E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(9): 995-1002
Received: 17-06-2025
Accepted: 21-07-2025

Shubham Ahirwar
Ph.D Research Scholar, Department of Horticulture, College of Agriculture, JNKVV Jabalpur, Madhya Pradesh, India

Reena Nair
Assistant Professor, Department of Horticulture, College of Agriculture, JNKVV Jabalpur, Madhya Pradesh, India

SK Pandey
Professor and Head, Department of Horticulture, College of Agriculture, JNKVV Jabalpur, Madhya Pradesh, India

Manoj K Awasthi
Professor, Department of Soil and Water Engineering, College of Agricultural Engineering, JNKVV, Jabalpur, Madhya Pradesh, India

R Shiv Ramakrishnan
Assistant Professor, Department of Plant Physiology, College of Agriculture, JNKVV Jabalpur, Madhya Pradesh, India

Surabhi Jain
Scientist (Statistic), PC unit, AICRP on Sesame and Niger, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Shubham Ahirwar
Ph.D Research Scholar, Department of Horticulture, College of Agriculture, JNKVV Jabalpur, Madhya Pradesh, India

Effect of irrigation levels and mulching on growth and yield performance of nigella (*Nigella sativa* L.)

Shubham Ahirwar, Reena Nair, SK Pandey, Manoj K Awasthi, R Shiv Ramakrishnan and Surabhi Jain

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i9n.3890

Abstract
The present study evaluated the interactive effects of irrigation scheduling and mulching on growth, physiological traits, and yield of Nigella sativa under semi-arid conditions of central India. The experiment was conducted in a split-plot design with four irrigation regimes (IW/CPE ratios of 1.0, 0.8, 0.6, and 0.4) as main plots and four mulching treatments (silver-black polythene, black polythene, organic mulch, and no mulch) as subplots. Results revealed that the highest plant height (66.71 cm), number of branches (8.21), and LAI (2.00) at harvest were recorded under IW/CPE 1.0 + silver-black mulch (T_2), closely followed by IW/CPE 0.8 + silver-black mulch (65.92 cm, 8.03 branches, and 1.97 LAI, respectively). The corresponding LAD values were 60.36 (T_2) and 58.60 (T_6) compared to only 27.89 under severe water deficit (IW/CPE 0.4 without mulch, T_{16}). Reproductive parameters also followed a similar trend, with maximum capsules per plant (37.86) and seeds per capsule (90.54) in T_2, whereas the lowest values (23.24 capsules and 77.76 seeds) occurred in T_{16}. Seed yield was markedly influenced, ranging from 1160.71 kg/ha in T_2 to 640.87 kg/ha in T_{16}, while harvest index varied from 33.04% (T_2) to 26.99% (T_{16}). The study clearly demonstrated that optimum irrigation (IW/CPE 0.8–1.0) coupled with reflective polythene mulches, particularly silver-black mulch, significantly enhanced water conservation, canopy longevity, and assimilate partitioning, thereby improving seed yield by 45–50% over deficit irrigation without mulch. These findings confirm that integrated irrigation–mulch management is a practical strategy for maximizing productivity and sustainability of nigella cultivation in semi-arid regions.

Keywords: *Nigella sativa*, IW/CPE ratio, drip irrigation, mulching, irrigation scheduling, mulching, leaf area index, seed yield, harvest index

Introduction
Agricultural water scarcity, exacerbated by climate change and increasing competition for freshwater resources, poses a serious threat to global food and medicinal plant security especially in semi-arid regions like central India. Efficient water management strategies, such as drip irrigation combined with mulching, have emerged as vital climate-smart techniques. These methods not only conserve water but also maintain or enhance yield across crop types (Bwire *et al*. 2024) [3] and (Demo and Asefa 2024) [4, 5]. *Nigella sativa* L., commonly known as black cumin, is valued for its medicinal and nutritional properties, including its oil and secondary metabolites. While water stress tends to reduce seed yield, studies note that moderate stress may enhance oil quality and concentrations of valuable compounds like thymoquinone (Bayati *et al* 2022) [2]. Research conducted in regions like Syria and Turkey has shown that deficit irrigation using only a fraction (25–75%) of potential evapotranspiration can maximize irrigation water use efficiency (IWUE), albeit with careful balance to avoid excessive yield loss (Yaghi *et al* 2024 [24]; Senyigit and Arslan 2018). Further, subsurface drip irrigation studies demonstrate that intermittent and deficit irrigation regimes significantly influence morphological traits and yield in *Nigella sativa*, indicating the relevance of precisely timed and measured water applications (Gültekin *et al* 2025) [9].
Mulching application both synthetic and organic mulch plays a critical role in conserving soil moisture by reducing evaporation, improving thermal regulation, and enhancing nutrient availability (Demo and Bogale 2024) [4, 5].

Although Nigella-specific mulching research is limited, similar findings in vegetable and other crop systems affirm that coupling mulching with drip irrigation markedly improves water use efficiency and productivity (Kirnak and Demirtas 2006 [15]; Jayakumar *et al*. 2024) [13]. Given the growing demand for sustainable nigella cultivation in water-scarce regions, there is a clear need for localized, experimental evaluation of how varying IW/CPE-based irrigation levels together with plastic and organic mulches influence growth of plants, seed yield and crop quality. This study aims to bridge this gap by evaluating the influence of varying drip irrigation levels and mulching on the growth and yield attributes of nigella. The findings will provide valuable insights for farmers and researchers in adopting efficient water management and soil conservation practices for enhanced crop performance.

