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Influence of hydrogel polymer and NO3-: NH4+ ratios on dill (Anethum graveolens L.) seed essential oil composition and yield

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Abstract

To evaluate the effects of hydrogel polymer levels (0, 10, 20, 30 g m^{-2}) and NO_3:NH_4 ratios (0: 100, 25: 75, 50: 50, 75: 25, and 100: 0) on dill seed yield and its essential oil constituents, an experiment was conducted in October 2012 in the experimental field of Islamic Azad University, Jiroft, Iran. Results showed that using 30 g m^{-2} hydrogel polymer with 75NO_3^-: 25 NH_4^+ ratio produced maximum seed yield and the same plus 100NO_3^-:0NH_4^+ led to a max essential oil yield. GC-MS analysis indicated that major constituents of dill seed oil were carvone, limonene, dillapiole, α-phellandrene, and trans-dihydrocarvone. The interactive effects of concurrent use of hydrogel polymer and NO3-:NH4+ ratios on the constituents were evaluated: non-use of super-absorbent polymer reduced components like α-terpinene, limonene, dillapiol, and trans-carvone, whereas its addition to such compounds as α-phellandrene, p-cymene, carvone, and trans-dihydrocarvone left a negative effect. In most cases, application of nitrate above 50% and reducing ammonium positively increased the compounds.

Keywords: Medicinal plant; Nitrogen; Nutrition; Iran; Water

1. Introduction

Since the Middle Ages, essential oils have been widely used for medicinal and cosmetic applications. Especially nowadays, they are used in pharmaceutical, sanitary, cosmetic, and agricultural and food industries (Orhan *et al*., 2013). They are volatile, natural, complex compounds and formed by aromatic plants as secondary metabolites (Bakkali *et al*., 2008). Dill (*Anethum graveolens* L.), one of these aromatic plants, is a biennial or annual herb of the parsley family (Apiaceae or Umbelliferae) coming from southwest Asia or southeast Europe and cultivated since ancient times (Wander and Bouwmeester, 1998). The dill seed contains 2.1% and 5.6% of essential oil in India and Russia, respectively (Embong *et al*., 1977; Gonzalez-Garcia *et al*., 2009; Singh, 2012). Major components of dill seed are carvone and limonene (Bakkali *et al*., 2008; Orhan *et al*., 2013). Comparing the results from the analysis of planted dill essential oil in Iran with other countries, Iranian dill essential oil rate is less, yet it has a higher quality; concerning the major components of dill, Iran has more α-phellandrene, limonene, and carvone rates (Sefidkon, 2001). Since dill essential oil compounds play a crucial role in nutrients consumption, it is necessary to provide better conditions for increasing the compounds both qualitatively and quantitatively.

The composition of the oil depends on plant size, ripeness of fruit and geographical origin (Embong *et al*., 1977; Huopalahti and Linko, 1983). In Iran, five components, namely α-phellandrene, limonene, dill ether, carvone, and

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dihydrochalcone, compose more than 95% of dill essential oils (Sefidkon, 2001). The growth of dill and its essential oil composition are affected by genetic makeup and environmental factors (Simon *et al*., 1992). The important environmental factors are the quantity of water and fertilizers (Nurzynska-Wierdak, 2013) like N (Sifola and Barbieri, 2006).

The optimization of irrigation for the production of fresh herbs and essential oils is important as water is a major component of the fresh produce and affects both mass and quality (Jones and Tardien, 1998). Deficiency in water supply reduces growth and yield due to the reduction in photosynthesis and plant biomass and in the case of aromatic plants may cause changes in the yield and composition of their essential oils (Woodhouse and Johnson, 1991; Said-Al Ahl *et al*., 2009). Also, because most areas of Iran are located in arid and semi-arid regions, it is essential to improve the utilization efficiency of water resources and fertilizer nutrients. Use of hydrogels for effective utilization of water in arid and semi-arid regions is one way to deal with water stresses; Hydrogel polymers which hold water for plant roots induce the heaviest total fresh mass and yield (El-Hady and Wanas, 2006; Han *et al*., 2013; Wu *et al*., 2008).

Hydrogel polymers are a group of new water-saving materials and soil conditioners (Bai *et al*., 2010) that can absorb and retain aqueous fluids up to several times their own weight (Foster and Keever, 1990; Han *et al*., 2013). Woodhouse and Johnson (1991) investigated the effect of hydrogel polymers on the establishment and growth of lettuce and barely. They found that using this polymer would increase available water, water use efficiency, dry matter production and water absorption in the presence of salts. Also, evidence showed that polymers can help the plants survive under drought conditions (Woodhouse and Jonhson, 1991). Huttermann *et al.* (1999) observed that use of various ratios of superabsorbent hydrogels when halfpennies were under water stress led to an exponential increase in soil water retention.

