorus (P) and potassium (K) contents were recorded under weed mulch in the 15$^{th}$ April planting, whereas the highest viable soil microbial population was recorded in the 15$^{th}$ June planting with weed mulch. Overall, the results demonstrated that 15$^{th}$ June planting with silver-black plastic mulch optimised growth, flowering and yield performance, while weed mulch enhanced the physico-chemical properties of the soil. Thus, the combined use of suitable planting schedules and mulching practices can improve both crop productivity and soil sustainability in marigold cultivation.

**Keywords:** Bidhan Marigold-2; mulching; physico-chemical properties; planting dates; silver-black plastic mulch

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## Introduction

Marigold is a widely grown flower that is valued for its ecological, therapeutic and decorative qualities. The Etruscan demigod ‘Tages’, who was known for his beauty and prophetic insight, is the source of the genus name ‘Tagetes’. The genus contains around 50 species (1), of which *Tagetes minuta* L. is mainly used for oil extraction, while *Tagetes erecta* L. and *Tagetes patula* L. are economically cultivated for loose flowers. Marigold is native to Central and South America, especially Mexico and belongs to the family Asteraceae. The Portuguese brought it to India, where it quickly became popular due to its adaptability to a wide range of soils and climates (2). It is commercially grown for garland making, bedding plants, potted displays and cut flowers. It is also used for pigment extraction (3) and as a feed supplement in chicken diets (4). In India, marigold is the most widely cultivated loose flower crop, with high production levels. Madhya Pradesh (307070 MT) is the leading producer, followed by Karnataka (125310 MT) and Tamil Nadu (120520 MT). As per National Horticulture Board (NHB) estimates, approximately 87070 ha are dedicated to marigold farming in India with a total production of 966150 MT (5). Various marigold cultivars are suitable for commercial production, one of which is ‘Bidhan Gold’, commonly known as ‘Bidhan Marigold-2’. It was released by Bidhan Chandra Krishi Viswavidyalaya in

2019 (6). The planting time of marigold varies with local weather conditions and market demand. Therefore, a specific planting schedule is required to improve flowering and economic returns. Marigold is a day-neutral plant and can be grown year-round, though it is mainly grown during the rainy season. The rainy season encourages weed growth due to which marigold faces heavy weed pressure during the early growth stages. Mulching controls weed growth (7) and improve the soil microclimate (8, 9). Additionally, it prevents soil erosion, reduces nutrient leaching, retains soil moisture (SM) and maintains temperature (10). Overall, mulching improves the physical, chemical and biological characteristics of the soil, thereby enhancing crop growth and productivity (11, 12). Considering the commercial importance of marigold, the influence of planting time and weed pressure on its performance, this study was undertaken to assess the impact of different planting dates and mulching treatments on marigold productivity and soil properties.

## Materials and Methods

### Experimental location and climate

The study was conducted in 2024 at the experimental field of Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, situated in the mid-hill zone at an altitude of 1276 m above mean sea level at 30°51′55″ N latitude and 77°10′13″ E longitude (Fig. 1), with a sub-temperate to sub-tropical climate. The monthly mean meteorological data recorded during the study period are presented in Fig. 2.

### Treatment details

The study was conducted using a factorial randomised block design (FRBD) and replicated thrice. The experiment comprised 20 treatment combinations of four planting dates viz., $P_1$: 15$^{th}$ April, $P_2$: 15$^{th}$ May, $P_3$: 15$^{th}$ June and $P_4$: 15$^{th}$ July and five mulching treatments viz., $M_1$: no-mulch (no-weeding), $M_2$: no-mulch (manual-weeding), $M_3$: weed mulch, $M_4$: silver-black plastic mulch and $M_5$: grass mulch (Table 1). In the mulching treatments, silver-black plastic sheets were laid on the beds before planting and small circular holes were made at the required plant spacing. For grass mulch, about two inches of dried grass were spread evenly over the beds after transplanting. In the weed mulch treatment, weeds that had been uprooted from the same beds were reapplied as mulch. Two control treatments were also included: the first involved neither mulching nor weeding, while the second involved manual weeding without the application of mulch.

### Cultivation practices

Seeds were sown in a nursery medium consisting of soil, sand and well-decomposed farmyard manure in a 2 : 1 : 1 ratio. Before transplanting, a basal dose of nitrogen (N), phosphorus (P) and potassium (K) (30 : 20 : 20 kg ha$^{-1}$) was added to all the plots. The seedlings were then transplanted into raised beds at 30 × 30 cm spacing in 1.0 × 1.0 m plots accommodating 9 plants. Standard cultural practices such as pinching, disbudding, weeding and irrigation were carried out as required.