Materials and Methods

The field experiment was carried out during *Rabi* 2024–25 at the Research Farm, College of Agriculture, Jabalpur (M.P.), situated at 22°49′ N latitude, 79°53′ E longitude, and 411 m above mean sea level, under a sub-tropical semi-arid climate. The soil was sandy clay loam, moderately fertile, low in available nitrogen, medium in phosphorus, and rich in potassium with a pH of 7.2. The study was conducted in a split-plot design with three replications, sixteen treatment combinations of irrigation levels and mulching practices were evaluated. These treatments included four irrigation schedules based on IW/CPE ratios (1.0, 0.8, 0.6, and 0.4), each combined with four different mulching treatments, namely black polythene mulch, silver-black polythene mulch, organic mulch, and without mulch. Accordingly, the treatments were designated as follows: T_1 – 1.0 IW/CPE with black polythene mulch, T_2 – 1.0 IW/CPE with silver-black polythene mulch, T_3 – 1.0 IW/CPE with organic mulch, and T_4 – 1.0 IW/CPE without mulch. Similarly, T_5 – 0.8 IW/CPE with black polythene mulch, T_6 – 0.8 IW/CPE with silver-black polythene mulch, T_7 – 0.8 IW/CPE with organic mulch, and T_8 – 0.8 IW/CPE without mulch. The next set included T_9 – 0.6 IW/CPE with black polythene mulch, T_{10} – 0.6 IW/CPE with silver-black polythene mulch, T_{11} – 0.6 IW/CPE with organic mulch, and T_{12} – 0.6 IW/CPE without mulch. Finally, under the lowest irrigation regime, T_{13} – 0.4 IW/CPE with black polythene mulch, T_{14} – 0.4 IW/CPE with silver-black polythene mulch, T_{15} – 0.4 IW/CPE with organic mulch, and T_{16} – 0.4 IW/CPE without mulch. Nigella (*Nigella sativa* L.) was sown at 30 × 10 cm spacing with a seed rate of 10 kg ha^{-1}, adopting recommended agronomic practices except for treatment variations. Each irrigation was applied at a fixed depth of 50 mm through drip irrigation when the ratio of irrigation water (IW) to cumulative pan evaporation (CPE) reached the designated level for each treatment, based on daily evaporation data were recorded using a U.S. Class-A open pan evaporimeter installed at the meteorological observatory of the Indian Meteorological Department, Adhartal, Jabalpur. During the cropping season, the mean maximum and minimum temperatures ranged between 24.6–34.8°C and 8.5–18.9°C, respectively, with an average relative humidity of 60–80% and total rainfall of about 48 mm, which was considered as effective rainfall for water use computation. Observations were recorded on growth parameters (plant height, number of branches), physiological indices (leaf area index and leaf area duration), yield attributes (capsules $plant^{-1}$, seeds $capsule^{-1}$, seed yield, harvest index). The collected data were statistically analyzed using analysis of variance (ANOVA) for split-plot design as per Gomez and Gomez (1984), and treatment means were compared at the 5% level of significance ($p \le 0.05$) using the Critical Difference (CD) test.

Results and Discussion

The observations on plant height and number of branches at successive stages are summarized in Table 3.1 and the corresponding trends are illustrated in Figure 3.1 and Figure 3.2 respecitively. Plant height of Nigella was significantly affected by the interaction between irrigation levels and mulching at all stages (45 DAS, 90 DAS, and harvest). The highest heights (18.91 cm, 61.57 cm, and 66.71 cm respectively) were recorded under IW/CPE 1.0 + silver-black polythene mulch (T_2), statistically similar to IW/CPE 0.8 + silver-black mulch (T_6). Enhanced vegetative growth under these treatments is likely due to improved soil moisture conservation and moderated soil temperature, which favour cell elongation and photosynthetic efficiency. These findings align that mulching fosters plant growth by limiting evaporation, improving soil temperature, and enhancing water availability (El-Beltagi *et al*. 2022) [6]. In contrast, the lowest plant heights (11.01 cm, 50.09 cm, and 55.29 cm) occurred in IW/CPE 0.4 without mulch (T_{16}), where limited water supply and elevated evaporation impeded growth. (Patel *et al*. 2007) [21], find the limited water supply under lower IW: CPE ratio (0.75 and 0.60) reduced the vegetative growth of the crop and hence, lesser water used by the fennel crop. Additionally, a study in cumin under drip irrigation demonstrated that moderate deficit irrigation levels (0.6–0.8 CPE) significantly increased plant height and branching compared to lower or surface irrigation regimes (Mehriya *et al*. 2022) [16]. The number of branch paralleled plant height trends. Maximum branching (5.46, 7.24, and 8.21 at successive stages) occurred under IW/CPE 1.0 + silver-black mulch (T_2), followed closely by IW/CPE 0.8 + silver-black mulch (T_6). Favorable moisture availability and moderated rhizosphere conditions likely promoted lateral shoot initiation and assimilate translocation. In contrast, the lowest branching (2.73, 4.57, and 5.22) was found in IW/CPE 0.4 without mulch (T_{16}), underscoring how moisture stress suppresses canopy development. The benefit of irrigation-mulch interactions on branching and overall canopy growth has been reported in other aromatic and medicinal crops. For example, in foxtail millet, drip irrigation combined with mulching significantly enhanced agronomic traits and canopy development compared to non-mulched conditions and no irrigation (Qiao *et al*. 2025) [22]. The highest growth attributes in fenugreek like plant height at harvest (62.44 cm), number of secondary branches $plant^{-1}$ (20.29), seed yield g plot (2360.0) and seed yield kg ha^{-1} (1950.36) were maximum found in water level 0.6 IW/CPE ratio through drip-irrigation followed by 0.8 IW/CPE ratio respectively (Lal *et al*. 2020) [16]. Furthermore, studies on bush tea under deficit irrigation and mulching showed improved growth characteristics including branching under moderate water regimes with mulch (Ndou *et al*. 2025) [19].

