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Effect of different water regimes and nitrogen applications on the growth, yield, essential oil content, and quality parameters of the oil rose (*Rosa damascena* Mill.)

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ABSTRACT

Oil rose (*Rosa damascena* Mill.) is a great important aromatic and medicinal plant widely used in cosmetics, food processing, pharmaceuticals, and agrochemical industries. Water supply and nutrition are vital for plant growth and yield. Water stress causes plant growth, development, and yield loss at different levels. This study was conducted to investigate the effect of different water and nitrogen levels (N) on growth, yield, and quality parameters and determine the chemical composition of oil rose through gas chromatography coupled with mass spectrometry (GC/MS) analysis. The fieldwork for this research was conducted from March 2014 to June 2018. According to the results of study treatments, the highest fresh flower yield per plant was determined with the $I_{0.50}$, 80 kg ha^{-1} treatment. In 2017 and 2018, as fertilizer level increased and irrigation level decreased, fresh flower yield, oil yield per plant, plant height, number of branches in plant, and leaf area values decreased. However, there was little tradeoff between reductions in applied water and fresh flower yield. Furthermore, the GC-MS results reveal little change in essential oil quality as water stress increases with diminished applied water. The yield response and essential oil quality are the direct result of the relatively invariant WUE.

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chemical composition; essential oil; Kırsehir; *Rosa damascena* Mill; water stress; yield components

Introduction

Oil rose (*Rosa damascena* Mill.) is an ornamental plant in parks, gardens, and houses, and beside a valuable plant due to the usage of important oil components in cosmetics, food processing, pharmaceuticals, agrochemical industries (Baydar et al. 2007; Ginova, Tsvetkov, and Kondakova 2012). However, oil rose is mainly known for its perfuming effects (Boskabady et al. 2011).

Rose oil accounts for the majority of the essential oil production in Turkey. According to 2010 statistics, approximately 10.4 million dollars' worth of rose oil has been exported. A significant part of the export is made to European Union countries (Kart, Murat, and Vecdi 2012). The main areas of rose cultivation in Turkey are in Isparta, Burdur, Afyon, and Denizli. Oil rose is grown in Turkey for preparing rose water, essential oil, and other rose products including hydrosol, absolute, ethanolic, aqueous, and chloroformic extractions from flowers, petals, and hips (seed-pot). Essential rose oil of this plant is one of the most expensive ones in the world markets

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due to its low oil content in oil rose and the deficiency of natural and synthetic substituents (Boskabady et al. 2011; Baydar and Baydar 2005).

Water supply and nutrition are vital for plant growth and yield of medicinal and aromatic plants. Today, many parts of the world are affected by water scarcity. Especially in arid and semi-arid regions, recycling of water and increasing water use efficiency (WUE) are among the possible strategies to overcome shortage of freshwater resources. The lack of water during the plant growth and development affects at different levels, such as physiological, biochemical, and developmental processes.

Nitrogen (N) fertilization has a significant effect on the quantity, quality, and components of essential oil. In general, N practices enhance oil yield in aromatic plants by increasing rate of photosynthetic, yield of plant biomass, and leaf area (Ram, Ram, and Singh 1995; Menghini et al. 1998; Rao 2001; Sifola and Barbieri 2006; Sangwan et al. 2001). Also, in aromatic plants, the content of essential oils and their compounds varied with the various factors, such as plant's genetic makeup (Muzika, Pregitzer, and Hanover 1989) and cultivation procedures such climate, habitat, harvesting season, water scarcity, and fertilizer (Min, Tawaha, and Lee 2005; Stutte 2006; Said-Al Ahl et al. 2009).

Earlier, many reports by different authors were reviewed on the quality and composition of rose oil (Kazaz and Kelen 1999; Aydinli and Tutas 2003, Aycı et al. 2005; Kazaz, Erbas, and Baydar 2009; Loghmani-Khouzani, Sabzi Fini, and Safari 2007; Kazaz et al. 2010, Dobreva and Kovacheva 2010; Baydar and Baydar 2005; Baydar et al. 2008a, 2008b; Verma, Padalia, and Chauhan 2011). However, studies on the physiology, morphology, and agronomic applications on yield and essential oil plants have not been sufficiently investigated. Water stress causes plant growth, development, and especially yield loss. Plant responses to water stress vary at different levels. Considering this, essential oil yield and quality attributes especially under environmental stress is an important research need. Thus, this study was conducted to investigate the effect of different water and N levels on growth, yield, and quality parameters and determine the chemical composition of oil rose through GC/MS analysis.

Materials and methods

Plant material, planting, and experimental design

The most common features of *Rose damascena* plant species are perennial erect shrub, climbing, or trailing. The flowers are pink, multi layered and strongly fragrant and usually bloom in spring. In this study, seedling of the oil rose was planted on 27 March 2014. This study was conducted in field experiments at the Agricultural Faculty of University of Kirsehir Ahi Evran for five years from 2014 to 2018 (39°10′N latitude, 34°22′ longitude, and 1136 m altitude).