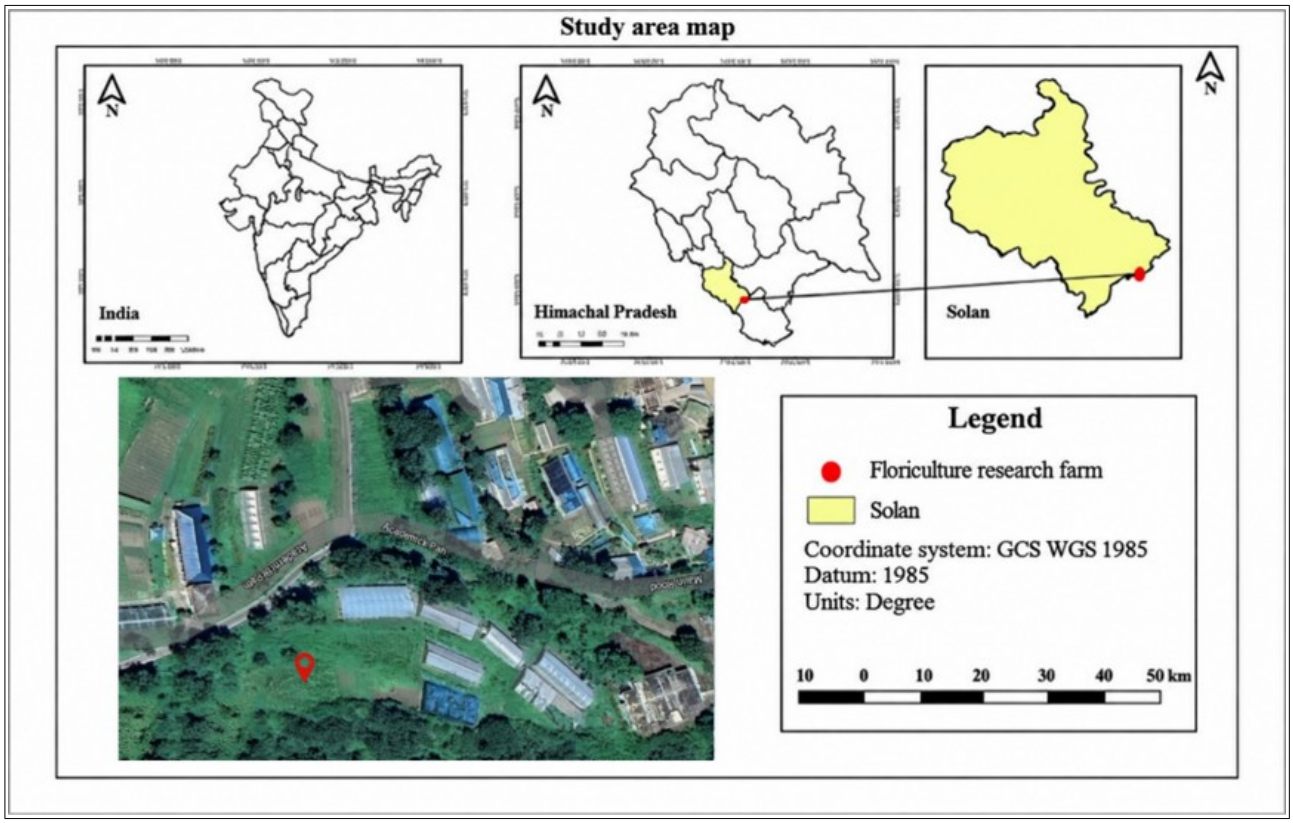



**Fig. 1.** Location of the experimental site.

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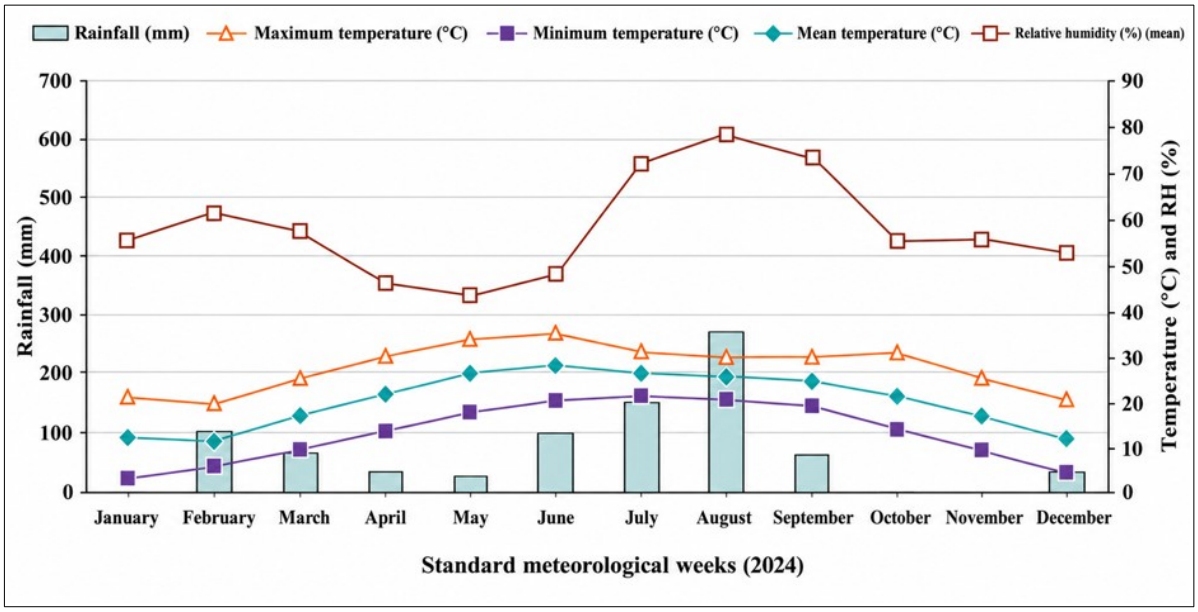



**Fig. 2.** Mean monthly meteorological data pertaining to the experimental period in 2024–25.

**Table 1.** Treatment specifications for the experimental field

| Treatment | Treatment label | Description |
|---|---|---|
| Planting dates | $P_1$ | 15th April 2024 |
| | $P_2$ | 15th May 2024 |
| | $P_3$ | 15th June 2024 |
| | $P_4$ | 15th July 2024 |
| Mulching treatments | $M_1$ | No-mulch (no-weeding) |
| | $M_2$ | No-mulch (manual-weeding) |
| | $M_3$ | Weed mulch |
| | $M_4$ | Silver-black plastic mulch |
| | $M_5$ | Grass mulch |

### Vegetative and flowering parameters

Vegetative traits and flowering characteristics were recorded from five plants randomly selected from each replication and treatment at the appropriate stage for each planting date. Plant height was measured from the base to the tip of the longest flowering shoot at peak bloom using a metre rod and spread was taken as the average between the outermost shoots in both the N-S and E-W directions. Days to bud initiation and flowering were counted from the planting date until the first flower buds became visible and the flowers were fully open. Flower diameter was determined by taking the mean span between the tips of the petals in both the N-S and E-W directions using a scale. Flower weight was measured using an analytical balance. The number of flowers per plant and per metre square were obtained by totalling the flowers collected from each picking at both levels. Shelf life was recorded from the time of harvest until the flowers lost their marketable quality. Flowering duration was recorded from the harvest of the first flower to the harvest of the last marketable flower. Yield was determined by measuring the combined weight of all marketable flowers obtained from successive pickings.

### Soil physico-chemical parameters

Prior to the experiment, soil samples were taken randomly from 0–15 cm depth and analysed for their properties (Table 2). Post-experimentation, soil samples from each treatment were obtained for soil property analysis. Soil pH and electrical conductivity (EC) were measured (13). Organic carbon (OC) was quantified (14), available N, P and K were also analysed (15–17). Soil moisture content was measured at fortnightly intervals from transplanting to the final harvest of flowers (18).

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**Table 2.** Pre-experimental soil properties in the field

| Soil property | Units | Method used | Value | Reference |
|---|---|---|---|---|
| pH | - | Suspension of soil : water (1 : 2) using a pH metre | 7.42 | (13) |
| Electrical conductivity | dS $m^{-1}$ | Suspension of soil : water (1 : 2) using a conductivity metre | 0.221 | (13) |
| Organic carbon | % | Rapid titration method | 1.19 | (14) |
| Available nitrogen | kg $ha^{-1}$ | Alkaline potassium permanganate method | 259.23 | (15) |
| Available phosphorus | kg $ha^{-1}$ | Olsen's method | 49.47 | (16) |
| Available potassium | kg $ha^{-1}$ | Ammonium acetate extraction method | 234.36 | (17) |
| Soil moisture | % | Gravimetric method | 11.73 | (18) |
| Bacterial count | × $10^7$ cfu $g^{-1}$ soil | Serial dilution-spread plate procedure (nutrient agar medium) | 8.24 | (19) |
| Fungal count | × $10^4$ cfu $g^{-1}$ soil | Serial dilution-spread plate procedure (potato dextrose agar medium) | 3.35 | (19) |
| Actinomycetes count | × $10^3$ cfu $g^{-1}$ soil | Serial dilution-spread plate procedure (Kenknight and Munaier medium) | 5.47 | (19) |

### Microbiological properties of soil

Upon completion of each planting date, soil microbial attributes were evaluated for each treatment. Bacteria, fungi and actinomycete populations were assessed using nutrient agar (NA), potato dextrose agar (PDA) and Kenknight and Munaier medium respectively (19). The standard serial dilution approach followed by the spread plate method was used to estimate microbial populations and the results were expressed as colony forming units per gram of soil (cfu $g^{-1}$).

### Statistical analysis

The data obtained from different treatments were analysed using the RStudio software (version 4.5.2) (20). A two-way analysis of variance (ANOVA) was performed following a FRBD. Differences among treatments were tested for significance at the 5 % level.