The observations on leaf area index and leaf area duration at successive stages are summarized in Table 3.2 and the corresponding trends are illustrated leaf area index in Figure 3.3 and leaf area duration in Figure 3.4. Leaf Area Index (LAI) was significantly influenced by irrigation levels and mulching across all growth stages (45 DAS, 90 DAS, and harvest). This significant effect of irrigation levels and mulching may be attributed to their combined role in improving soil moisture availability, moderating temperature and enhancing nutrient uptake. Adequate irrigation maintains cell turgour and promotes leaf expansion, while mulching reduces evaporation losses, suppresses weed competition, and creates a favorable microclimate in the root zone. Simultaneously, these practices facilitate greater canopy development and leaf proliferation, resulting in higher LAI values at 45 DAS, 90 DAS and harvest stages compared to stressed or unmulched conditions. At 45 DAS, the maximum LAI (0.36) was observed under IW/CPE 1.0 + silver-black mulch (T_2), followed closely by IW/CPE 0.8 + silver-black mulch (0.35; T_6). In contrast, the minimum LAI (0.13) was recorded in IW/CPE 0.4 without mulch (T_{16}). Similarly, at 90 DAS, the highest LAI was under T_2 (2.00) and T_6 (1.97), while the lowest value (0.90) was again under T_{16}. At harvest, the maximum LAI remained under T_2 (1.99) and T_6 (1.94), whereas T_{16} recorded the minimum (0.95). This trend clearly demonstrates that higher irrigation levels (IW/CPE 1.0 and 0.8), when combined with mulching, particularly silver-black mulch, maintain a denser canopy and prolonged leaf activity. Conversely, under severe water stress (IW/CPE 0.4) without mulching, leaf expansion was restricted, leading to the lowest LAI. Similar observations were reported by Ozer *et al*. (2020) [20] in Nigella. Research in fennel also supports that mulching with optimum irrigation sustains higher LAI throughout the crop cycle (Meena *et al*., 2020). Leaf area duration (LAD) values exhibited trends similar to LAI. The results revealed that leaf area duration of Nigella was significantly influenced by irrigation levels and mulching practices at both 45–90 DAS and 90 DAS–maturity stages. Maximum LAD was observed under 1.0 IW/CPE with silver-black polythene mulch (53.85 and 60.36, respectively), closely followed by 0.8 IW/CPE with silver-black mulch (52.02 and 58.60, respectively), while the lowest was recorded under 0.4 IW/CPE without mulch (23.36 and 27.89). These findings suggest that higher irrigation levels in combination with mulching, particularly silver-black polythene, sustained photosynthetic activity for a longer period by conserving soil moisture, moderating temperature, and delaying leaf senescence. Conversely, severe water stress at 0.4 IW/CPE without mulch accelerated leaf senescence and reduced canopy longevity, thereby shortening LAD. Similar results were reported in *Nigella sativa* where mulching mitigated drought stress and maintained leaf turgor (Karimi & Baziar, 2023) [14] and drip irrigation at 80–100% ETc improved vegetative growth compared to severe deficit (Hendi, *et al*., 2021) [12]. Ghamarnia *et al*. (2010) [7], who reported that deficit irrigation markedly reduces LAD and assimilation duration in Nigella.

The results related to yield attributes and seed yield are given in Table 3.3 and their graphical representation is shown in Figure 3.5. The number of capsules per plant was significantly influenced by irrigation levels and mulching practices. The highest capsule number was recorded under IW/CPE 1.0 + silver-black polythene mulch (T_2: 37.86), which was statistically at par with IW/CPE 0.8 + silver-black mulch (T_6: 37.38) and IW/CPE 1.0 + black mulch (T_1: 37.05), reflecting the positive impact of optimum irrigation and moisture conservation through polythene mulches. Silver-black mulch proved superior by reducing evaporative losses and enhancing canopy microclimate, thereby supporting higher photosynthesis and capsule retention. Intermediate values were obtained in organic mulch treatments (T_3 and T_7) and without mulch under moderate irrigation (T_4 and T_8), suggesting partial benefits of organic residues in conserving moisture. In contrast, the lowest capsule number (23.24) was observed under IW/CPE 0.4 without mulch (T_{16}), closely followed by T_{12} (25.21) and T_{13} (28.67), where severe water deficit coupled with absence of mulch reduced leaf area duration, assimilate supply, and flower retention, resulting in fewer capsules. Overall, the results confirm that optimum irrigation (1.0–0.8 IW/CPE) with polythene mulching, particularly silver-black, provides the most favorable environment for capsule production, while moisture stress and lack of mulching significantly reduce reproductive efficiency, in agreement with earlier reports on Nigella sativa and related spice crops (Ghamarnia *et al*. 2010) [7].

The number of seeds per capsule varied significantly among different irrigation × mulch treatments. The maximum seed count (90.54) was observed under IW/CPE 1.0 + silver-black polythene mulch (T_2)**,** closely followed by IW/CPE 0.8 + silver-black mulch (T_6: 90.35) and IW/CPE 1.0 + black mulch (T_1: 90.13)**,** indicating that optimal irrigation paired with reflective, moisture-retentive mulching supported favorable physiological conditions during flowering and seed set. Moderate values were recorded in T_3 (1.0 IW/CPE + organic mulch: 89.47) and T_4 (1.0 IW/CPE without mulch: 89.10)**,** suggesting some buffering by organic mulch or adequate moisture alone. However, the lowest seed number per capsule (77.76) occurred under IW/CPE 0.4 without mulch (T_{16})**,** followed by T_{15} (81.83) and T_{12} (81.38)**,** reflecting the detrimental impact of severe water stress and lack of mulch on reproductive success. Reduced seed set under such conditions likely results from compromised photosynthetic activity, early leaf senescence, and insufficient assimilate supply for seed development. These findings are corroborated by the study on subsurface drip and intermittent irrigation reported that higher irrigation enhances seed number and yield in black cumin (Gültekin *et al*. 2025) [9]. These align with general agronomic findings in spiced crops whereby moisture stress during flowering leads to lower seed set and decreased reproductive efficiency.