The experimental design was arranged in split plots as a randomized block with three replications. Trial was formed from a total of $9 \times 3 = 27$ parcels with a parcel size of $4.5\,m^2$ (9 m × 0.5 m) made up of 0.5 m intra-row spacing and 2 m row spacing and 2 m block distances. Each block consisted of three plots of 9 m long and 0.5 m wide. There was a buffer strip of 2 m between two adjacent blocks. Spacing between adjacent rows was 2 m, and plants in a row were planted 0.50 m apart. Study treatments consisted of three different irrigation levels (I_1, I_2, and I_3) or three plant-pan coefficients (Kcp1: 0.5; Kcp2: 0.75, and Kcp3: 1.00) were adjusted according to the class-A pan evaporation using, and three different fertilizes levels (N_1: 80 kg ha^{-1} (0.036 kg 4.5 m^{-2}), N_2: 120 kg ha^{-1} (0.054 kg 4.5 m^{-2}), and N_3:160 kg ha^{-1} (0.072 kg 4.5 m^{-2}). Irrigation levels were dependent on plant-pan coefficients. Thus, irrigation treatments were defined as $I_{0.50}$, $I_{0.75}$, and $I_{1.00}$. Irrigation was applied every 7 d.

Table 1. The monthly mean meteorological data of the 2014–2018 growing seasons and the long years in the experimental region.

Climatic factors	Year	Months						
		March	April	May	June	July	August	September
Highest recorded temperature (°C)	2014	21.1	27.2	30.4	34.4	36.5	38.2	35.9
	2015	23.6	24.4	32.2	28.3	36.8	36.3	36.0
	2016	24.5	28.3	28.1	36.2	36.7	36.8	33.6
	2017	20.1	27.3	30.2	35.0	38.3	37.5	37.8
	2018	24.8	27.4	29.3	34.8	37.1	36.4	34.5
	Average[a]	20.7	25.2	28.7	32.6	35.5	35.3	32.1
Lowest recorded temperature (°C)	2014	−6.4	−2.9	5.9	10.3	13.8	14.6	5.2
	2015	−4.7	−3.0	2.2	8.4	11.7	9.8	11.0
	2016	−7.0	−0.3	4.6	6.8	11.9	13.4	3.8
	2017	−4.1	−1.5	3.7	8.8	12.9	14.0	7.7
	2018	−3.4	−0.6	6.3	10.7	13.9	13.0	7.5
	Average[a]	−7.5	−1.9	3.1	7.3	11.1	10.9	5.4
Mean monthly temperature (°C)	2014	7.4	13.2	16.3	19.9	25.5	25.9	19.9
	2015	7.0	8.8	16.0	18.4	23.0	24.8	23.0
	2016	7.1	13.8	14.9	21.0	24.2	25.7	18.4
	2017	7.3	10.7	15.2	20.7	26.0	25.6	23.1
	2018	9.7	14.0	17.3	21.5	25.2	25.0	20.2
	Average[a]	5.6	10.8	15.3	19.5	23.1	23.0	18.6
Mean monthly relative humidity (%)	2014	64.4	54.8	61.3	54.1	39.2	39.7	50.9
	2015	76.2	66.2	58.1	66.9	47.0	47.5	40.8
	2016	60.7	47.4	63.7	53.0	42.5	43.8	48.2
	2017	60.8	52.4	59.4	54.3	36.0	43.2	31.7
	2018	66.2	49.1	64.8	53.4	43.0	39.2	45.9
	Average[a]	67.9	63.6	61.5	55.0	48.3	48.4	52.6
Total monthly precipitation (mm)	2014	56.0	23.2	46.6	36.0	13.4	17.0	30.8
	2015	87.8	26.4	27.4	141.1	20.3	12.8	1.8
	2016	44.8	24.0	98.2	18.5	5.8	0.2	42.7
	2017	41.5	29.0	49.9	18.4	0.4	16.0	0.0
	2018	87.7	4.4	69.5	26.5	3.5	3.2	1.2
	Average[a]	38.5	44.3	45.4	35.4	7.0	5.4	12.7

[a]Includes long years average (1960–2018) values; Source: Kirsehir Meteorological Station Climate Data, 2018.

Climatic conditions of the research area, soil physical, and chemical characteristics

The location (Kirsehir) represents the semi-arid and mid-continental climate feature in Mid-Anatolia Region Kirsehir of Turkey and endowed with hot summers, cold winters, and low in precipitation. The annual average annual temperature is 11.3 °C and the annual precipitation ranges from 250 to 500 mm and averages 383.3 mm (less than 400 mm). During the four-year flowering period of oil rose in May minimum temperature ranged from 2.2 to 6.3 °C, and maximum temperature ranges from 28.1 to 32.2 °C, relative humidity varies from 58.1 to 64.8% and rainfall was in between 27.4 and 98.2 mm; in June minimum temperature ranged from 6.8 to 10.7 °C, and maximum temperature ranges from 28.3 to 36.2 °C, relative humidity varies from 53.0 to 66.9% and rainfall was in between 18.5 and 146.1 mm Meteorological data were recorded at Kirsehir Meteorology Station, approximately 3 km from the experiment field (Table 1).