## Results

### Influence of planting dates on vegetative traits and flowering characteristics

Significant variations in vegetative and floral traits of marigold cv. 'Bidhan Marigold-2' were observed due to different planting dates and mulching treatments (Table 3). The crop planted on 15$^{th}$ June exhibited the highest plant height (117.23 cm), plant spread (60.89 cm), flower diameter (6.79 cm), flower weight (10.05 g) and shelf life (5.29 days). Conversely, the 15$^{th}$ April planting recorded the lowest plant height (94.43 cm), plant spread (52.26 cm), flower diameter (5.89 cm), flower weight (7.05 g) and shelf life (2.85 days). However, the maximum number of flowers per plant (142.83), per square metre (1289.58), longest flowering duration (51.36 days), earliest bud formation (48.89 days) and flowering (60.32 days) were recorded in 15$^{th}$ April planting. In contrast, the 15$^{th}$ July planting recorded the minimum number of flowers per plant (92.76), per square metre (841.27), shortest flowering duration (41.24 days), delayed bud formation (53.23 days) and flowering (71.37 days). Flower yield per plant ranged from 1191.68 g on the 15$^{th}$ June planting to 767.28 g on the 15$^{th}$ July planting.

### Influence of planting dates on soil characteristics

The pH and EC showed slight variation and ranged from 7.35–7.41 and 0.215–0.237 dS $m^{-1}$ respectively, which are within safe limits for crop cultivation. The highest levels of soil organic carbon (SOC) (1.24 %), available N (358.05 kg $ha^{-1}$), P (64.91 kg $ha^{-1}$) and K (308.02 kg $ha^{-1}$) were observed on 15$^{th}$ April planting (Table 4). The corresponding lowest values of SOC (1.10 %), available N (343.75 kg $ha^{-1}$), P (59.69 kg $ha^{-1}$) and K (300.59 kg $ha^{-1}$) were observed in the 15$^{th}$ July planting. Soil moisture content increased progressively from 16.12 % in the 15$^{th}$ April planting to 22.66 % in the 15$^{th}$ July planting. Similarly, microbial populations varied significantly among planting dates, with the highest bacterial (11.14 × $10^7$ cfu $g^{-1}$), fungal (4.41 × $10^4$ cfu $g^{-1}$) and actinomycete (6.37 × $10^3$ cfu $g^{-1}$) counts observed in the 15$^{th}$ June planting, while the lowest counts of bacteria, fungi and actinomycetes (8.80 × $10^7$ cfu $g^{-1}$, 3.89 × $10^4$ cfu $g^{-1}$ and 6.04 × $10^3$ cfu $g^{-1}$) were recorded in the 15$^{th}$ April planting.

### Influence of mulching treatments on vegetative traits and flowering characteristics

Among the mulching treatments, silver-black plastic mulch recorded the highest plant height (116.13 cm), plant spread (61.20 cm), flower weight (9.19 g), flower diameter (6.82 cm), shelf life (4.52 days), number of flowers per plant (124.83), number of flowers per square metre (1130.10), flowering duration (51.68 days) and flower yield per plant (1139.37 g). It also resulted in the earliest bud initiation (46.32 days) and flowering (61.19 days). In contrast, the no-mulch and no-weeding treatment exhibited the lowest plant height (99.25 cm), plant spread (49.62 cm), flower weight (7.98 g), flower diameter (5.92 cm), shelf life (3.40 days), number of flowers per plant (110.48), number of flowers per square metre (999.27), flowering duration (43.18 days) and flower yield per plant (874.32 g), along with the delayed bud initiation (54.95 days) and flowering (70.64 days).

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**Table 3.** Effect of different planting dates and mulching treatments on vegetative traits and flowering characteristics