Hydrogels can also reduce irrigation water consumption and improve fertilizer retention in soil (El-Hady and Wanas, 2006) and enhancement of plant growth (Foster and Keever, 1990; Woodhouse and Jonhson, 1991). The required N content for optimum dill seed yield is 80–100 kg ha^{-1}. N used by plants plays a key role in the biosynthesis of numerous compounds which are essential oil constituents (Omer *et al*., 2005; Said-Al Ahl *et al*., 2009, Nurzynska-Wierdak, 2013). The absorbable N form significantly affects the plant essential oil constituents (Hornok, 1980). The absorbable N forms are ammonium (NH_4^+) or nitrate (NO_3^-) ions (Omer *et al*., 2005; Gonzalez-Garcia *et al*., 2009). The availability of these forms to the plant is an important environmental variable which affects plant growth. Root proliferation and overall growth rate (Abbes *et al*., 1995) and plant yields (Wang *et al*., 2009) are usually greater with a mixture of NH_4^+ and NO_3^- than with either form alone (Omer *et al*., 2005). Gonzalez-Garcia*et al* (2009) studied the effect of different NH_4^+: NO_3^- ratios (0: 100, 20: 80, 40: 60 and 100: 0) on the growth, production, and quality of chives and basil. They reported that the best results were obtained from the 0: 100 and 20: 80 ratios in chives and basil, respectively.

To our knowledge, studies on agronomic factors such as using hydrogel and NH_4^+: NO_3^- ratio on yield and essential oils of dill have not been investigated thoroughly until now. This study was performed to evaluate the effects of different levels of hydrogel and various NO_3^-: NH_4^+ ratios on yield and some of the essential oil constituents of *Anethum graveolens* L. in Jiroft, south of Kerman province in Iran.

2. Materials and Methods

2.1. Field test plots

In October 2012, a 1200 m^2 region was selected in the experimental field of Islamic Azad University of Jiroft, Iran. The region is located between 28° 32' N, 57° 32' E and 675 m above sea level, with an arid and semi-arid climate. The mean annual precipitation of the region is 175 mm, while the average relative humidity is 55-60% with a maximum temperature of 49°C and a minimum of 1°C, which can rarely be -2 °C. The factorial experiment was conducted based on randomized complete block designs with two factors and 3 replicates. Before sowing, soil physicochemical characteristics of the field were determined (Table 1). The first factor―N fertilizer― was added to the soil about 150 kg ha^{-1} at five levels of NO_3^-: NH_4^+ ratios (0: 100, 25: 75, 50: 50, 75: 25, and 100: 0) ―as potassium nitrate for nitrate and ammonium sulfate for ammonium―along with the secondary factor hydrogel―superabsorbent (A200)―at four levels (0, 10, 20 and 30 g m^{-2}). Each 20 plot per block had eight rows of 5 m in length; the distance between each row was 25 cm with 10 cm between seeds in each row. Each plot was 50 cm away from another with 1 m between replicates. Before planting, the superabsorbent polymer was placed into the 20 cm depth of the soil heavily irrigated to be swollen. To prevent the potassium influence, it was separately added with the same amount of all treatments (except for the ones that already received potassium nitrate). Sampling was taken from the middle parts of each plot, not from the margins. Harvesting of dill was performed when the seeds got a golden brown color and characteristics of the seeds were examined: seed yield (kg ha^{-1}) and essential oil content (%).

Table 1. Soil physical and chemical characteristics of the field

Depth(cm)	Soil texture (%)			Textural class	Bulk density (g/cm^3)	pH	EC (dS/m)	Organic carbon (%)	Available P (ppm)	Available K (ppm)
	sand	silt	clay							
0-20	81.6	15	3.4	Sand	1.47	8.4	0.64	0.25	11	163
20-40	80.2	14.4	5.4	Sand	1.59	8.5	0.66	0.04	3	82

Data were analyzed using Statistical Analysis System (SAS). Means were compared using Duncan multiple range test. The graphs were drawn using Excel software. A value of $P < 0.05$ was selected to represent statistical significance.

2.2. Apparatus and Analysis

The dried seeds were ground and added to water and boiled in a Clevenger-type apparatus for some hours; they were ordinarily hydro-distilled in the apparatus to extract the essential oils. After being cooled, the collected oil was measured for its volume and weight; the extracted essential oils were dried over anhydrous sodium sulfate and stored in dark bottles in a refrigerator at 4 °C until gas-liquid chromatography (GLC) analyses. The essential oil was analyzed via a Shimadzu, Japan, model GC-9A system joined to a Varian 3400 mass-spectrometer. Separations were carried out using a DB-5 capillary column (30 m × 0.25 mm i.d., 0.25µm film thicknesses). The injector and detector temperatures were maintained at 290 °C. The column temperature was initially kept at 50 °C for 5 minutes and then gradually increased to 250°C at the rate of 3°C min^{-1}. Helium was used as carrier gas at a constant flow of 1.0 ml min^{-1}. By calculating Kovats retention indices (RI) (for the identification of compounds (from retention times of n-alkanes (C6–C24) and measuring sample components, the peak point was identified. The components were identified via comparison of their mass spectra with those of NIST3.0 libraries supplied with the computer-controlling GC/MS system and published literature. The main compounds of the essential oil were identified by matching their retention times with those of the authentic samples that were injected under the same conditions. The relative percentage of each compound was calculated from the peak area corresponding to each compound. The relative percentage of the oil constituents was calculated from GC peak areas (Guenther, 1961).