Physico-chemical properties of the soil were: clay loam, pH (7.45–7.75), electrical conductivity (EC) (0.56–1.64 dS m^{-1}), and available P and K were 16.9–48.3 and 281.3–657.2 kg ha^{-1}, respectively (Table 2).

Agricultural practices

According to soil analysis results, ammonium sulfate (21% N) fertilizer (15 kg per ha) was given with the planting of seedlings on 27 March 2014. Later, Lombrico organic fertilizer (0.405 L 202.25 m^2) was given together with irrigation water between 17 July and 17 August 2014 and 15 July and 15 August 2015. Pruning was done regularly every March from 2015 to 2018. The

Table 2. Physico-chemical characteristics of the experiment soil.

Physico characteristics							
Depth (cm)	Distribution of particles (%)			Structure	Field Capacity (mass%)	Wilting Point (mass%)	Soil bulk density (g cm^{-3})
	Sand	Silt	Clay				
0–30	41.7	23.6	34.7	Clay loam	30.39	14.13	1.29
30–60	41.8	18.2	40.0	Clay loam	32.42	16.85	1.27
60–90	41.1	15.6	43.3	Clay loam	39.95	21.16	1.20
Chemical characteristics							
Depth (cm)	pH		EC (dS m^{-1})	Lime (%)	Available nutrients (kg ha^{-1})		Organic matter (%)
					P_2O_5	K_2O	
0–30	7.75		0.56	31.01	48.3	657.2	0.78
30–60	7.46		1.64	31.16	16.9	281.3	0.69
60–90	7.45		1.34	34.00	24.1	281.3	0.39

different fertilizer levels (N_1: 80 kg ha^{-1}, N_2: 120 kg ha^{-1}, and N_3:160 kg ha^{-1}) planned in the study were given together with irrigation water in the middle of July and August in 2016 and 2017. All other agriculture practices (pests of plants, weed cleaning, pruning, hoeing, etc.) were done during the growing season, if needed.

Irrigation and ET

Seedlings of oil rose were planted on 27 March 2014. Plants were allowed to grow for the first two years until uniform growth was attained. Thus, irrigation treatments were started on 22–24 June and ended on 8–12 September during the first 4 years of 2014, 2015, 2016, and 2017 and after 1 year of regrowth harvesting was done on 22 May–June 2015, 12 May–June 2016, 27 May–June 2017, and 03 May–31 May 2018 (Tables 3a and 3b). However, the data of all parameters examined in our research were collected in the third to the fifth years of experiment (2016–2018).

A nearby well supplied irrigation water. The water was classified as C3S1with a low sodium risk and a high electrical conductance United States Salinity Laboratory (USSL 1954). The 16 mm diameter lateral pipes carrying 4 L h^{-1} water had inline drippers with 20 cm spacing. Soil water contents were measured by the gravimetric method from the soil samples taken from soil depths at 30–60 and 90 cm increments in each plot at planting seedlings, pre-irrigations, and at the final irrigation date. Experimental plots were irrigated by precipitation at the beginning for a uniform plant establishment. The seedlings of oil rose were irrigated by drip irrigation for a soil profile of 0–90 cm to field capacity. Subsequent irrigations were applied according to the prescribed irrigation rate sat 7-d intervals. Irrigation scheduling methods based on pan evaporation are widely used because of their easy applications (Elliades 1988). Cumulative evaporation between the irrigations was measured with a class-A pan located near the plots.

Irrigation water volume was calculated, class-A pan evaporation, using Eq. (1) as described by Doorenbos and Pruitt (1977) and Ertek et al. (2012), where I : the volume of irrigation water applied (L), E_{pan} : the cumulative evaporation at class-A pan in the irrigation intervals (mm), K_{cp} : the plant-pan coefficient, and A: the plot area (m^2). Thus, treatments occurred from three different irrigation levels ($I_1 = E_{\text{pan}} \times K_{\text{cp1}}$, $I_2 = E_{\text{pan}} \times K_{\text{cp2}}$, and $I_3 = E_{\text{pan}} \times K_{\text{cp3}}$).

$$I = E_{\text{pan}} \cdot K_{\text{cp}} \cdot A \tag{1}$$

Soil water was measured throughout the crop growth season. The soil water content, up to the 90 cm depth in 30 cm increments, was measured gravimetrically (oven-dry basis) at seedling planting, pre-irrigation, and at final harvest. Evapotranspiration (ET) was calculated for each treatment by the water balance method (Eq. (2)) (James 1988), where, ET: the evapotranspiration (mm), I: the irrigation water (mm), P: the precipitation (mm), Cr: the capillary rise (mm), Dp: the water loss by deep percolation (mm), Rf: the surface run-off (mm), and Ds: the change in profile soil water content (mm).

Table 3a. Amounts of irrigation water applied to treatments in the first and second experiment year.