| Vegetative and flowering characteristics<br>Treatments | Plant height (cm) | Plant spread (cm) | Days taken to bud initiation | Days taken to first flowering | Flower diameter (cm) | Flower weight (g) | Number of flowers per plant | Number of flowers per square metre | Shelf life (days) | Flowering duration (days) | Flower yield per plant (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Planting dates** | | | | | | | | | | | |
| $P_1$ | 94.43$^{c}$ | 52.26$^{c}$ | 48.89$^{b}$ | 60.32$^{d}$ | 5.89$^{c}$ | 7.05$^{d}$ | 142.83$^{a}$ | 1289.58$^{a}$ | 2.85$^{d}$ | 51.36$^{a}$ | 1008.31$^{b}$ |
| $P_2$ | 115.04$^{a}$ | 56.98$^{b}$ | 49.39$^{b}$ | 63.63$^{c}$ | 6.64$^{a}$ | 9.03$^{b}$ | 123.54$^{b}$ | 1118.14$^{b}$ | 4.31$^{b}$ | 48.88$^{b}$ | 1049.52$^{b}$ |
| $P_3$ | 117.23$^{a}$ | 60.89$^{a}$ | 51.99$^{a}$ | 68.19$^{b}$ | 6.79$^{a}$ | 10.05$^{a}$ | 111.17$^{c}$ | 1006.85$^{c}$ | 5.29$^{a}$ | 47.96$^{b}$ | 1191.68$^{a}$ |
| $P_4$ | 108.57$^{b}$ | 53.92$^{c}$ | 53.23$^{a}$ | 71.37$^{a}$ | 6.24$^{b}$ | 8.29$^{c}$ | 92.76$^{d}$ | 841.27$^{d}$ | 3.27$^{c}$ | 41.24$^{c}$ | 767.28$^{c}$ |
| Significance | * | * | * | * | * | * | * | * | * | * | * |
| SE | 0.75 | 0.48 | 0.15 | 0.15 | 0.07 | 0.20 | 0.65 | 6.10 | 0.08 | 0.21 | 3.13 |
| **Mulching treatments** | | | | | | | | | | | |
| $M_1$ | 99.25$^{b}$ | 49.62$^{c}$ | 54.95$^{a}$ | 70.64$^{a}$ | 5.92$^{b}$ | 7.98$^{a}$ | 110.48$^{d}$ | 999.27$^{d}$ | 3.40$^{a}$ | 43.18$^{c}$ | 874.32$^{a}$ |
| $M_2$ | 104.02$^{ab}$ | 52.33$^{bc}$ | 53.02$^{b}$ | 68.86$^{b}$ | 6.24$^{ab}$ | 8.39$^{a}$ | 114.45$^{cd}$ | 1036.63$^{cd}$ | 3.60$^{a}$ | 44.80$^{c}$ | 948.95$^{a}$ |
| $M_3$ | 110.07$^{ab}$ | 56.67$^{ab}$ | 51.05$^{c}$ | 65.44$^{c}$ | 6.38$^{ab}$ | 8.53$^{a}$ | 117.10$^{bc}$ | 1062.57$^{bc}$ | 3.95$^{a}$ | 47.40$^{b}$ | 998.94$^{a}$ |
| $M_4$ | 116.13$^{a}$ | 61.20$^{a}$ | 46.32$^{e}$ | 61.19$^{e}$ | 6.82$^{a}$ | 9.19$^{a}$ | 124.83$^{a}$ | 1130.10$^{a}$ | 4.52$^{a}$ | 51.68$^{a}$ | 1139.37$^{a}$ |
| $M_5$ | 114.64$^{a}$ | 60.25$^{a}$ | 49.05$^{d}$ | 63.26$^{d}$ | 6.59$^{a}$ | 8.93$^{a}$ | 121.00$^{ab}$ | 1091.24$^{ab}$ | 4.18$^{a}$ | 49.73$^{ab}$ | 1059.41$^{a}$ |
| Significance | * | * | * | * | * | * | * | * | * | * | * |
| SE | 0.84 | 0.54 | 0.16 | 0.17 | 0.08 | 0.22 | 0.73 | 6.82 | 0.09 | 0.24 | 3.50 |
| **Interactions** | | | | | | | | | | | |
| $P_1 \times M_1$ | 89.56$^{l}$ | 45.01$^{j}$ | 52.77$^{e}$ | 64.80$^{i}$ | 5.47 | 6.38 | 130.40$^{e}$ | 1171.06$^{e}$ | 2.33 | 47.40$^{gh}$ | 858.37$^{m}$ |
| $P_1 \times M_2$ | 92.39$^{kl}$ | 49.81$^{hi}$ | 51.03$^{f}$ | 63.60$^{j}$ | 5.66 | 6.81 | 138.78$^{d}$ | 1255.58$^{d}$ | 2.67 | 48.20$^{fg}$ | 953.90$^{j}$ |
| $P_1 \times M_3$ | 94.88$^{jk}$ | 53.59$^{g}$ | 48.63$^{i}$ | 59.67$^{m}$ | 5.82 | 6.99 | 141.97$^{c}$ | 1286.69$^{c}$ | 2.87 | 51.73$^{cd}$ | 1018.50$^{h}$ |
| $P_1 \times M_4$ | 99.07$^{hi}$ | 56.85$^{ef}$ | 44.83$^{k}$ | 56.13$^{o}$ | 6.34 | 7.69 | 154.03$^{a}$ | 1392.87$^{a}$ | 3.27 | 56.27$^{a}$ | 1151.84$^{d}$ |
| $P_1 \times M_5$ | 96.27$^{ij}$ | 56.05$^{f}$ | 47.17$^{j}$ | 57.40$^{n}$ | 6.15 | 7.39 | 148.95$^{b}$ | 1341.69$^{b}$ | 3.13 | 53.20$^{b}$ | 1058.96$^{g}$ |
| $P_2 \times M_1$ | 104.72$^{g}$ | 49.67$^{i}$ | 53.43$^{d}$ | 68.30$^{f}$ | 6.25 | 8.58 | 117.45$^{h}$ | 1064.42$^{h}$ | 3.73 | 45.20$^{kl}$ | 906.85$^{k}$ |
| $P_2 \times M_2$ | 109.06$^{f}$ | 52.03$^{gh}$ | 51.10$^{f}$ | 66.43$^{g}$ | 6.45 | 8.89 | 121.17$^{g}$ | 1097.09$^{g}$ | 3.93 | 47.13$^{hi}$ | 968.30$^{i}$ |
| $P_2 \times M_3$ | 115.94$^{cd}$ | 57.81$^{def}$ | 49.43$^{h}$ | 63.10$^{jk}$ | 6.55 | 8.99 | 123.28$^{fg}$ | 1118.22$^{fg}$ | 4.27 | 48.47$^{f}$ | 1030.81$^{h}$ |
| $P_2 \times M_4$ | 123.13$^{a}$ | 63.02$^{b}$ | 45.03$^{k}$ | 59.37$^{m}$ | 7.11 | 9.52 | 130.54$^{e}$ | 1181.40$^{e}$ | 5.07 | 52.33$^{bc}$ | 1219.77$^{b}$ |
| $P_2 \times M_5$ | 122.35$^{ab}$ | 62.36$^{b}$ | 47.97$^{i}$ | 60.97$^{l}$ | 6.83 | 9.18 | 125.27$^{f}$ | 1129.56$^{f}$ | 4.53 | 51.27$^{d}$ | 1121.85$^{e}$ |
| $P_3 \times M_1$ | 108.44$^{f}$ | 56.15$^{f}$ | 56.57$^{a}$ | 73.23$^{c}$ | 6.38 | 9.47 | 106.21$^{j}$ | 963.36$^{j}$ | 4.80 | 43.93$^{m}$ | 1079.32$^{f}$ |
| $P_3 \times M_2$ | 113.83$^{de}$ | 57.55d$^{ef}$ | 54.17$^{c}$ | 71.23$^{d}$ | 6.69 | 9.76 | 107.74$^{j}$ | 976.20$^{j}$ | 4.93 | 45.67$^{jk}$ | 1143.20$^{d}$ |
| $P_3 \times M_3$ | 117.74$^{c}$ | 61.53$^{bc}$ | 52.23$^{e}$ | 68.43$^{ef}$ | 6.79 | 9.92 | 111.11$^{i}$ | 1008.55$^{i}$ | 5.33 | 48.13$^{fg}$ | 1192.69$^{c}$ |
| $P_3 \times M_4$ | 123.25$^{a}$ | 65.51$^{a}$ | 46.83$^{j}$ | 62.43$^{k}$ | 7.22 | 10.57 | 116.89$^{h}$ | 1058.71$^{h}$ | 5.87 | 51.93$^{cd}$ | 1311.66$^{a}$ |
| $P_3 \times M_5$ | 122.91$^{a}$ | 63.73$^{ab}$ | 50.17$^{g}$ | 65.63$^{h}$ | 6.91 | 10.51 | 113.89$^{i}$ | 1027.44$^{i}$ | 5.53 | 50.13$^{e}$ | 1231.50$^{b}$ |
| $P_4 \times M_1$ | 94.27$^{jk}$ | 47.63$^{i}$ | 57.03$^{a}$ | 76.23$^{a}$ | 5.57 | 7.50 | 87.87$^{m}$ | 798.22$^{m}$ | 2.73 | 36.20$^{p}$ | 652.72$^{q}$ |
| $P_4 \times M_2$ | 100.81$^{h}$ | 49.93$^{hi}$ | 55.77$^{b}$ | 74.17$^{b}$ | 6.16 | 8.09 | 90.10$^{lm}$ | 817.63$^{lm}$ | 2.87 | 38.20$^{o}$ | 730.40$^{p}$ |
| $P_4 \times M_3$ | 111.71$^{ef}$ | 53.73$^{g}$ | 53.90$^{cd}$ | 70.57$^{d}$ | 6.35 | 8.21 | 92.07$^{l}$ | 836.81$^{l}$ | 3.33 | 41.27$^{n}$ | 753.76$^{o}$ |
| $P_4 \times M_4$ | 119.06$^{bc}$ | 59.45$^{cd}$ | 48.57$^{i}$ | 66.83$^{g}$ | 6.61 | 8.98 | 97.87$^{k}$ | 887.41$^{k}$ | 3.87 | 46.20$^{ij}$ | 874.22$^{l}$ |
| $P_4 \times M_5$ | 117.01$^{cd}$ | 58.85$^{de}$ | 50.90$^{f}$ | 69.03$^{e}$ | 6.48 | 8.67 | 95.90$^{k}$ | 866.28$^{k}$ | 3.53 | 44.33$^{lm}$ | 825.32$^{n}$ |
| Significance | * | * | * | * | NS | NS | * | * | NS | * | * |
| SE | 1.67 | 1.07 | 0.33 | 0.33 | 0.16 | 0.44 | 1.46 | 13.64 | 0.18 | 0.47 | 6.99 |

Values in a column with the same letter are not significantly different (Duncan's Multiple Range Test at $p \leq 0.05$). SE: standard error; NS: not significant; *: significant at the 5 % level.