Seed yield of *Nigella sativa* was markedly influenced by irrigation scheduling and mulching practices. The data of seed yield at successive stages are summarized in Table 3.3 and the corresponding trends are illustrated leaf area index in Figure 3.5. The highest seed yield (1160.71 kg/ha) was recorded under IW/CPE 1.0 + silver-black polythene mulch (T_2), which was statistically at par with T_6 i.e. IW/CPE 0.8 + silver-black mulch (1095.24 kg/ha) and T_1 i.e. IW/CPE 1.0 + black mulch (1087.30 kg/ha). These results suggest that optimum irrigation (1.0–0.8 IW/CPE) coupled with reflective polythene mulches provided a favorable balance between water availability, microclimate regulation, and reduced evaporation, thereby enhancing source–sink relationships and assimilate partitioning toward seed filling. Intermediate yields were obtained in organic mulch treatments T_3 and T_7 (1011.90 and 930.56 kg/ha, repsectively), indicating that although organic residues conserve soil moisture, they are less effective than synthetic mulches in minimizing evaporative losses. Conversely, the lowest yield (640.87 kg/ha) was obtained under IW/CPE 0.4 without mulch (T_{16}), followed by T_{15} (656.75) and T_{13} (670.63), highlighting the detrimental effect of severe water stress on photosynthate accumulation, capsule retention, and seed filling. These results align with Patel *et al*., (2007) [21], irrigation at 0.9 IW:CPE ratio is optimum for higher productivity in Coriander. Similarly, Bhunia highlighted that among the different irrigation schedules, IW/CPE ratio of 0.8 proved markedly superior, producing higher yields compared to the lower irrigation levels of 0.6 and 0.4. The better performance under frequent irrigation was attributed to improved nutrient availability in the root zone, which facilitated greater nutrient uptake and ultimately enhanced crop growth and yield. Dhaker eported that drip irrigation increased seed yield by 29.5% over surface irrigation, with the IW/CPE ratio of 1.0 being the most effective for fenugreek, as it maintained favorable soil moisture during the critical flowering and pod formation stages. Similarly, in the present investigation on Nigella, irrigation at

IW/CPE 1.0 and 0.8, particularly when combined with mulching (silver-black or black polythene), ensured optimum soil moisture availability, which promoted higher seed yield and biomass accumulation compared to lower irrigation levels (0.6 and 0.4 IW/CPE) without mulch. These findings confirm that IW/CPE 1.0–0.8 with polythene mulch, particularly silver-black, is the most effective strategy for maximizing seed yield in nigella under central Indian conditions.

The harvest index (HI) showed a similar trend to seed yield, reflecting the efficiency of biomass partitioning into economic yield. The maximum HI (33.04%) was observed under IW/CPE 1.0 + silver-black polythene mulch (T_2), which was statistically at par with T_1 (32.55%) and T_6 (32.41%), indicating that optimum irrigation combined with synthetic mulching enhanced reproductive efficiency by maintaining photosynthetic activity and extending leaf area duration. Treatments with Organic mulch under 1.0 and 0.8 IW/CPE also maintained relatively higher HI, while the lowest values were consistently associated with the lowest irrigation regime (0.4 IW/CPE), irrespective of mulching treatment, suggesting partial benefits but reduced efficiency compared to polythene mulches. In contrast, the lowest HI (26.99%) was noted in IW/CPE 0.4 without mulch (T_{16}), followed by T_{15} (27.43) and T_{13} (27.67), which may be attributed to poor assimilate partitioning into seeds under severe moisture deficit, as much of the biomass was lost to maintenance respiration rather than yield. These findings are in close agreement with studies on nigella and related spice crops. Guttierrez, P. (2017) [10] showed that the harvest index increased when the amount of water applied was higher. The combined use of optimum irrigation (IW/CPE 1.0 and 0.8) with plastic mulches, particularly silver-black mulch, not only enhanced soil moisture conservation but also improved input-use efficiency by creating a favorable micro-environment for nutrient uptake and better crop growth. Conversely, deficit irrigation (IW/CPE 0.6 and 0.4) coupled with no mulch treatment significantly reduced plant performance due to moisture stress and rapid soil water losses. These results emphasize that integrating irrigation scheduling with mulching practices can serve as a practical strategy to maximize water productivity, nutrient-use efficiency, and overall sustainability in nigella cultivation.

Table 1: Effect of irrigation levels and mulching on plant height (cm) and number of branches per plants in nigella

S. No.	Treatments	Plant Height (cm)			Number of Branches per Plants		
		45 DAS	90 DAS	At Harvest	45 DAS	90 DAS	At Harvest
T1	1.0 IW/CPE + Black Polythene mulch	17.87^{ab}	61.08^{ab}	66.30^{a}	4.95^{bc}	6.80^{bc}	7.79^{bc}
T2	1.0 IW/CPE + Silver Black Polythene mulch	18.91^{a}	61.57^{a}	66.71^{a}	5.46^{a}	7.24^{a}	8.21^{a}
T3	1.0 IW/CPE + Organic mulch	16.20^{bc}	58.86^{abc}	64.06^{ab}	4.66^{cde}	6.40^{de}	7.42^{de}
T4	1.0 IW/CPE + without mulch	13.95^{def}	56.62^{cd}	61.50^{bcd}	4.26^{fg}	6.00^{fg}	7.01^{fg}
T5	0.8 IW/CPE + Black Polythene mulch	17.63 ^{ab}	61.03 ^{ab}	66.24^{a}	4.84^{cd}	6.60^{cd}	7.59^{cd}
T6	0.8 IW/CPE + Silver Black Polythene mulch	18.36^{a}	61.35^{a}	66.56^{a}	5.20^{ab}	7.07^{ab}	7.99^{ab}
T7	0.8 IW/CPE + Organic mulch	15.55^{c}	58.21^{bc}	63.42^{abc}	4.61^{de}	6.39^{de}	7.40^{de}
T8	0.8 IW/CPE + without mulch	12.54^{efgh}	55.01^{def}	60.22^{cde}	3.86^{h}	5.60^{hi}	6.57hi
T9	0.6 IW/CPE + Black Polythene mulch	13.63 ^{efg}	56.29 ^{cde}	60.82^{bcd}	3.99^{gh}	5.81^{gh}	6.83gh
T10	0.6 IW/CPE + Silver Black Polythene mulch	13.99^{def}	56.66^{cd}	61.86^{bcd}	4.45^{ef}	6.21^{ef}	7.21ef
T11	0.6 IW/CPE + Organic mulch	12.35^{efgh}	54.89^{def}	60.10^{cde}	3.71^{hi}	5.41^{ij}	6.43ij
T12	0.6 IW/CPE + without mulch	11.24^{h}	52.37^{fg}	57.03^{ef}	2.85^{lm}	4.72^{lm}	5.38l
T13	0.4 IW/CPE + Black Polythene mulch	12.15 ^{gh}	53.53 ^{ef}	58.73^{def}	3.26^{jk}	5.04^{kl}	6.02k
T14	0.4 IW/CPE + Silver Black Polythene mulch	12.22^{gh}	54.82^{def}	60.03^{cde}	3.46^{ij}	5.19^{jk}	6.20jk
T15	0.4 IW/CPE + Organic mulch	11.79^{h}	53.35^{ef}	58.45^{def}	3.12^{kl}	4.89^{klm}	5.46l
T16	0.4 IW/CPE + without mulch	11.01^{h}	50.09^{g}	55.29^{f}	2.73^{m}	4.57^{m}	5.22l
S.Em±		0.6	1.03	1.18	0.1	0.12	0.13
C.D. (at 5%)		1.76	2.99	3.45	0.3	0.35	0.37
CV		7.29	3.14	3.32	4.42	3.57	3.22