3. Results and Discussion

3.1. Seed yield

Based on the results, use of hydrogel had a significant effect on the seed yield (Table 2). Maximum yield with 721.15 kg ha^{-1} was obtained from 20 g m^{-2} superabsorbent polymer and a minimum of 399.04 kg ha^{-1} from non-use of the polymer. Yield increase due to the risen polymer can be a result of increased plants available water (Woodhouse and Jonhson, 1991); water is absorbed by the polymers that increase the water retention capacity of soils (El-Hady and Wanas, 2006; Bai *et al*., 2010; Han *et al*., 2013). Polymers gradually release water and nutrients to increase the efficiency of water and fertilizer consumption as well as plant yields (Islam *et al*., 2011); this accords with El-Hady *et al.* (2006) on cucumber and El-Badea *et al.* (2011) on potato yield. Furthermore, hydrogels can reduce evapotranspiration (Islam *et al*., 2011), improve soil structure (Han *et al*., 2013), result in better respiration, soil water conservation around roots, and nutrient supplies (El-Hady *et al*., 2006) and organic matter conservation (Han *et al*., 2013). Also different ratios of NO_3^-: NH_4^+ had a significant effect on seed yield (Table 3). Maximum seed yield (840.4 kg ha^{-1}) was gained by using $50NO_3^-$: $50NH_4^+$ and the least yield (206.89 kg ha^{-1}) were related to using 100% ammonium and no consumption of nitrate.

The interaction between different levels of hydrogel polymers and ratios of nitrate to ammonium had significant influences on the seed yield (Figure 1). Use of 30 g m^{-2} hydrogel polymer and $75NO_3^-$: $25NH_4^+$ ratio led to a maximum dill seed yield of 1556.6 Kg ha^{-1}. Hydrogel polymers with negative charge surfaces raised the soil cation exchange capacity and water absorption and improved cationic nutrient material because fertilizers were not leached out. Our results accorded with Abraham and Pillai (1995) and demonstrated that the use of hydrophilic polymers caused ammonium to be less leached from the soil and thus kept in it. If the accumulation of NH_4^+ is high on hydrogel polymers, dill seed yield declines. This accumulation leaves the following effects on the plants:

1- Acidification of the soil of the rhizosphere (Tabatabaei *et al*., 2006; Gonzalez-Garcia *et al*., 2009) which leads to a decrease in photosynthesis (Tabatabaei *et al*., 2006); greater photosynthetic rates at low NH_4^+ concentrations likely originate from changes in plant water relations.

2- Increase in the antagonistic effects of the interaction between absorption and translocation of NH_4^+ and other cations (Hamlin *et al*., 1999) like Ca^{+2}, Mg^{+2}, K^+, and also P (Gonzalez-Garcia *et al*., 2009), which reduce plant growth and, consequently, plant development, as reported by Rothstein and Cregg (2005) in Fraser fir, Abbes *et al.* (1995) in onions and Tabatabaei *et al.* (2006) in strawberry.

3- Fine-root production is disturbed, problematizing water transport and plant nutrition (Rothstein and Cregg, 2005).

4- Decrease in stomata conductance (possibly due to the increased root to shoot ratios) and water uptake in a variety of plant species (Lu *et al*., 2005) and

5- Decrease in root hydraulic conductivity and elevated abscisic acid levels under NH_4^+ nutrition have also been implicated (Jeschke and Hartung, 2000).

Also, Garcia-Gonzalez *et al.* (2009) reported that the supplied N form directly influences nutrient absorption and pH of the rhizosphere. For most plant species, low quantities of NH_4^+ accompanied by a supply of NO_3^- are favorable for growth, but the response depends on the species and the age of the plant. Mengel and Kirkby (1987) reported that plant species grow better when nitrogen is supplied as NO_3^- instead of NH_4^+. They also showed that growth and production of biomass in chives decreased when NH_4^+ was used. According to their findings, some herbs like basil and Japanese mint showed different responses for the production of essential oils and oil components when fertilized with NO_3-N and NH_4-N. Zhang *et al.* (1996) indicated that ammonium was unfavorable to saponin formation (a secondary metabolite) on the ginseng cell growth.

Table 2. The effect of hydrogel polymer on seed yield, seed essential oil yield, and essential oil constituents

Hydrogel polymer	Seed yield (Kg/ha)	Seed Essential oil yield (%)	*α*-pinene	*β*-pinene	*α*-phellandrene	carvone	limonene	dillapiol	*p*-cymene	*α*-terpinene	trans carvone	trans-dihydrocarvone	dill ether
0	399.04^{d}	3.52^{b}	1.11^{a}	1.20^{a}	3.13^{a}	58.75^{b}	24.03^{c}	3.49^{c}	1.44^{b}	2.31^{b}	2.64^{d}	3.09^{b}	1.41^{ab}
10 g/ m^2	538.96^{c}	3.39^{d}	1.08^{a}	1.19^{a}	3.05^{b}	59.19^{a}	24.60^{a}	3.77^{a}	1.50^{a}	2.31^{b}	2.87^{c}	3.47^{a}	1.45^{a}
20 g/m^2	721.15^{a}	3.47^{c}	1.12^{a}	1.20^{a}	2.99^{c}	58.00^{c}	24.04^{c}	3.65^{b}	1.46^{b}	2.29^{b}	3.08^{a}	2.94^{c}	1.34^{b}
30 g/m^2	592.58^{b}	3.65^{a}	1.13^{a}	1.22^{a}	3.05^{b}	57.91^{c}	24.39^{b}	3.66^{b}	1.43^{b}	2.49^{a}	2.92^{b}	3.09^{b}	1.42^{ab}