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**Table 4.** Effect of different planting dates and mulching treatments on soil characteristics

| Soil characteristics / Treatments | pH | EC (dS $m^{-1}$) | Organic carbon (%) | Available nitrogen (kg $ha^{-1}$) | Available phosphorus (kg $ha^{-1}$) | Available potassium (kg $ha^{-1}$) | Soil moisture (%) | Bacterial count (× $10^7$ cfu $g^{-1}$ soil) | Fungal count (× $10^4$ cfu $g^{-1}$ soil) | Actinomycetes count (× $10^3$ cfu $g^{-1}$ soil) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Planting dates** | | | | | | | | | | |
| $P_1$ | 7.39 | 0.229 | $1.241^{a}$ | $358.05^{a}$ | $64.91^{a}$ | $308.02^{a}$ | $16.12^{c}$ | $8.80^{b}$ | $3.89^{b}$ | $6.04^{b}$ |
| $P_2$ | 7.38 | 0.226 | $1.176^{b}$ | $353.44^{a}$ | $64.16^{a}$ | $306.41^{ab}$ | $16.93^{c}$ | $8.95^{b}$ | $4.34^{a}$ | $6.20^{ab}$ |
| $P_3$ | 7.36 | 0.223 | $1.146^{b}$ | $346.61^{a}$ | $62.72^{a}$ | $302.37^{bc}$ | $20.64^{b}$ | $11.14^{a}$ | $4.41^{a}$ | $6.37^{a}$ |
| $P_4$ | 7.36 | 0.221 | $1.103^{c}$ | $343.75^{a}$ | $59.69^{b}$ | $300.59^{c}$ | $22.66^{a}$ | $8.88^{b}$ | $3.97^{b}$ | $6.10^{b}$ |
| Significance | NS | NS | * | * | * | * | * | * | * | * |
| SE | 0.01 | 0.01 | 0.01 | 0.93 | 0.26 | 0.29 | 0.27 | 0.02 | 0.01 | 0.01 |
| **Mulching treatments** | | | | | | | | | | |
| $M_1$ | 7.39 | 0.223 | $1.150^{cd}$ | $333.49^{e}$ | $59.18^{c}$ | $298.29^{e}$ | $17.37^{c}$ | $8.87^{a}$ | $3.82^{c}$ | $5.81^{c}$ |
| $M_2$ | 7.36 | 0.218 | $1.133^{d}$ | $341.37^{d}$ | $61.06^{b}$ | $301.75^{d}$ | $16.56^{c}$ | $9.09^{a}$ | $3.87^{bc}$ | $6.04^{bc}$ |
| $M_3$ | 7.38 | 0.225 | $1.211^{a}$ | $368.09^{a}$ | $66.18^{a}$ | $310.54^{a}$ | $19.44^{b}$ | $10.00^{a}$ | $4.44^{a}$ | $6.44^{a}$ |
| $M_4$ | 7.37 | 0.234 | $1.159^{bc}$ | $349.87^{c}$ | $62.79^{b}$ | $303.77^{c}$ | $21.23^{a}$ | $9.48^{a}$ | $4.25^{abc}$ | $6.23^{ab}$ |
| $M_5$ | 7.37 | 0.224 | $1.181^{b}$ | $359.48^{b}$ | $65.14^{a}$ | $307.38^{b}$ | $20.84^{ab}$ | $9.75^{a}$ | $4.36^{ab}$ | $6.36^{a}$ |
| Significance | NS | NS | * | * | * | * | * | * | * | * |
| SE | 0.01 | 0.01 | 0.01 | 1.04 | 0.30 | 0.33 | 0.30 | 0.03 | 0.01 | 0.01 |
| **Interactions** | | | | | | | | | | |
| $P_1 \times M_1$ | 7.41 | 0.223 | $1.233^{b}$ | $342.13^{i}$ | $61.53^{e}$ | $301.16^{h}$ | $14.31^{ij}$ | $8.25^{m}$ | $3.45^{n}$ | $5.59^{m}$ |
| $P_1 \times M_2$ | 7.37 | 0.224 | $1.223^{b}$ | $349.38^{gh}$ | $63.41^{d}$ | $305.07^{ef}$ | $13.39^{j}$ | $8.50^{l}$ | $3.48^{m}$ | $5.89^{j}$ |
| $P_1 \times M_3$ | 7.40 | 0.230 | $1.263^{a}$ | $376.56^{a}$ | $67.90^{a}$ | $315.36^{a}$ | $16.73^{h}$ | $9.30^{gh}$ | $4.28^{g}$ | $6.36^{d}$ |
| $P_1 \times M_4$ | 7.40 | 0.237 | $1.233^{b}$ | $357.77^{de}$ | $65.36^{bc}$ | $307.13^{d}$ | $18.97^{ef}$ | $8.87^{j}$ | $4.03^{l}$ | $6.10^{i}$ |
| $P_1 \times M_5$ | 7.39 | 0.230 | $1.253^{a}$ | $364.38^{bc}$ | $66.36^{b}$ | $311.37^{b}$ | $17.19^{gh}$ | $9.05^{i}$ | $4.19^{j}$ | $6.27^{e}$ |
| $P_2 \times M_1$ | 7.40 | 0.217 | $1.163^{def}$ | $336.73^{j}$ | $61.48^{e}$ | $300.53^{hi}$ | $15.45^{i}$ | $8.49^{l}$ | $4.11^{k}$ | $5.77^{k}$ |
| $P_2 \times M_2$ | 7.37 | 0.222 | $1.150^{f}$ | $348.32^{gh}$ | $63.23^{d}$ | $304.54^{fg}$ | $14.31^{ij}$ | $8.62^{k}$ | $4.18^{j}$ | $6.13^{h}$ |
| $P_2 \times M_3$ | 7.38 | 0.227 | $1.230^{b}$ | $368.61^{b}$ | $66.39^{b}$ | $311.37^{b}$ | $17.33^{gh}$ | $9.51^{f}$ | $4.52^{b}$ | $6.46^{c}$ |
| $P_2 \times M_4$ | 7.37 | 0.237 | $1.166^{de}$ | $351.95^{fg}$ | $63.37^{d}$ | $306.30^{de}$ | $19.35^{def}$ | $8.91^{j}$ | $4.37^{e}$ | $6.22^{fg}$ |
| $P_2 \times M_5$ | 7.38 | 0.225 | $1.170^{d}$ | $361.58^{cd}$ | $66.33^{b}$ | $309.30^{c}$ | $18.21^{fg}$ | $9.24^{h}$ | $4.49^{c}$ | $6.39^{d}$ |
| $P_3 \times M_1$ | 7.36 | 0.221 | $1.126^{g}$ | $329.16^{lm}$ | $57.83^{g}$ | $296.64^{k}$ | $19.23^{def}$ | $10.32^{e}$ | $4.27^{gh}$ | $6.16^{h}$ |
| $P_3 \times M_2$ | 7.36 | 0.217 | $1.106^{h}$ | $335.60^{jk}$ | $61.33^{e}$ | $299.29^{ij}$ | $19.22^{def}$ | $10.64^{d}$ | $4.33^{f}$ | $6.24^{ef}$ |
| $P_3 \times M_3$ | 7.37 | 0.221 | $1.196^{c}$ | $365.66^{bc}$ | $65.76^{bc}$ | $309.28^{c}$ | $20.25^{de}$ | $11.82^{a}$ | $4.55^{a}$ | $6.55^{a}$ |
| $P_3 \times M_4$ | 7.36 | 0.233 | $1.130^{g}$ | $346.14^{hi}$ | $63.13^{d}$ | $301.37^{h}$ | $21.74^{c}$ | $11.26^{c}$ | $4.38^{e}$ | $6.37^{d}$ |
| $P_3 \times M_5$ | 7.36 | 0.224 | $1.170^{d}$ | $356.50^{e}$ | $65.53^{bc}$ | $305.29^{ef}$ | $22.75^{bc}$ | $11.63^{b}$ | $4.49^{c}$ | $6.51^{b}$ |
| $P_4 \times M_1$ | 7.37 | 0.227 | $1.076^{i}$ | $325.95^{m}$ | $55.89^{h}$ | $294.85^{l}$ | $20.48^{d}$ | $8.40^{l}$ | $3.46^{n}$ | $5.73^{l}$ |
| $P_4 \times M_2$ | 7.35 | 0.215 | $1.050^{j}$ | $332.17^{kl}$ | $56.25^{h}$ | $298.08^{j}$ | $19.34^{def}$ | $8.61^{k}$ | $3.48^{m}$ | $5.89^{j}$ |
| $P_4 \times M_3$ | 7.36 | 0.223 | $1.153^{ef}$ | $361.52^{cd}$ | $64.65^{c}$ | $306.15^{de}$ | $23.47^{b}$ | $9.38^{g}$ | $4.41^{d}$ | $6.37^{d}$ |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_4 \times M_4$ | 7.35 | 0.231 | $1.106^{h}$ | $343.63^{i}$ | $59.31^{f}$ | $300.27^{hi}$ | $24.85^{a}$ | $8.89^{j}$ | $4.23^{i}$ | $6.21^{g}$ |
| $P_4 \times M_5$ | 7.36 | 0.217 | $1.130^{g}$ | $355.47^{ef}$ | $62.32^{de}$ | $303.57^{g}$ | $25.18^{a}$ | $9.10^{i}$ | $4.26^{h}$ | $6.27^{e}$ |
| Significance | NS | NS | * | * | * | * | * | * | * | * |
| SE | 0.01 | 0.01 | 0.01 | 2.09 | 0.59 | 0.65 | 0.61 | 0.05 | 0.01 | 0.01 |