Table 3.2: Effect of irrigation levels and mulching on leaf area index (LAI) and leaf area duration (LAD) of nigella

S. No.	Treatments	Leaf area index (LAI)			Leaf Area Duration (LAD)	
		45 DAS	90 DAS	At Harvest	45 DAS to 90 DAS	90 DAS to at Maturity
T1	1.0 IW/CPE + Black Polythene mulch	0.32^{b}	1.94^{bc}	1.85^{bc}	50.74^{bc}	56.85^{bc}
T2	1.0 IW/CPE + Silver Black Polythene mulch	0.36^{a}	2.0^{a}	1.99^{a}	53.85^{a}	60.36^{a}
T3	1.0 IW/CPE + Organic mulch	0.29^{cd}	1.85^{de}	1.76^{cd}	48.10^{d}	54.07^{de}
T4	1.0 IW/CPE + without mulch	0.25^{fg}	1.69^{g}	1.58^{ef}	43.63^{f}	49.11^{g}
T5	0.8 IW/CPE + Black Polythene mulch	0.31^{bc}	1.90^{cd}	1.80^{c}	49.66^{c}	55.47^{cd}
T6	0.8 IW/CPE + Silver Black Polythene mulch	0.35^{a}	1.97^{ab}	1.94^{ab}	52.02^{b}	58.60^{ab}
T7	0.8 IW/CPE + Organic mulch	0.28^{de}	1.79^{ef}	1.70^{d}	46.51^{e}	52.35^{ef}
T8	0.8 IW/CPE + without mulch	0.22^{h}i	1.58^{h}	1.48^{g}	40.53^{g}	45.94^{h}
T9	0.6 IW/CPE + Black Polythene mulch	0.23^{gh}	1.66^{g}	1.55^{fg}	42.59^{f}	48.19^{g}
T10	0.6 IW/CPE + Silver Black Polythene mulch	0.26^{ef}	1.77^{f}	1.67^{de}	45.72^{e}	51.54^{f}
T11	0.6 IW/CPE + Organic mulch	0.20i	1.48^{i}	1.38^{h}	37.97^{hhgh}	42.84^{i}
T12	0.6 IW/CPE + without mulch	0.14^{kl}	1.11^{k}	1.09^{i}	28.12^{k}	32.89^{k}
T13	0.4 IW/CPE + Black Polythene mulch	0.17^{i}	1.44^{i}	1.29^{h}	36.25^{i}	40.96^{i}
T14	0.4 IW/CPE + Silver Black Polythene mulch	0.18^{i}	1.44^{i}	1.32^{h}	36.42^{i}	41.42^{i}
T15	0.4 IW/CPE + Organic mulch	0.16^{jk}	1.20^{j}	1.15^{i}	30.57^{i}	35.24^{j}
T16	0.4 IW/CPE + without mulch	0.13^{l}	0.901	0.95^{j}	23.36^{l}	27.89^{l}
S.Em±		0.008	0.02	0.03	0.52	0.67
C.D. (at 5%)		0.022	0.06	0.1	1.52	1.95
CV		5.501	2.28	3.70	2.17	2.46

Table 2: Effect of irrigation levels and mulching on seed yield and harvest index in nigella

S. No.	Treatments	Seed Yield	Harvest Index
T_1	1.0 IW/CPE + Black Polythene mulch	1087.30 [b]	32.55[a]
T_2	1.0 IW/CPE + Silver Black Polythene mulch	1160.71 [a]	33.04[a]
T_3	1.0 IW/CPE + Organic mulch	1011.90 [c]	31.96[a]
T_4	1.0 IW/CPE + without mulch	934.52 [de]	31.28[abc]
T_5	0.8 IW/CPE + Black Polythene mulch	1019.84 [c]	31.94[a]
T_6	0.8 IW/CPE + Silver Black Polythene mulch	1095.24 [ab]	32.41[a]
T_7	0.8 IW/CPE + Organic mulch	930.56 [de]	31.51 [ab]
T_8	0.8 IW/CPE + without mulch	878.97 [e]	31.29[abc]
T_9	0.6 IW/CPE + Black Polythene mulch	932.54 de	31.62 [ab]
T_{10}	0.6 IW/CPE + Silver Black Polythene mulch	976.19 [cd]	31.79 [ab]
T_{11}	0.6 IW/CPE + Organic mulch	805.56 [f]	30.97[abcd]
T_{12}	0.6 IW/CPE + without mulch	757.94 [fg]	30.62 [abcde]
T_{13}	0.4 IW/CPE + Black Polythene mulch	670.63 [hi]	27.67 [cde]
T_{14}	0.4 IW/CPE + Silver Black Polythene mulch	718.25 [gh]	28.09 [bcde]
T_{15}	0.4 IW/CPE + Organic mulch	656.75 [hi]	27.43 [de]
T_{16}	0.4 IW/CPE + without mulch	640.87 [i]	26.99 [e]
S.Em±		23.01	1.29
C.D. (at 5%)		67.17	3.75
CV		4.47	7.25