Irrigation dates	Irrigation water (mm)	Irrigation dates	Irrigation water (mm)
04.07.2014	92.09[a]	14.07.2015	115.25[a]
11.07.2014	20	22.07.2015	49
18.07.2014	16	29.07.2015	30
24.07.2014	40	05.08.2015	76
31.07.2014	35	13.08.2015	43
07.08.2014	38	20.08.2015	50
14.08.2014	57	27.08.2015	34
21.08.2014	57	03.09.2015	49
28.08.2014	22	10.09.2015	30
04.09.2014	51	–	–
11.09.2014	35	–	–
Total irrigation, mm	463.90	Total irrigation, mm	476.25
Total ET, mm	631.39	Total ET, mm	774.63
Total rainfall, mm	142.60	Total rainfall, mm	348.40

[a]Irrigation water applied to field capacity of available soil moisture in 90.

Table 3b. Amount of irrigation water applied to treatments in the third and fourth experiment year.

	2016-Treatments				2017-Treatments		
Irrigation dates	$I_{0.50}$	$I_{0.75}$	$I_{1.00}$	Irrigation dates	$I_{0.50}$	$I_{0.75}$	$I_{1.00}$
30.06.2016	67.59[a]	67.59	67.59	05.07.2017	170.65[a]	170.65	170.65
06.07.2016	30.55	45.82	61.10	11.07.2017	67.00	100.50	134.00
14.07.2016	20.55	30.75	40.00	18.07.2017	64.00	99.60	128.00
21.07.2016	40.50	60.75	81.00	01.08.2017	45.00	67.50	90.00
28.07.2016	35.00	52.50	70.00	08.08.2017	53.00	79.50	106.00
04.08.2016	52.80	79.20	105.60	15.08.2017	56.00	83.30	111.00
11.08.2016	48.50	72.75	97.00	22.05.2017	40.00	60.00	80.00
18.08.2016	51.90	77.85	103.80	29.08.2017	44.00	66.00	88.00
25.08.2016	50.01	75.22	100.30	05.09.2017	45.00	67.50	90.00
01.09.2016	35.00	53.50	70.00	12.09.2017	48.00	72.00	96.00
08.09.2016	47.25	70.86	94.50	19.09.2017	39.00	58.50	78.00
15.09.2016	41.90	62.85	83.58	26.09.2017	41.00	61.50	82.00
Total irrigation mm	521.55	749.64	974.47	Total irrigation mm	712.65	986.55	1253.65
ET, mm	844.84	1065.59	1290.32	ET, mm	1069.59	1329.49	1598.44
Total rainfall, mm	11.20	11.20	11.20	Total rainfall, mm	0.0	0.0	0.0

[a]Irrigation water applied to field capacity of available soil moisture in 90 cm.

$$\mathrm{ET} = I + P + Cr - Dp - Rf - Ds \tag{2}$$

WUE was calculated using Eq. (3) as described by Howell, Cuenca, and Solomon (1990) and Ertek et al. (2012), where, WUE : the water use efficiency (g plant^{-1} mm^{-1}), E_y : the economical fresh flower weight (yield) (g plant^{-1}), and ET : the evapotranspiration (mm).

$$\mathrm{WUE} = \frac{E_y}{\mathrm{ET}} \tag{3}$$

Yield response factor (K_y) was calculated using Eq. (4) as described by Stewart et al. (1977) and Doorenbos and Kassam (1986), where Ya : the actual fresh flower (weight) yield (g plant^{-1}), Ym : the maximum fresh flower yield (g plant^{-1}), and ETa : the actual plant water consumption (mm). ETm : the maximum plant water consumption (mm).

$$Ky = \frac{1 - \left(\frac{Ya}{Ym}\right)}{1 - \left(\frac{\mathrm{ET}a}{\mathrm{ET}m}\right)} \tag{4}$$

A nearby weather station recorded daily precipitation. Cr was zero because there was no groundwater rising problem in the area. If available water in the root zone (90 cm) and total volume of applied irrigation water were above the field capacity, we assumed any water leakage becomes deep percolation (Kanber et al. 1993; Ertek et al. 2006a). On the other hand, since irrigation water volume was calculated and applied according to pan evaporation, there was no surface runoff (Ertek et al. 2006b; Kiymaz and Ertek 2015a, 2015b).

Plant height, number of branches per plant, leaf area, leaf water and chlorophyll contents, fresh flower yield, and essential oil yield at the 50% flowering stage of all were measured. All physiological and yield measurements were based on 81 plants, randomly selecting three plants from each plot (treatment).

Leaf area, relative water, and chlorophyll content

Replicates were collected by taking three leaves of each of the 81 plants. Individual leaf area was calculated as LL × LW × 0.75 (Birch, Vos, and van der Putten 2003) where LL, LW, and A are leaf area, leaf length, leaf maximum width, and a constant ($A = 0.75$), respectively, and total leaf area per plant was calculated by summation of individual leaf areas (Kıymaz and Beyaz 2019). Leaf relative water content (RWC) was determined according to Turner's methods (1981). Chlorophyll content was measured according to the protocol proposed by Curtis and Shetty (1996).