Values in a column with the same letter are not significantly different (Duncan's Multiple Range Test at $p \leq 0.05$).

EC: electrical conductivity; SE: standard error; NS: not significant; *: significant at the 5 % level.

### Influence of mulching treatments on soil characteristics

Soil organic carbon content was highest under weed mulch (1.21 %) and lowest under the no-mulch and manual-weeding treatment (1.13 %). Application of weed mulch enhanced soil nutrient availability, resulting in the highest available N (368.09 kg $ha^{-1}$), P (66.18 kg $ha^{-1}$) and K (310.54 kg $ha^{-1}$). It likewise recorded the highest viable bacterial (10.00 × $10^{7}$ cfu $g^{-1}$), fungal (4.44 × $10^{4}$ cfu $g^{-1}$) and actinomycete (6.44 × $10^{3}$ cfu $g^{-1}$) counts. In contrast, the no-mulch and no-weeding treatment exhibited the lowest levels of available N (333.49 kg $ha^{-1}$), P (59.18 kg $ha^{-1}$) and K (298.29 kg $ha^{-1}$), accompanied by the lowest viable bacterial (8.87 × $10^{7}$ cfu $g^{-1}$), fungal (3.82 × $10^{4}$ cfu $g^{-1}$) and actinomycete (5.81 × $10^{3}$ cfu $g^{-1}$) counts. The chord diagram shown in Fig. 3 illustrates the strength of associations between mulching treatments and soil parameters, where wider ribbons indicate stronger positive relationships and narrower ribbons represent weaker associations. Weed mulch ($M_3$) exhibited strong linkages with SOC, N, P, K and microbial populations. Grass mulch ($M_5$) exhibited moderate associations with both soil nutrient status and microbial activity, while silver-black plastic mulch ($M_4$) showed a prominent association with SM. Conversely, the no-mulch treatments ($M_1$ and $M_2$) displayed comparatively weaker relationships with most soil physico-chemical attributes. Silver-black plastic mulch maintained the highest SM (21.23 %), while the no-mulch and manual-weeding treatment exhibited the lowest moisture content (16.56 %). Furthermore, a heatmap of SM (%) measured at fortnightly intervals across planting dates and mulching treatments is shown in Fig. 4; lighter shades indicate lower moisture levels, while darker shades represent higher moisture content. Soil moisture varied considerably across planting dates, mulching treatments and sampling periods. Overall, moisture content increased from the April ($P_1$) to the July ($P_4$) planting. Mulched treatments, particularly silver-black plastic mulch ($M_4$) and grass mulch ($M_5$), consistently maintained higher SM than the non-mulched treatments ($M_1$ and $M_2$).

### Cost economics of different planting dates and mulching treatments

The benefit-cost (B : C) ratio for different planting dates and mulching treatments is shown in the radial graph (Fig. 5). The concentric rings represent increasing levels of B : C ratio, where darker shades indicate higher economic returns. Each sector corresponds to a specific combination of planting date and mulch type, showing clear variability in profitability due to management interactions. The highest ratio (2.66 : 1) was observed on the 15th June planting with silver-black plastic mulch, whereas the lowest ratio (1.82 : 1) was observed on the 15th July planting under the no-mulch and no-weeding treatment.

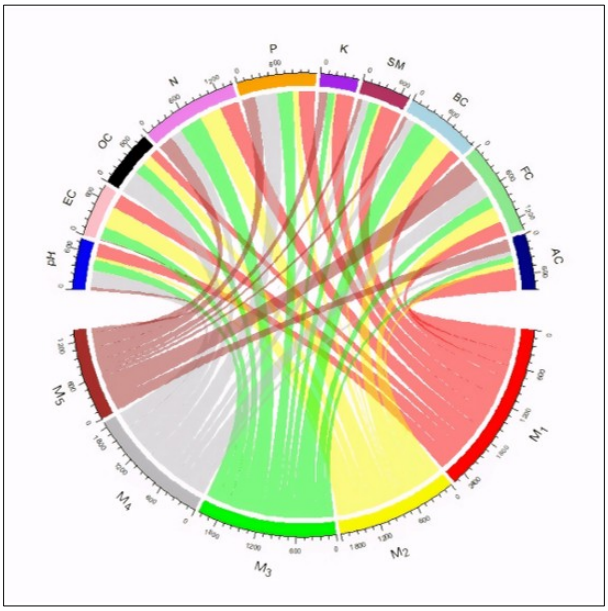



**Fig. 3.** Chord diagram of correlations between mulching treatments and soil parameters.

pH: soil pH; EC: electrical conductivity; OC: organic carbon; N: nitrogen; P: phosphorus; K: potassium; SM: soil moisture; BC: bacterial count; FC: fungal count; AC: actinomycetes count.