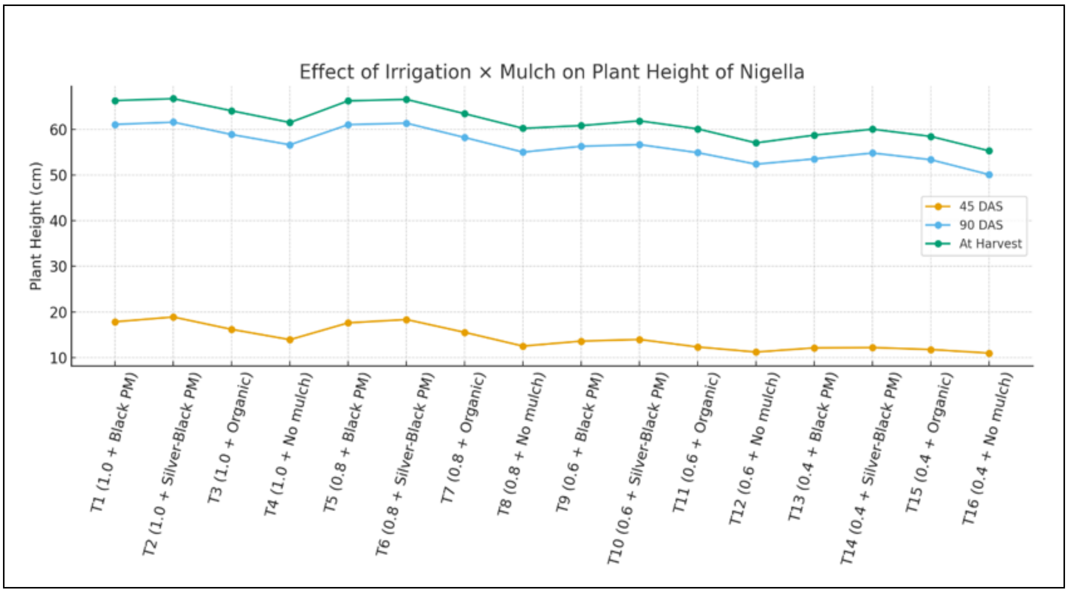

Fig 1: Plant height (cm) of nigella as influenced by irrigation levels and mulching

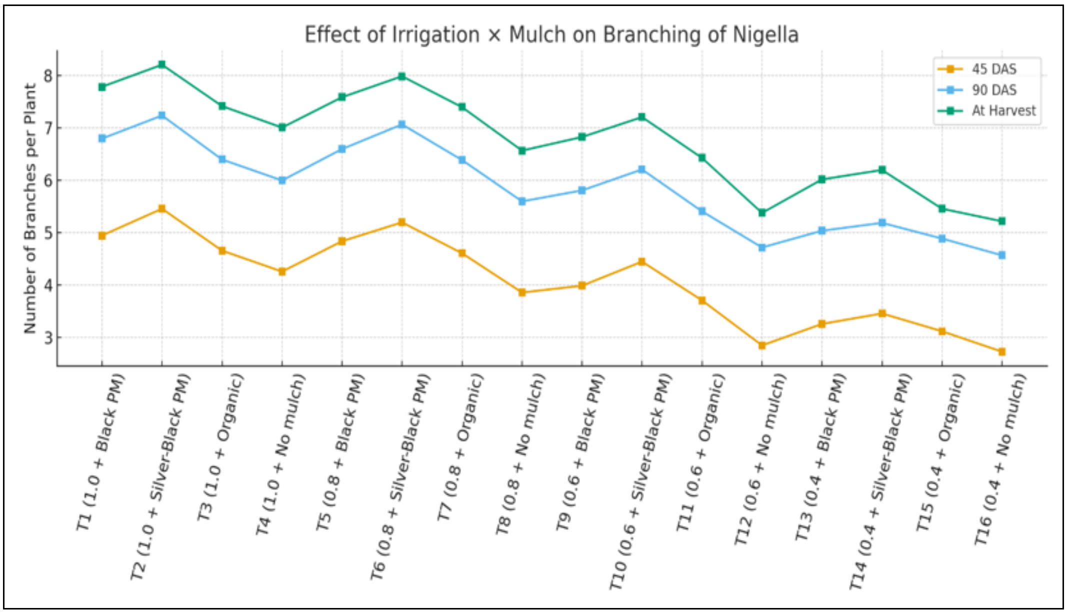

Fig 2: Number of branching per plant of nigella as influenced by irrigation levels and mulching

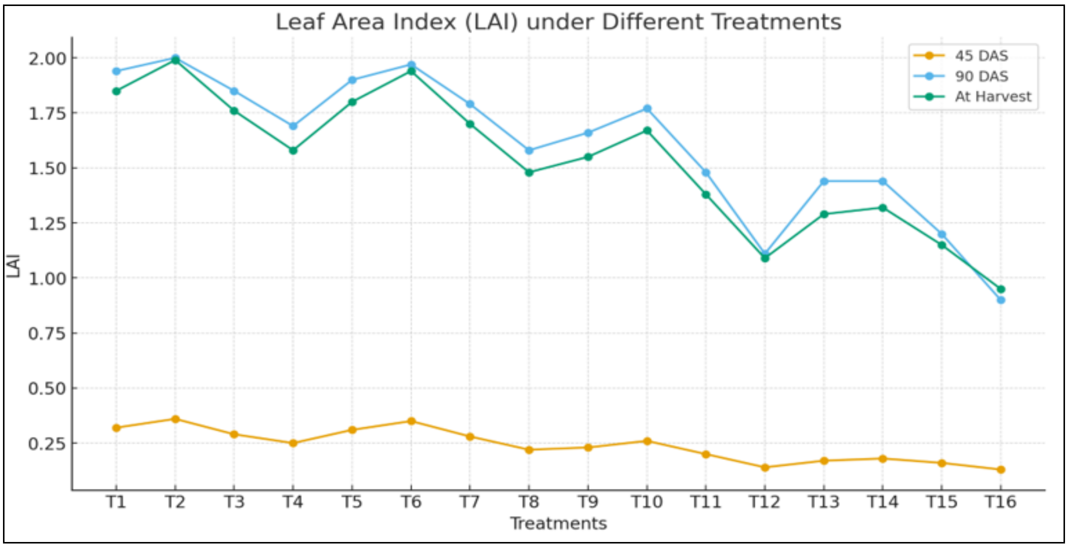

Fig 3: Leaf Area Index (LAI) of nigella as influenced by irrigation levels and mulching