Growth characters, fresh flower yield, and yield components

Fresh flowers were collected early in the morning during third and fourth harvesting and measured fresh weights. The fresh flower yield data (average of plants in each plot) were recorded as g $plant^{-1}$.

Essential oil extraction, oil content, and identification of the oil components

Fresh oil rose flowers were collected from each treatment early in the morning (6:00–7:00 AM) by manual plucking during the flower harvesting (May and June 2015–2016, 2017–2018). The essential oils were extracted from 1000 g (fresh weight) of rose flowers placed in 6 L Clevenger hidrodistillation apparatus (Clevenger 1928) and extracted for 3 h with 3 L of pure water. The total rose oil was extracted and was obtained at the end of distillation by the method described in British Pharmacopoeia (1963). The obtained essential oil was stored at 4 °C until analyzed. The essential oil composition of was determined by gas chromatography/mass spectrometry (GC/MS) according to procedures outlined in (Adams 2007) at Laboratory of Sebati Rose Oil Factory in Isparta province, Turkey and stored in the computer library namely Wiley, New York mass spectral (MS) library, National Institute of Standards and Technology, NIST (Stein 2005).

Statistical analysis

The obtained data were subjected to statistical analysis using MINITAB statistical software version 17 (Kıymaz and Beyaz 2019). The analysis of variance (two-way-ANOVA) was performed to compare means. Means were separated with Tukey multiple range test at $p \leq .05$.

Results and discussion

Irrigation water applied, ET, and yield

In order to bring the roses to a certain seedling growth and oil maturity for the first two years (2014–2015) after seedling, the amount of water and fertilizer were given to all parcels equally, and then in the last two years (2016–2017), it was aimed to start the application of different irrigation and fertilizers. Thus, in this study, all data obtained from the targeted treatments in the

Table 4. Amounts of irrigation water applied to treatments and other parameters.

Year	Treatment	I mm	ET mm	N kg ha^{-1}	Fresh flower yield g plant^{-1}	WUE g plant^{-1} mm^{-1}
2016	$I_{1.00}N_1$	974.47	1290.32	80	1031.67	0.800
	$I_{1.00}N_2$	974.47	1290.32	120	988.33	0.766
	$I_{1.00}N_3$	974.47	1290.32	160	932.78	0.723
	$I_{0.75}N_1$	749.64	1065.49	80	975.56	0.793
	$I_{0.75}N_2$	749.64	1065.49	120	945.00	0.775
	$I_{0.75}N_3$	749.64	1065.49	160	822.78	0.606
	$I_{0.50}$ N_1	521.55	844.84	80	831.67	0.948
	$I_{0.50}N_2$	521.55	844.84	120	825.67	0.925
	$I_{0.50}$ N_3	521.55	844.84	160	715.56	0.848
2017	$I_{1.00}N_1$	1253.65	1598.44	80	1001.67	0.626
	$I_{1.00}N_2$	1253.65	1598.44	120	896.67	0.561
	$I_{1.00}N_3$	1253.65	1598.44	160	933.56	0.584
	$I_{0.75}N_1$	986.55	1329.49	80	975.56	0.734
	$I_{0.75}N_2$	986.55	1329.49	120	945.00	0.711
	$I_{0.75}N_3$	986.55	1329.49	160	822.78	0.619
	$I_{0.50}N_1$	712.65	1069.59	80	831.67	0.778
	$I_{0.50}N_2$	712.65	1069.59	120	825.67	0.772
	$I_{0.50}N_3$	712.65	1069.59	160	715.56	0.669

I: the amount of water applied; ET: plant water consumption; N: nitrogen; WUE: water use efficiency

last two years are presented. Similarly, previous studies revealed that irrigation and N application had different effects on seedling growth and the two effects were interactive (Qiu et al. 2016).

Tables 3a and 3b present information about the amount of irrigation applied and irrigation dates. The first and the last irrigations in the first and second experiment year were performed on 4–14 July and 10–11 October and the relevant dates of the third and fourth year were 30 June– 5 July and 15–26 October. The plants of the first and the second year were irrigated 11–9 times at 7-d intervals, respectively. A total of 92.09 mm and 115.25 mm water were applied to all plants prior to the scheduled irrigation in the first year and the second year, respectively. Similarly, a total of 67.59 and 170.65 mm water were applied to all plants prior to the scheduled irrigation in the third and fourth year. Soil water deficit in all plots was replenished to field capacity at soil depth of 0–90 cm and then scheduled irrigation in the third and fourth year, based on 7-d cumulative evaporation, were initiated.

The amount of water applied (I), ET, fresh flower yield, WUE in the third, and fourth year are given in Table 4. As our results shown, the lowest and the highest values of irrigation water applied and ET were observed in the $I_{0.50}$ and $I_{1.00}$ treatments, respectively, in growing periods. The ET values increased depend on the different levels of irrigation.