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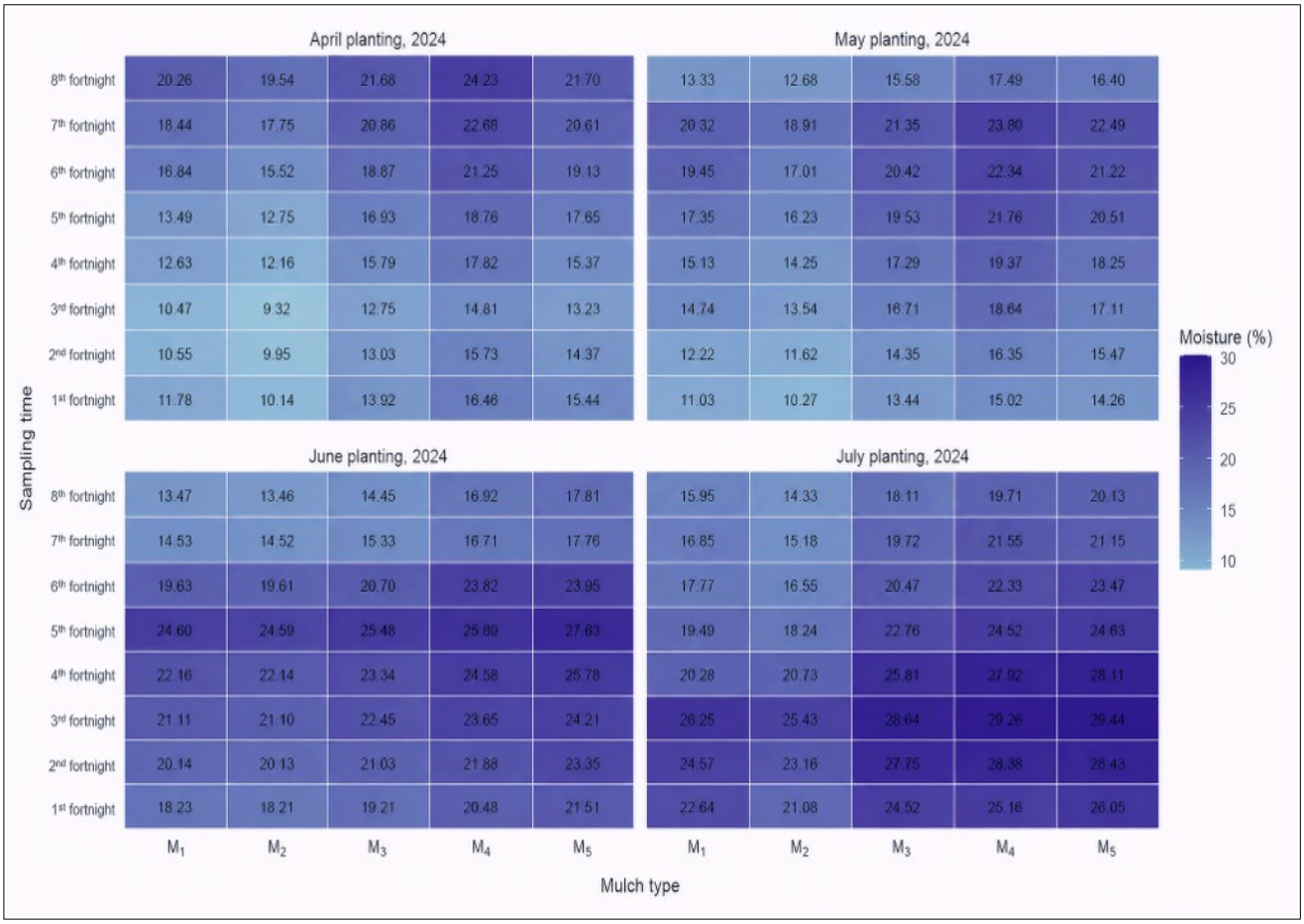



**Fig. 4.** A heatmap of soil moisture content (%) measured at fortnightly intervals across planting dates and mulching treatments.

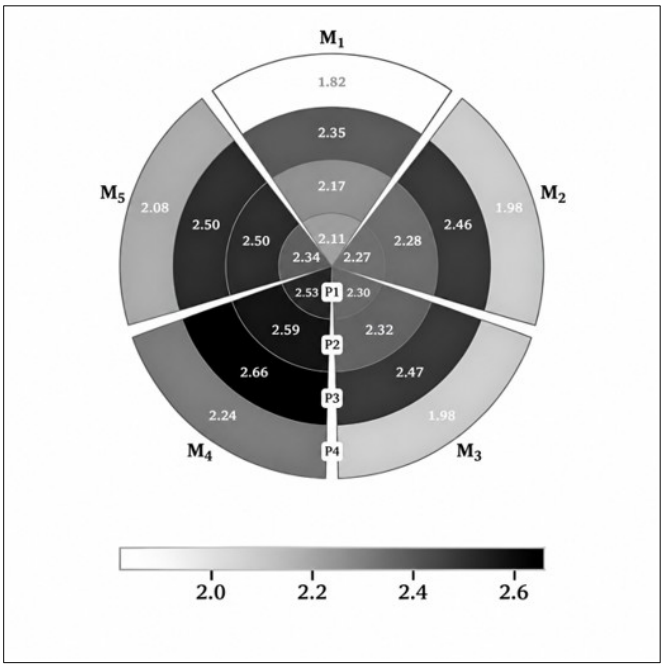



**Fig. 5.** Radial heatmap of benefit-cost ratio for different combinations of planting dates and mulching treatments.

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### Pearson correlation of soil properties with marigold yield and quality traits

The correlation matrix (Fig. 6) showed a positive relationship of flower weight, flowers per plant, yield per plant and shelf life with soil macronutrients, microbial biomass, OC and SM, except for soil pH and EC. Among these, SM showed the strongest correlations with flower weight (r = 0.874), flowers per plant (r = 0.897), yield per plant (r = 0.889) and shelf life (r = 0.933).

## Discussion

### Influence of planting dates on vegetative traits and flowering characteristics

The differences in plant height, plant spread, flower diameter, flower weight and shelf life can be linked to the favourable growing conditions including adequate rainfall and moderate temperatures during late planting period which encouraged strong vegetative growth. These conditions enhanced photosynthesis and nutrient uptake which resulted in better flower quality (21–23), whereas the poor performance during early planting could be attributed to the high temperature and low SM, which hindered root growth and reduced nutrient uptake (24). In addition, the assimilates available for flower development were distributed among a larger number of flowers, resulting in smaller and lighter blooms (25). The variation in flowering behaviour among planting dates may also be explained by differences in the prevailing environmental conditions during crop growth. Early bud initiation and flowering in April planting may be due to the higher light intensity and temperature during the initial growth stages, which accelerated floral induction and advanced the transition from vegetative to reproductive phase. The earlier shift from vegetative to reproductive growth extended the flowering duration, thereby increasing flower production (26). Conversely, high humidity and excess SM during the monsoon period may have delayed floral differentiation by promoting prolonged vegetative growth. This reduction in the effective flowering period limited flower production, resulting in fewer flowers per plant (27, 28). Although April planting produced the highest number of flowers, the maximum flower yield per plant was obtained in June planting due to the production of larger and heavier flowers under favourable temperature and moisture conditions (29, 30). Excessive rainfall and high humidity during July planting may have increased flower damage and disease incidence, thereby reducing flower yield (23).