Within each column, means followed by the same letters are not significantly different at 5% level

Table 3. The effect of NO_3:NH_4 on seed yield, seed essential oil yield, and essential oil constituents

NO_3:NH_4	Seed yield (Kg/ha)	Seed Essential oil yield(%)	*α*-pinene	*β*-pinene	*α*-phellandrene	carvone	limonene	dillapiol	*p*-cymene	*α*-terpinene	Trans carvone	trans-dihydro carvone	dill ether
100:0	573.34^{c}	4.54^{a}	1.17^{a}	1.22^{a}	3.08^{b}	58.73^{b}	24.64^{b}	3.51^{e}	1.42^{bc}	2.37^{b}	3.17^{b}	3.58^{b}	1.39^{b}
75:25	830.40^{b}	4.99^{b}	1.10^{a}	1.19^{ab}	3.19^{a}	59.03^{ab}	24.11^{c}	3.54^{d}	1.50^{a}	2.29^{c}	2.81^{d}	3.99^{a}	1.35^{b}
50:50	840.40^{a}	3.51^{c}	1.11^{a}	1.18^{b}	3.02^{c}	59.09^{a}	24.90^{a}	3.86^{a}	1.50^{a}	2.29^{c}	2.95^{c}	3.28^{d}	1.55^{a}
25:75	363.41^{d}	3.00^{d}	1.08^{a}	1.19^{ab}	2.97^{d}	58.7^{b}	23.84^{d}	3.69^{b}	1.40^{c}	2.51^{a}	2.21^{e}	3.41^{c}	1.36^{b}
0:100	206.89^{e}	2.49^{e}	1.09^{a}	1.21^{ab}	3.02^{c}	57.71^{c}	23.84^{d}	3.60^{c}	1.43^{b}	2.30^{c}	3.24^{a}	1.50^{e}	1.37^{b}

Within each column, means followed by the same letters are not significantly different at 5% level

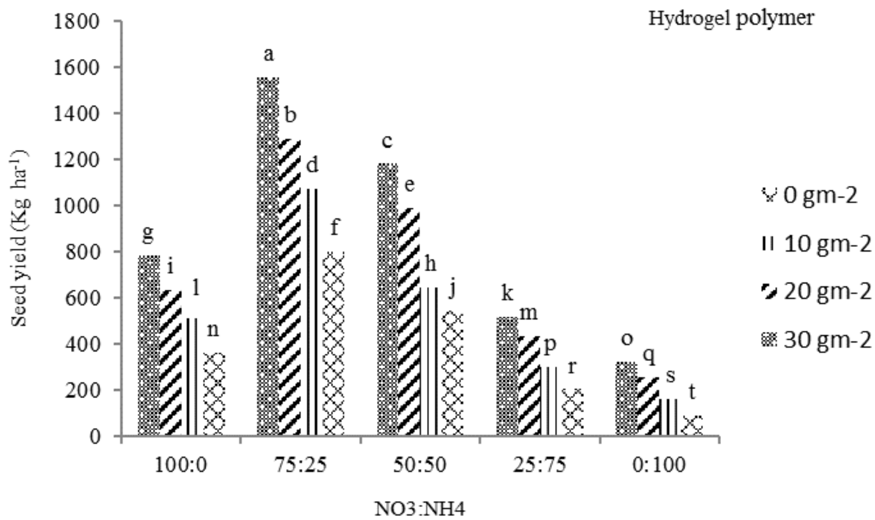

Fig. 1. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on dill seed yield

3.2. Essential oil percentage

In the present study, a supply of 30 g m^{-2} polymer led to a maximum yield of 3.65% and with 10 g m^{-2}, the minimum rate was 3.39% for dill seed essential oil (Table 2). Also different ratios of NO_3^-: NH_4^+ had a significant effect on essential oil percentage (Table 3). Maximum essential oil percentage (4.54) was gained by using 100% nitrate and no consumption of ammonium.

Due to the rise in the nitrate consumption as a result of the growth and the increase in the seed yield, the essence increases accordingly.

In addition, the interactive effect of the simultaneous use of various nitrate to ammonium ratios and superabsorbent polymers considerably affected the dill seed essential oil (Figure 2). The highest rate for the essential oil (4.74%) came from 100% nitrate without ammonium application and 30 g m^{-2} superabsorbent; the lowest rate (2.36%) originated from 100% ammonium without nitrate application and 10 g m^{-2} superabsorbent (Figure 1). Such essential oil yields are possibly affected by dill seed yield (the reasons were mentioned previously). Increase in the dill seed essential oil is a result of the rise in nitrate and hydrogel due to rise in seed yield. Our results agreed with Singh *et al.* (1987) findings on dill and Saeid-Al Ahl *et al.* (2009) on anise, indicating that water deficiency has reduced the essential oil yield of these plants.