The growing periods, in the third year, the highest and the lowest value of WUE was ranged from 0.948 to 0.606 g plant^{-1}mm^{-1} in the $I_{0.50}N_1$ and $I_{0.75}N_3$ treatments, respectively. In the fourth year, the highest value (averaging 0.778 g plant^{-1}mm^{-1}) and the lowest yield value (0.561 g plant^{-1}mm^{-1}) obtained from the $I_{0.50}N_1$ to $I_{1.00}N_2$ treatments. The WUE values decreased in levels from $I_{1.00}$ to $I_{0.50}$ in growing periods depend on the amount of applied water and the yield. De Costa and Ariyawansa (1996) defined the WUE, as the biomass produced per unit of water used. Increasing WUE is also a promising way to improve crop yield, especially in water-limited environments (De Costa and Ariyawansa 1996).

Figure 1 plots fresh flower yield per plant as a function of ET water loss from irrigated soil. Table 4 shows ET increases as the amount of irrigation water applied increases but WUE remains virtually unchanged in response to water stress. Figure 1 demonstrates that reducing applied water in this ET range does not reduce fresh flower yield per plant, this being a result of the invariant WUE.

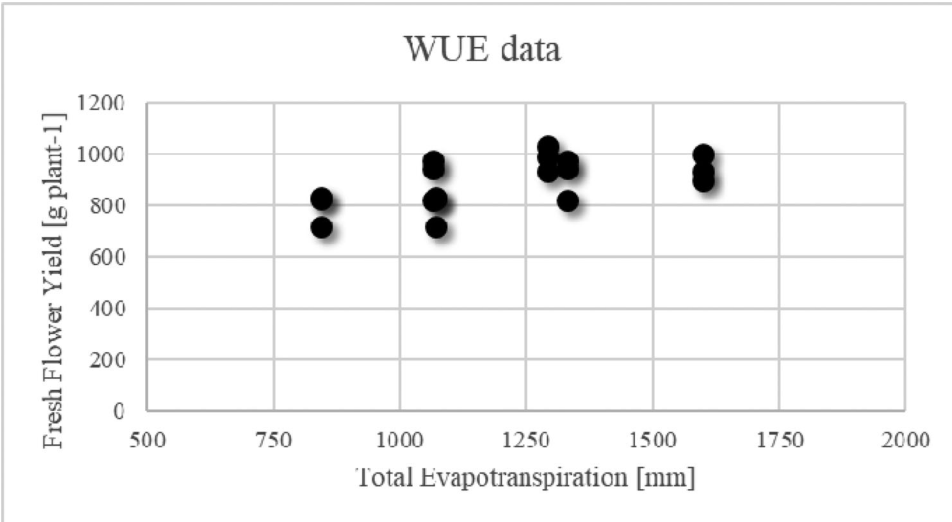

Figure 1. Plots fresh flower yield per plant as function of ET water loss from irrigated soil.

Table 5. The effect different water and nitrogen levels on fresh yield and some vegetative characters of oil rose (*Rosa damascena* Mill.) in the third and fourth experiment year of flower harvesting.

Treatments	Yield: Fresh flower yield plant^{-1} (g)		Yield: Oil yield plant^{-1} (ml)		Vegetative characters: Plant height (cm)		Vegetative characters: Number of branches in plant (number)		Vegetative characters: Leaf area (cm^2)	
	2017 (3)	2018 (4)	2017 (3)	2018 (4)	2017 (3)	2018 (4)	2017 (3)	2018 (4)	2017 (3)	2018 (4)
$I_{1.00}$ N_1	1031.67^{a}	1001.11^{a}	0.66^{a}	0.68^{a}	98.67^{a}	116.67^{a}	7.00^{a}	7.67^{a}	19.74^{a}	36.32
$I_{1.00}$ N_2	988.33^{ab}	896.67^{ab}	0.41^{ab}	0.58^{ab}	90.67^{c}	102.00^{ab}	5.00^{c}	5.33^{bcd}	16.60^{b}	48.59
$I_{1.00}$ N_3	932.78^{ab}	933.56^{ab}	0.36^{b}	0.52^{ab}	83.00^{e}	95.67^{b}	4.00^{d}	5.00^{cd}	16.16^{bc}	37.54
Mean	984.26	943.78	0.48	0.59	90.78	104.78	5.33	6.00	17.50	40.95
$I_{0.75}$ N_1	845.44^{ab}	975.56^{ab}	0.27^{b}	0.44^{ab}	97.00^{ab}	103.67^{ab}	6.00^{b}	6.67^{ab}	15.77^{bcd}	37.22
$I_{0.75}$ N_2	825.56 ^{ab}	945.00^{ab}	0.28^{b}	0.41^{ab}	88.67^{cd}	99.67^{ab}	5.00^{c}	5.00^{cd}	15.11^{bcd}	26.92
$I_{0.75}$ N_3	646.11 ^{b}	822.78^{ab}	0.30^{b}	0.38^{b}	81.00^{e}	94.00b	3.33^{e}	4.67^{cd}	13.04^{de}	24.58
Mean	772.37	914.45	0.28	0.41	88.89	99.11	4.78	5.45	14.64	32.66
$I_{0.50}$ N_1	800.56^{ab}	831.67^{ab}	0.28^{b}	0.32^{b}	94.33^{b}	103.00^{ab}	5.00^{c}	6.00^{bc}	13.36^{cde}	34.06
$I_{0.50}$ N_2	781.67ab	825.67^{ab}	0.22^{b}	0.35^{b}	86.67^{d}	98.00^{b}	4.00^{d}	5.00^{cd}	13.00^{de}	31.12
$I_{0.50}$ N_3	716.11ab	715.56^{b}	0.25^{b}	0.33^{b}	76.33^{f}	90.33^{b}	3.00^{e}	4.00^{d}	11.20^{e}	24.43
Mean	766.11	790.97	0.25	0.33	85.78	97.11	4.00	5.00	12.52	30.29
#Rate (%)	↓ 22.16	↓ 16.19	↓ 47.55	↓ 43.82	↓ 5.51	↓ 7.32	↓ 25	↓ 16.67	↓ 28.46	↓26.03
Summary of ANOVA	–	–	–	–	–	–	–	–	–	–
Water regimes (I)	*	*	**	**	**	*	**	**	**	**
Nitrogen (N)	ns	ns	ns	ns	**	**	**	**	**	**
I × N	ns	ns	ns	ns	ns	ns	**	ns	ns	ns