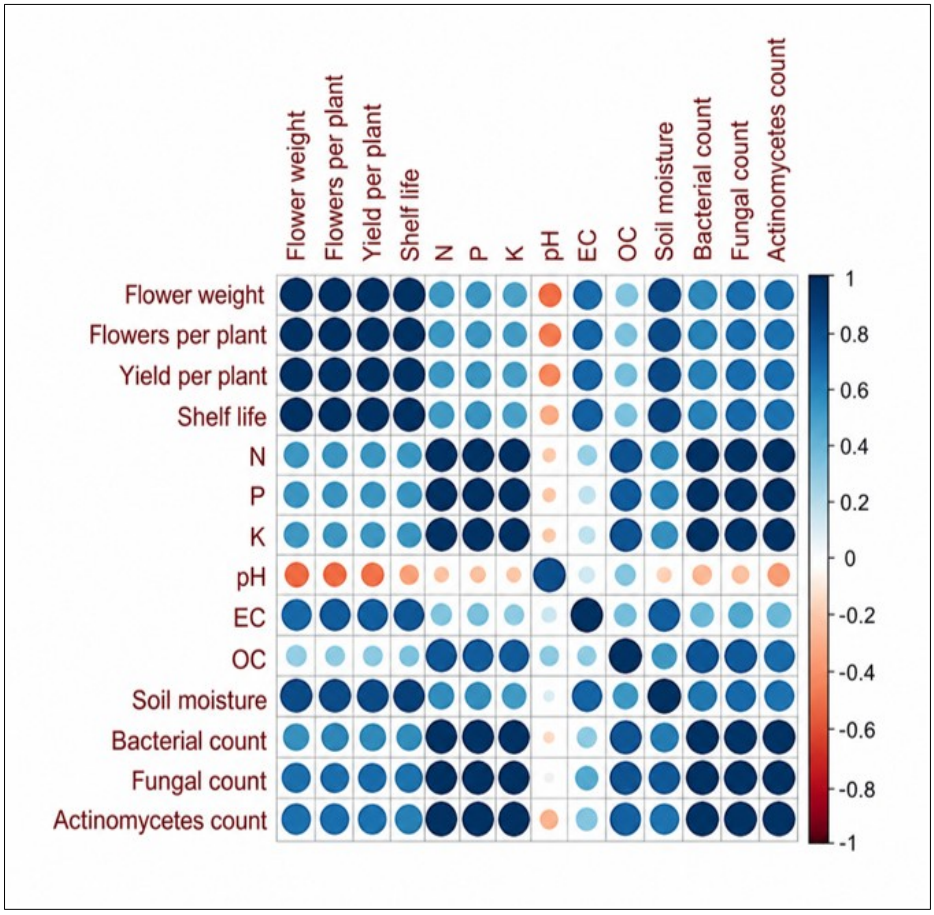



**Fig. 6.** Correlation of marigold flower yield and quality parameters with soil properties.
pH: soil pH; EC: electrical conductivity; OC: organic carbon; N: nitrogen; P: phosphorus; K: potassium.

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### Influence of planting dates on soil characteristics

Planting dates markedly influenced most soil physico-chemical properties, while soil pH and EC showed little variation. Higher SOC and nutrient levels under April planting may have resulted from increased organic matter inputs during the longer growing period, leading to enhanced nutrient mineralisation and improved soil fertility, whereas lower nutrient and carbon levels under July planting may be attributed to higher rainfall, which likely increased nutrient losses through leaching. Differences in SM among planting dates may be attributed to variations in rainfall and atmospheric conditions. Higher rainfall coupled with humid weather during July favoured moisture retention, whereas warmer and drier conditions during April increased moisture depletion from the soil. The higher microbial populations observed under June planting may be attributed to favourable SM and temperature conditions, which enhanced microbial growth and activity. Improved vegetative growth during this period likely increased root biomass and rhizosphere exudation, providing a readily available carbon source for soil microorganisms. Conversely, the lower microbial populations under April planting may be associated with high temperature and low SM, which restricted microbial activity and reduced substrate availability required for microbial growth (31).

### Influence of mulching treatments on vegetative traits and flowering characteristics

The superior performance under silver-black plastic mulch may be attributed to its ability to create a favourable microclimate by regulating soil hydro-thermal conditions, conserving moisture and suppressing weed growth. These conditions promoted vigorous plant growth (32–34) and uniform plant development (35) by enhancing root growth, nutrient uptake and overall assimilate production. Improved soil environment under mulch may also have accelerated physiological processes, leading to earlier bud initiation and flowering (36) through better photosynthetic efficiency and hormonal regulation influenced by reflected light, thereby resulting in enhanced floral yield and quality attributes (37, 38). On the other hand, the poor performance under the no-mulch and no-weeding treatment may be attributed to strong weed competition for nutrients, water and light (39), which adversely restricted plant growth and development (40). Additionally, the absence of mulch led to greater moisture loss and temperature fluctuations. These combined stresses may have disrupted physiological and hormonal processes resulting in poor flower quality and delayed flowering (41–45).

### Influence of mulching treatments on soil characteristics

Mulching treatments influenced SOC dynamics primarily through differences in organic residue input. The higher SOC under weed mulch is mainly due to the continuous addition of decomposing weed biomass, which increased organic matter input into the soil along with enhanced root exudation contributing additional labile carbon to the rhizosphere. However, the lower SOC under the no-mulch and manual-weeding treatment is primarily due to the removal of weed biomass, resulting in reduced organic matter return to the soil. Weed mulch enhanced NPK availability through the constant input of organic residue, which stimulated microbial proliferation and accelerated nutrient mineralisation. Lack of soil cover and organic residue inputs under the no-mulch and no-weeding treatment reduced organic matter addition and microbial substrate availability. Strong weed competition further intensified nutrient depletion, resulting in lower availability of NPK (46, 47). Variation in SM may be attributed to differences in soil cover management. Silver-black plastic mulch likely enhanced moisture retention by minimising evaporative losses through surface coverage, thereby reducing direct exposure of soil to solar radiation and wind (37, 38). In the absence of mulch, reduced surface protection and lower organic residue input exposed the soil to greater evaporation, resulting in comparatively lower SM content.

### Cost economics of different planting dates and mulching treatments

The variation in B : C ratio across treatments indicates a strong influence of planting time and mulching on economic returns. The highest B : C ratio under June planting with silver-black plastic mulch may be associated with better alignment of crop growth with monsoon conditions, ensuring sufficient SM and reduced irrigation demand. The mulch likely improved moisture conservation and suppressed weed emergence, resulting in better nutrient uptake and higher yield, which enhanced overall profitability. On the other hand, the lowest B : C ratio observed in July planting without mulching and weeding may be attributed to poor crop management conditions, where absence of mulch and weed control led to depletion of SM and nutrients. Additionally, excessive rainfall during this period adversely affected crop development, causing flower damage and higher disease incidence. These combined factors resulted in reduced yield and lower economic returns despite sustained production costs.

## Conclusion

The study on planting dates and mulching materials identified effective strategies for maximising marigold production. June planting increased vegetative and floral development which resulted in higher yield and quality. Among mulching treatments, silver-black plastic mulch was found to be the most effective and recorded the highest yield and benefit-cost (B : C) ratio. These results offer practical guidance for marigold growers to improve productivity, quality and profitability. Improved irrigation management and the use of organic mulches can support soil health and environmental sustainability. Strategic planting time and targeted resource allocation maximise growth and yield potential. Collectively, these practices promote a sustainable and resilient marigold production system. The present findings provide a

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useful framework for optimising marigold production practices and support the development of sustainable cultivation strategies across diverse agro-climatic conditions.

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## Authors' contributions

BK and SRD contributed to conceptualisation. $MR^1$ was responsible for data curation, formal analysis and investigation. BK, SRD, BSD, US, NS and $MR^1$ contributed to the methodology. BK handled project administration. $MR^1$ and AK contributed to software development and writing the original draft. BK and SRD supervised the work. $MR^1$, S and $MR^2$ contributed to writing, reviewing and editing the manuscript. All authors read and approved the final manuscript [$MR^1$ stands for Mukul Rana and $MR^2$ for Mehak Rana].

## Compliance with ethical standards

### Conflict of interest

Authors do not have any conflict of interests to declare.

### Ethical issues

None

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