3.3. Essential oil constituents

In our study, use of superabsorbent polymers had a considerable bearing on dill essential oil constituents. Maximum rates for carvone (59.19%), limonene (24.6%), dill apiol (3.77%), trans-dihydrocarvone (3.47%), p-cymene (1.50%) and dill ether (1.45%) came from 10 g m^{-2} superabsorbent polymer, whereas maximum rates for α-terpinene (2.49%), trans-carvone (3.08%), and α-phellandrene (3.13%) were respectively obtained from 30, 20 g m^{-2} and non-use of polymer (Table 2). The assumption is that the formation and accumulation of some compounds like limonene and carvone in plants, similar to Forouzandeh *et al.* (2012) on basil, increase under arid environmental conditions (Simon *et al*., 1992; Vineeta *et al*., 2013). Moreover, polymer application did not significantly affect α- and β-pinene (Table 2).

Using different ratios of nitrate to ammonium did not have any significant effect on α- pinene. The highest β-pinene (1.22%) was obtained from the use of 100% nitrate and lack of ammonium use. The ratio of $75NO_3^-$: $25NH_4^+$ resulted in the highest α-phellandrene (3.19%) and trans-dihydrocarvone (3.99%) and the ratio of $50NO_3^-$: $50NH_4^+$ resulted in the highest rate of limonene (24.90%), dill apiol (3.86%), carvone (59.09%), dill ether (1.55%) and *p*-cymene (1.50%). Furthermore, lack of nitrate use and 100% ammonium led to the highest rate of trans-carvone (3.24%). The maximum rate of α-terpinene (2.51%) resulted from $25NO_3^-$: $75NH_4^+$ (Table 3).

The interactive effect of the simultaneous use of various nitrate to ammonium ratios and superabsorbent polymers considerably affected most of the compounds. Maximum rates for α-phellandrene (3.5%) and limonene (26%) was achieved by applying $50NO_3^-$: $50NH_4^+$ and non-use of superabsorbent polymer (Figures 3 and 4). The highest rates for carvone (60.93%), trans-dihydrocarvone (4.83%), and p-cymene (1.60%) from $75NO_3^-:25NH_4^+$ ratio respectively resulted from non-use, 30 20 g m^{-2} of polymer (Figures 5, 6 and 7). Using 100% nitrate with non-use of ammonium, maximum rates for dill apiol (3.94%) and trans-carvone (3.91%) were obtained from 10 g m^{-2} and non-use of polymer, respectively (Figures 8 and 9). Furthermore, the highest rate for α-terpinene (2.76%) was gained via combining 25% nitrate, 75% ammonium, and 30 g m^{-2} polymer (Figure 10). The interactive effects on α- and β-pinene, dill ether were not significant. In other words, increase or decline in the hydrogel, ammonium, and nitrate had no effect on these constituents. Researches including Lee *et al.* (2005) have had reports on the reduction of terpenes (compounds similar to limonene) concentrations due to the increased fertilizers consumed; with nutrient deficiency, terpene rises in rate, but with increased N its concentration declines. In general, terpene concentration and composition responses to changes in fertility depend on plant species, growth stages, and environmental conditions.

The reason why in this study use of a nitrate-contained fertilizer better affects most of the essential oil compounds than ammonium is debatable. Concerning the reasons, with additional rates of ammonium and hydrogel in the soil, as hydrogel has negative charges, it absorbs a great deal of ammonium. This way, other required cations for the plant become leached out and unavailable to it (ammonium and cations affect one another antagonistically). Calcium is one leached-out element that has a positive influence on the constituents.

Lee *et al.* (2005) reported that Mg^{+2} is known as a co-factor in tobacco terpenes biosynthesis; or in basil, calcium is highly related to herbal oils but nitrate does not have such antagonistic effects. For instance, because limonene is an intermediate compound in the biosynthesis of carvone and the di-hydrogenase enzyme (that converts limonene to trans-carveol and then to carvone) needs a high pH, and some compounds like carvone are oxygenated ones, therefore, use of nitrate (as an oxygenated compound) raises pH, and its use has a more positive influence on the carvone rate of the plant more than that of ammonium. Results from the experiments on dill seeds indicated that carvone, limonene, dillapiol, α-phellandrene, and trans-dihydrocarvone constituted approximately 90% of the seed essential oil compounds, which agreed with Embong *et al.* (1977) and Sefidkon (2001).