ns: non-significant; *significant at $p \leq .05$; **significant at $p \leq .01$.
Different letters at the same column show significant differences at .05 level.
#Decrease and/or increase rate of parameters between means of $I_{1.00}$ and $I_{0.50}$, Increase: ↑ and decrease: ↓

Water–yield relationships

Table 5 shows weight of fresh rose flowers and the growth characters. As presented in Table 5, the highest fresh flower yield (averaging 1031.67 g plant^{-1}) was recorded in the $I_{1.00}N_1$ treatment. On the other hand, the lowest one (716.11 g plant^{-1}) obtained from the $I_{0.50}N_3$ treatments for 2017. Similarly, in the fourth year, the highest fresh flower yield value (averaging 1001.11 gr

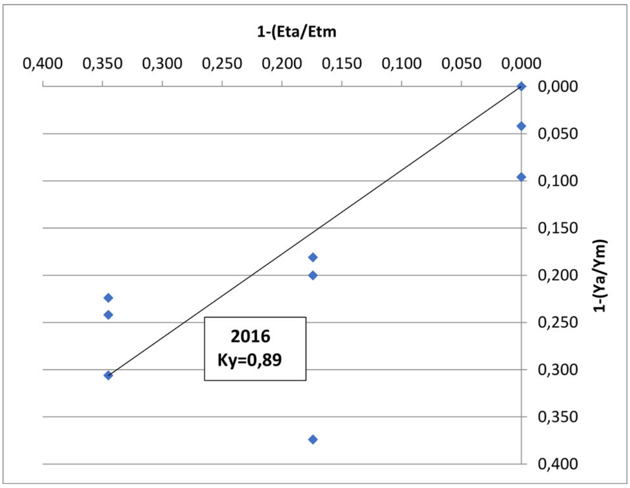

Figure 2a. The relationship between relative yield decrease and relative evapotranspiration deficit for oil rose in the total growing period.

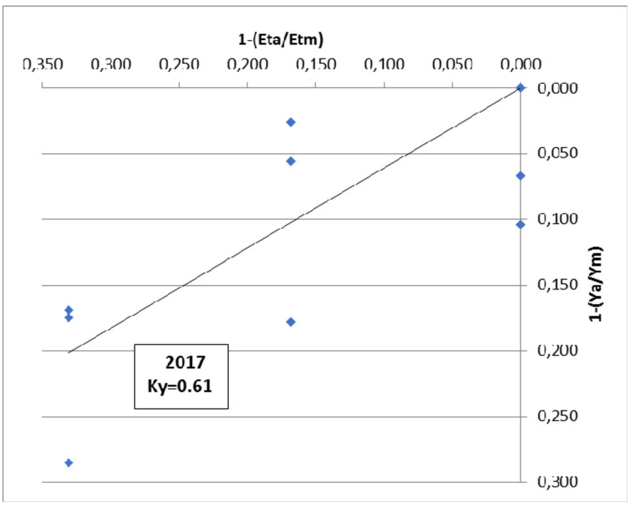

Figure 2b. The relationship between relative yield decrease and relative evapotranspiration deficit for oil rose in the total growing period.

plant^{-1}) and the lowest fresh flower yield value (715.56 g plant^{-1}) obtained from the $I_{1.00}N_1$ to $I_{0.50}N_3$ treatments for 2018.