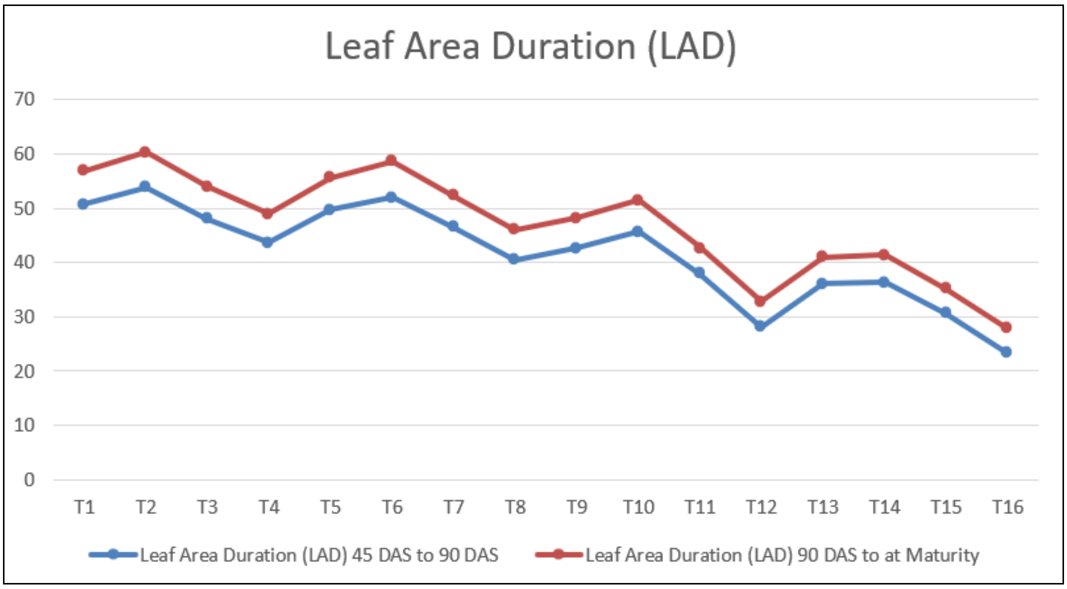

Fig 4: Leaf Area Duration (LAD) of nigella as influenced by irrigation levels and mulching

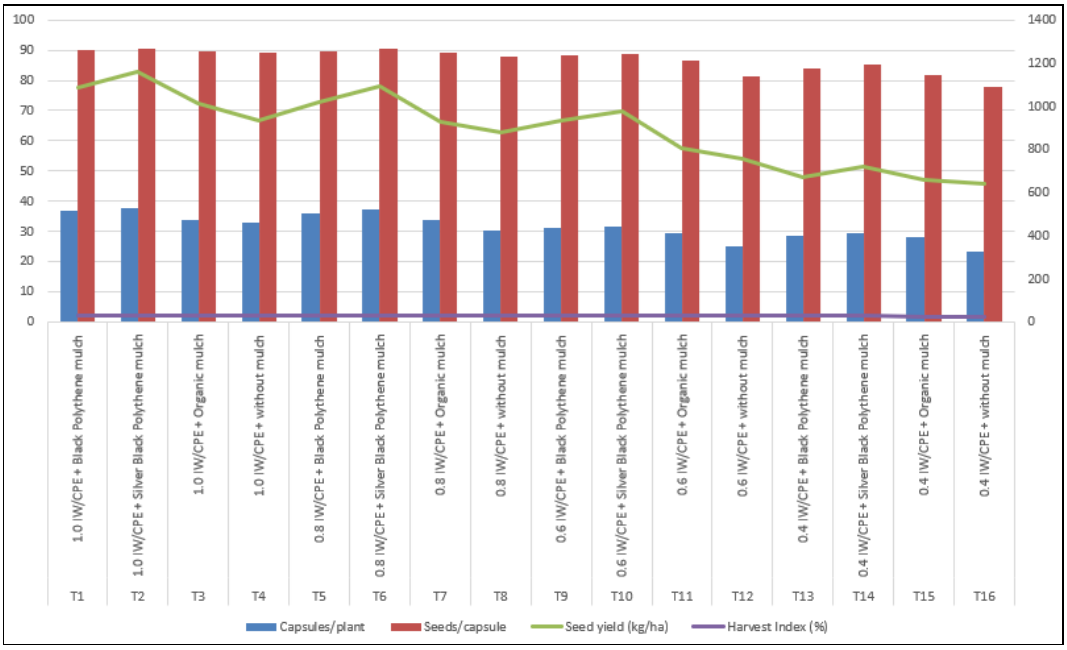

Fig 5: Effect of irrigation levels and mulching on yield attributes and yield of nigella

Conclusion

The investigation clearly demonstrated that irrigation leveling based on IW/CPE ratios in conjunction with mulching practices significantly influenced the growth, physiological traits, and yield performance of Nigella. Higher irrigation regimes (IW/CPE 1.0 and 0.8) coupled with silver-black and black polythene mulches consistently recorded superior growth indices such as leaf area index (LAI) and leaf area duration (LAD), reflecting improved photosynthetic surface and prolonged assimilatory capacity. Enhanced growth translated into greater reproductive efficiency, as evident from the higher number of capsules per plant, seeds per capsule, and ultimately seed yield. The treatment combination IW/CPE 1.0 + silver-black mulch (T_2) was most effective, producing the maximum seed yield (1160.71 kg/ha) and harvest index (33.04%), closely followed by IW/CPE 0.8 + silver-black mulch (T_6) and IW/CPE 1.0 + black mulch (T_1). In contrast, severe deficit irrigation (IW/CPE 0.4) without mulch (T_{16}) resulted in marked reductions in LAI, LAD, capsule number, seed yield (640.87 kg/ha), and harvest index (26.99%), confirming the adverse impact of moisture stress on biomass partitioning and yield formation. The results reaffirm that integrating optimum irrigation scheduling (IW/CPE 0.8–1.0) with reflective mulches enhances water use efficiency, microclimatic moderation, and assimilate allocation towards reproductive sinks, thereby ensuring sustainable yield improvement in nigella cultivation under semi-arid conditions.