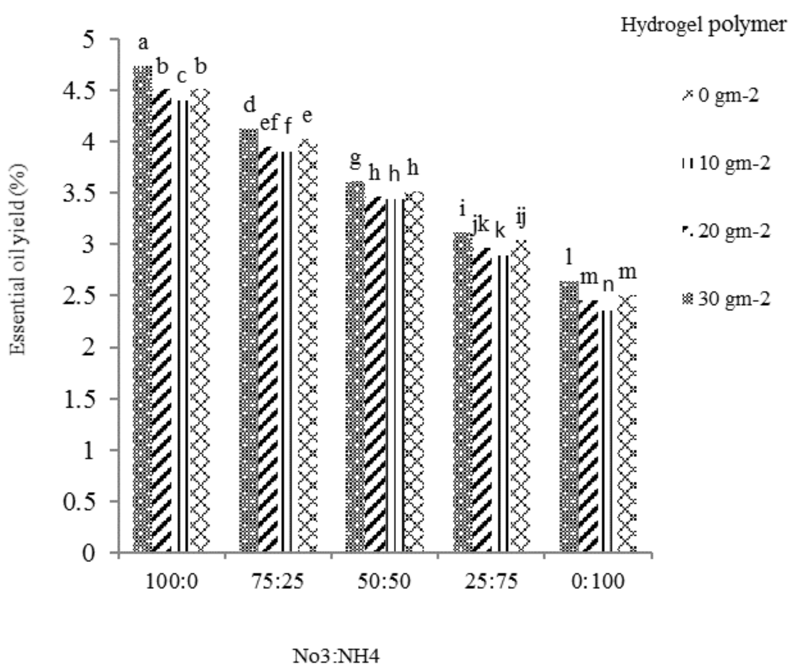

Fig. 2. Interaction effect of hydrogel polymer and $NO_3^-:NH_4^+$ ratio on dill essential oil percentage

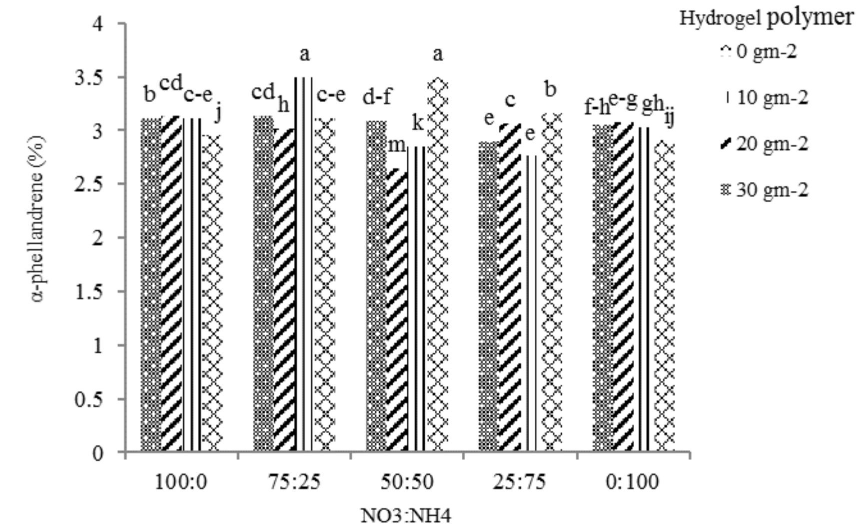

Fig. 3. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on *α*-phellandrene percentage

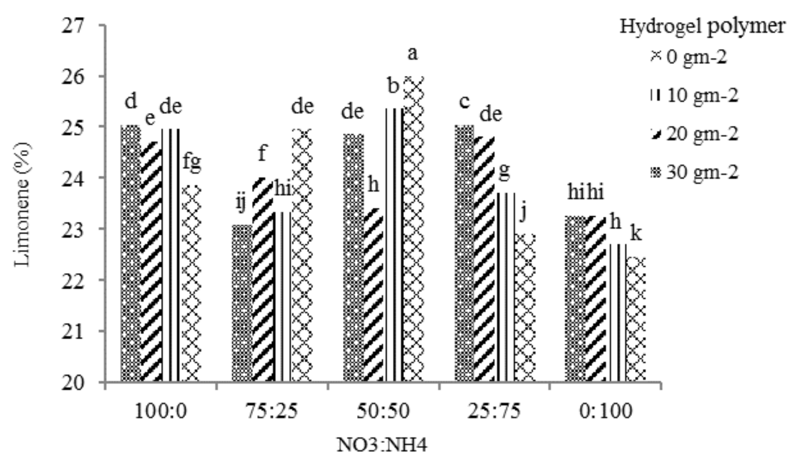

Fig. 4. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on limonene percentage

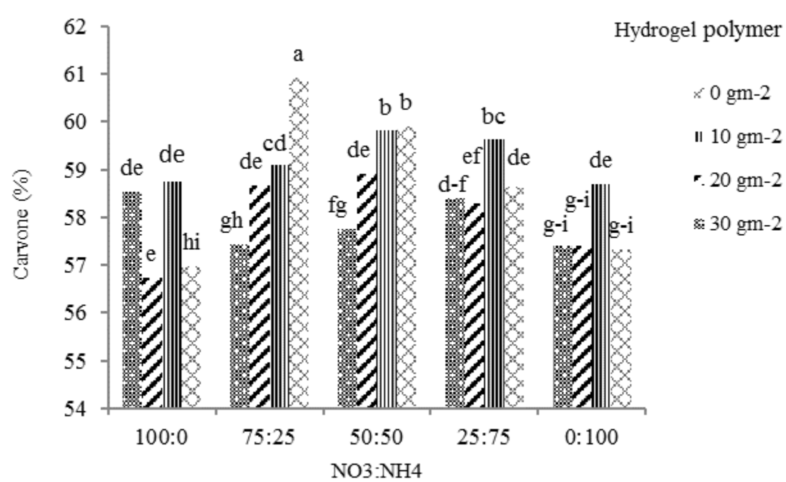

Fig. 5. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on carvone percentage

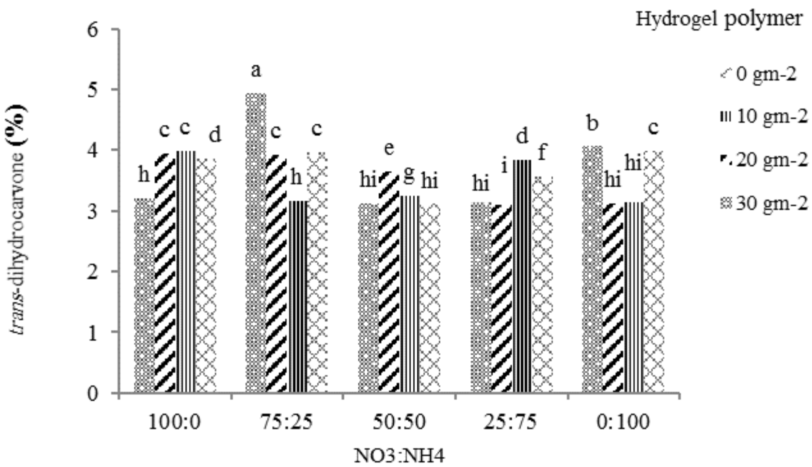

Fig. 6. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on trans-diydrocarvone percentage

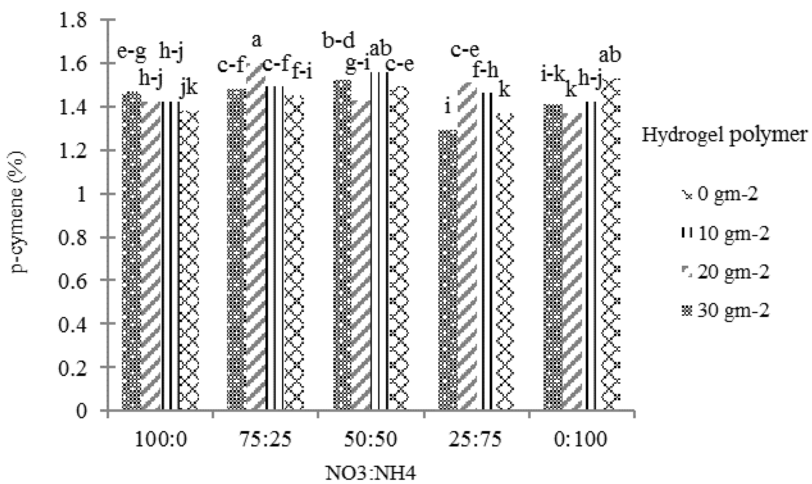

Fig. 7. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on *p*-cymene percentage

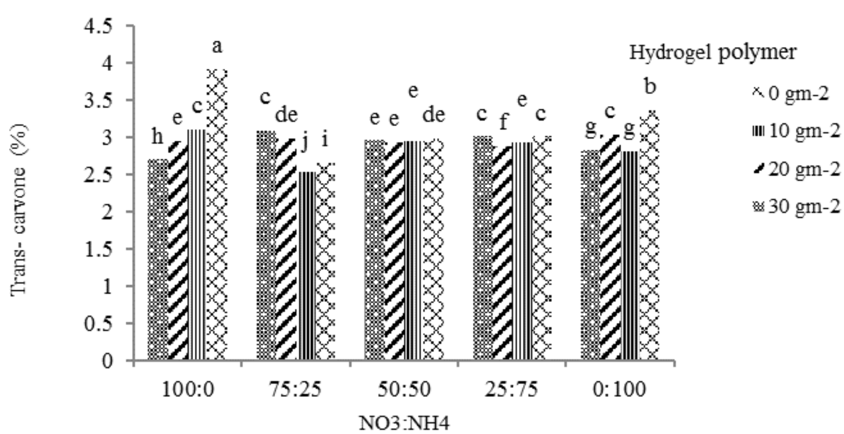

Fig. 8. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on dill apiol percentage

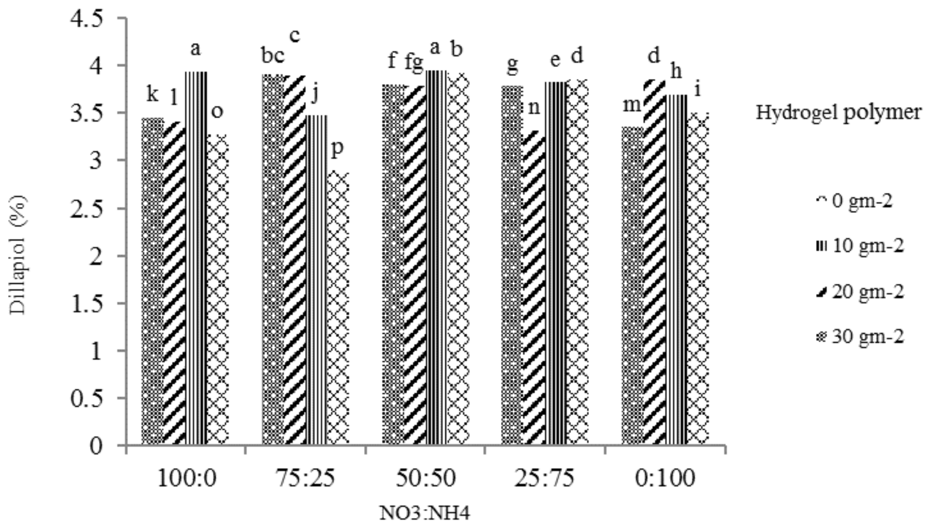

Fig. 9. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on trans-carvone percentage