References

1. Abdou NM, Roby MH, Abdulkreem A, Elkelish A, Sayed AA, Alharbi BM, *et al*. Compost Improving Morphophysiological and Biochemical Traits, Seed Yield, and Oil Quality of *Nigella sativa* under Drought Stress. Agronomy. 2023;13(4):1147. https://doi.org/10.3390/agronomy13041147
2. Bayati P, Karimmojeni H, Razmjoo J, Pucci M, Abate G, Baldwin TC, *et al*. Physiological, Biochemical, and Agronomic Trait Responses of *Nigella sativa* Genotypes to Water Stress. Horticulturae. 2022;8:193.
3. Bwire D, Watanabe F, Suzuki S, Suzuki K. Improving Irrigation Water Use Efficiency and Maximizing Vegetable Yields with Drip Irrigation and Poly-Mulching: A Climate-Smart Approach. Water. 2024;16(23):3458. https://doi.org/10.3390/w16233458
4. Demo AH, Asefa Bogale G. Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture. Front. Agron. 2024;6:1361697. https://doi.org/10.3389/fagro.2024.1361697
5. Demo AH, Asefa Bogale G. Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture. Frontiers in Agronomy. 2024;6:1361697.
6. El-Beltagi HS, Basit A, Mohamed HI, Ali I, Ullah S, Kamel EAR, *et al*. Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. Agronomy. 2022;12(8):1881. https://doi.org/10.3390/agronomy12081881
7. Ghamarnia H, Khosravy H, Sepehri S. Yield and water use efficiency of (*Nigella sativa* L.) under different irrigation treatments in a semi-arid region in the West of Iran. Journal of Medicinal Plants Research. 2010;4(16):1612-1616.
8. Gültekin R, Ertek A, Görgişen C, Yeter T, Avağ K, Yıldırım YE. Impact of intermittent and deficit irrigation practices in subsurface drip systems on yield and morphological traits of black cumin (*Nigella sativa* L.). Paddy Water Environ. 2025;23:373–388. https://doi.org/10.1007/s10333-025-01021-y
9. Gültekin R, Ertek A, Görgişen C, Yeter T, Avağ K, Yıldırım YE. Impact of intermittent and deficit irrigation practices in subsurface drip systems on yield and morphological traits of black cumin (*Nigella sativa* L.). Paddy and Water Environment. 2025;1-16.
10. Guttierrez P. Effect of different irrigation levels on yield, quality and phenology of black cumin (*Nigella sativa* L.). 2017.
11. Han M, Zhang L, Liu X. Subsurface irrigation with ceramic emitters improves wolfberry yield and economic benefits on the Tibetan Plateau, China. Journal of Arid Land. 2023;15(11):1376-1390.
12. Hendi DM, Saleh FEM, Hefzy M. Productivity and quality of *Nigella sativa* L. plant influenced by Moringa extract application under different drip irrigation levels. 2021.
13. Jayakumar M, Bosu S, Kantamaneni K, Rathnayake U, Surendran U. Drip irrigation on productivity, water use efficiency and profitability of turmeric (*Curcuma longa*) grown under mulched and non-mulched conditions. Results in Engineering. 2024;22:102018.
14. Karimi A, Baziar MR. Improving the growth and yield of black seed (*Nigella sativa* L.) by combining nitrogen and wheat straw mulch at different irrigation intervals. Journal of Agricultural Science and Sustainable Production. 2023;33(1):203-218.
15. Kirnak H, Demirtas MN. Effects of Different Irrigation Regimes and Mulches on Yield and Macronutrition Levels of Drip-Irrigated Cucumber Under Open Field Conditions. Journal of Plant Nutrition. 2006;29(9):1675–1690. https://doi.org/10.1080/01904160600851619
16. Lal Mehriya M, Geat N, Sarita, Singh H, Mattar MA, Elansary HO. Response of Drip Irrigation and Fertigation on Cumin Yield, Quality, and Water-Use Efficiency Grown under Arid Climatic Conditions. Agronomy. 2020;10(11):1711. https://doi.org/10.3390/agronomy10111711
17. Lal G, Singh R, Metha RS, Meena NK, Maheriya SP, Choudhary MK. Study on irrigation levels based on IW/CPE ratio and irrigation methods on growth and yield of Fenugreek (*Trigonella foenium graecum* L.). Legume Research-An International Journal. 2020;43(6):838-843.
18. MM ES. Evaluation the Impact of Mulch Technique and Irrigation Intervals on Coriander Plant Growth, Productivity and Volatile Oil Active Components Under Southern Valley (Toshka) Conditions. Horticulture Research Journal. 2025;3(2):44-54.
19. Ndou VT, Mabhaudhi T, Goge M, Papo T, Shozi M, Ramphinwa ML, *et al*. Plant Growth, Yield, and Quality of Bush Tea (*Athrixia phylicoides*) as Affected by Deficit Hidrico and Mulching. Plants. 2025;14(12):1743. https://doi.org/10.3390/plants14121743
20. Ozer H, Coban F, Sahin U, Ors S. Response of black cumin (*Nigella sativa* L.) to deficit irrigation in a semi-arid region: Growth, yield, quality, and water productivity. Industrial Crops and Products. 2020;144:112048. https://doi.org/10.1016/j.indcrop.2019.112048
21. Patel BS, Joshi MK, Patel JC, Patel NB. Influence of irrigation based on IW/CPE ratio and nitrogen levels on yield and water use efficiency of fennel (*Foeniculam vulgare* Mill.). Production Development, Quality and Export of Seed Spices. 2007:262-266.
22. Qiao J, Li G, Liu M, Zhang T, Wen Y, Wang J, *et al*.

Effects of Different Planting Patterns on Growth and Yield Components of Foxtail Millet. Agronomy. 2025;15(4):840. https://doi.org/10.3390/agronomy15040840

23. Şenyiğit U, Arslan M. Effects of Irrigation Programs Formed by Different Approaches on the Yield and Water Consumption of Black Cumin (*Nigella sativa* L.) under Transition Zone in the West Anatolia Conditions. Journal of Agricultural Sciences. 2018;24(1):22-32. https://doi.org/10.15832/ankutbd.446366
24. Yaghi T, Arslan A, Saeed H. Effect of Deficit Irrigation Technique on Black Cumin (*Nigella sativa* L.) Water Use Efficiency. JAST. 2024;26(2):449-461.