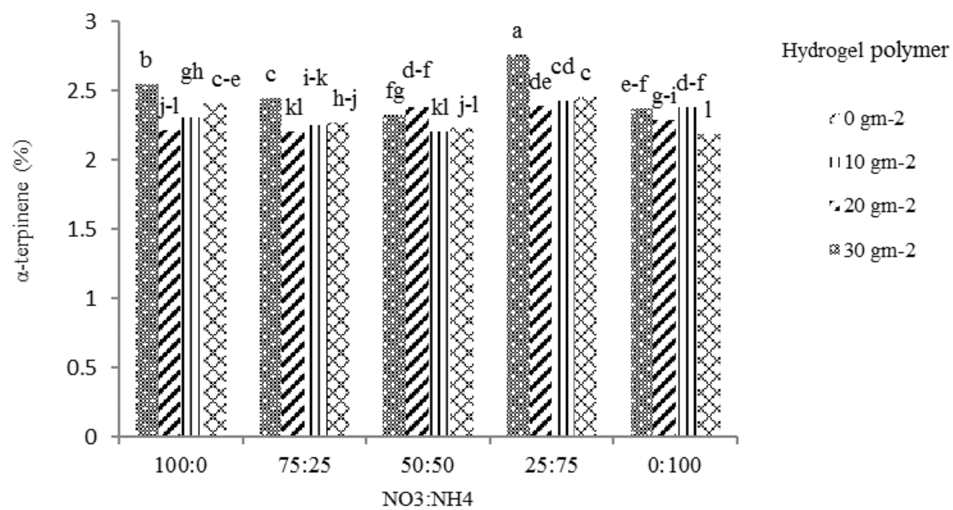

Fig. 10. Interaction effect of hydrogel polymer and NO_3^-:NH_4^+ ratio on *α* –terpinen percentage

4. Conlusion

Based on our results, generally, the highest dill seed yield was obtained from $75NO_3^-$: $25NH_4^+$ and 30 g m^{-2} polymer consumption. Maximum dill essential oil percentage was also achieved by 100% nitrate and non-use of ammonium accompanied by 30 g m^{-2} of superabsorbent (Figure 1, Tables 2, 3). The evaluation of the interactive effects of the concurrent application of N forms and hydrogel polymer on dill essential oil compounds showed that use of the superabsorbent polymer raised α-terpinene, limonene, dillapiol, and trans-carvone, whereas adding this polymer to α-phellandrene, p-cymene, carvone and trans-dihydrocarvone affected the essential oil composition negatively. Also, applying more than 50% nitrate and reducing ammonium in most of the compounds raised them positively. Carvone, limonene, dillapiol, trans-dihydrocarvone, and α-phellandrene composed about 90% of the common essential oil compounds of the seeds under test (Figures 3 to 10 and Table 2, 3).

High rates of superabsorbent can increase the available water for the plant which is absorbed by polymers at irrigation and gradually released, leading to an increase in its efficiency and yield. The rise of available water and nutrient conservation capacity, reduction of their leaching out, respiration enhancement, the appropriate and rapid growth of the roots, and finally an increase in yield are all driven by the superabsorbent. The superabsorbent has no nutritional role in soil, and plant growth after using polymer is a result of improvement in the soil's physical conditions. The water-soluble compounds with a low molecular weight (like nutrients) can be absorbed by the superabsorbent and gradually release to be assimilated by the roots. Thus, applying this matter in water-deficient areas can raise yield and reduce negative effects of the drought stress. When the only fertilizer source for the soil is ammonium-type, the photosynthetic materials made in the aerial organs produce amino acids of low molecular weights and their accumulation suppresses photosynthesis. Nitrate is the most common fertilizer source for plantation, and it is considered superior in its inducing better plant growth, even if other sources are available with appropriate ratios. The high NH_4 concentration in the soil induces ammonium toxicity due to ambient acidification, which affects the assimilation status of other minerals and brings about the shortage of nutrients.

Our results indicated that lack of ammonium or its extreme rate is not appropriate for dill growth and yield. Moreover, the significance of the interactive effect of nitrate to ammonium ratio and super-absorbent polymer on dill seed yield and yield components signifies the super-absorbent role in absorbing and conserving water for the plant, leading to an increase in dill yield and yield components.

Nevertheless, excessive fertilizer consumption has negative influences on the environment; for instance, nitrate that is leached out from the soil enters the underground waters and pollutes them. Therefore, it is recommended that biofertilizers or a mixture of organic and inorganic fertilizers be used instead of chemical N ones.

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