In the third year (2017), the highest oil yield was obtained from $I_{1.00}N_1$ to $I_{1.00}N_2$ treatment (with 0.66–0.41 ml), while the lowest oil yield was obtained from $I_{0.50}N_2$ treatment (0.22 ml) harvested during the vegetative growth stage. In the fourth year (2018), the highest and the lowest oil yield were obtained from $I_{1.00}N_1$, $I_{1.00}N_2$, and $I_{0.50}N_2$ treatments (with 68–0.58 ml and 0.32 ml). Our study showed that only water regimes (I) on *Rosa damascena* Mill. significantly ($p < .01$) affected essential oil yield both harvested in 2017 and 2018. From these findings, the increase in essential oil yield could be explained through the increase in fresh flower yield because of increasing irrigation levels. Generally, oil yields trends to decrease depend on I and N levels in flowering period in oil rose.

Table 6. The effect different water and nitrogen levels on physiological parameters of oil rose (*Rosa damascena* Mill.) in the third and fourth experiment year of flower harvesting.

	Chlorophyll a (μg chlorophyll g^{-1} fresh tissue)		Chlorophyll b (μg chlorophyll g^{-1} fresh tissue)		Total chlorophyll (μg chlorophyll g^{-1} fresh tissue)		Leaf relative water content (%)	
Treatments	2017 (3)	2018 (4)	2017 (3)	2018 (4)	2017 (3)	2018 (4)	2017 (3)	2018(4)
$I_{1.00}$ N1	1326.00 ^{a}	1466.24^{a}	597.76 ^{a}	767.18^{a}	1221.20^{a}	1452.61^{a}	98.53^{a}	94.23^{a}
$I_{1.00}$ N2	982.39 ^{d}	1298.85^{bc}	447.040 ^{a}	573.75^{a}	908.77^{ab}	1184.87^{ab}	77.75^{cd}	81.42^{bc}
$I_{1.00}$ N3	896.43^{e}	1067.15^{e}	325.626 ^{a}	593.02^{a}	750.02^{b}	1090.59^{ab}	67.00^{def}	79.09^{bc}
Mean	1068.27	1277.41	456.81	644.66	960.00	1242.69	81.09	84.91
$I_{0.75}$ N1	1130.02 ^{b}	1392.35^{ab}	451.85 ^{a}	714.76^{a}	985.29^{a}	1366.16^{a}	91.14^{ab}	88.74^{ab}
$I_{0.75}$ N2	958.35 ^{d}	1184.75 ^{cd}	346.95 ^{a}	528.69^{a}	800.70^{b}	1085.92^{ab}	75.50^{cd}	79.16^{b}
$I_{0.75}$ N3	797.56 ^{f}	999.65^{e}	423.09 ^{a}	561.62^{a}	795.71^{b}	1027.49^{ab}	63.27^{ef}	68.35^{de}
Mean	961.98	1192.25	407.30	601.69	860.57	1159.86	78.33	78.75
$I_{0.50}$ N1	1047.03 ^{c}	1343.79 ^{b}	418.97 ^{a}	507.79^{a}	913.23^{ab}	1143.25^{ab}	81.39^{bc}	83.24^{bc}
$I_{0.50}$ N2	932.13 ^{de}	1110.24 ^{de}	357.45 ^{a}	452.52^{a}	798.05^{b}	976.31^{ab}	72.26^{cde}	75.98^{cd}
$I_{0.50}$ N3	730.49 ^{g}	846.94 ^{f}	423.82 ^{a}	358.71^{a}	763.76^{b}	757.78^{b}	58.70^{f}	57.71^{e}
Mean	903.22	1100.32	400.09	439.68	825.01	959.11	70.78	72.31
#Rate (%)	↓ 15.45	↓ 13.86	↓ 12.42	↓ 31.80	↓ 14.06	↓ 22.82	↓ 12.71	↓ 14.84
Summary of ANOVA								
Water regimes (I)	**	**	ns	ns	ns	*	**	**
Nitrogen (N)	**	**	ns	ns	**	0.005	**	**
I × N	**	ns	ns	ns	ns	ns	ns	*

ns: non-significant; *significant at $p \leq .05$; **significant at $p \leq .01$.
Different letters at the same column show significant differences at .05 level.
#Decrease and/or increase rate of parameters between means of $I_{1.00}$ and $I_{0.50}$, Increase: ↑ and decrease: ↓

However, the interaction between I and N levels was found significant ($p < .01$) for number of branches in plant, except plant height, and leaf area. In general, there was also a significant only N and water levels had an impact on plant height, number of branches in plant, and leaf area in the third and fourth year of flower harvesting at a 1% level of significance.

The yield response factors (*Ky*) of treatments in 2016 and 2017 were determined as 0.89 and 0.61, respectively (Figure 2(a,b)), indicating that the third and fourth-year unit yields per unit of water deficiency may be decreased to 0.89 and 0.61, respectively. Average *Ky* value was 0.75 for 2016–2017. This situation reveals may change the value of *Ky* depending on the climatic conditions. Reviews in the literature indicate that a value of *Ky* lower than 1.0 can tolerate to the water deficit (Carvalho et al. 2016; Kıymaz and Beyaz 2019). Therefore, *Ky* values could be used as an indicator to determine adaptability of oil rose against to water stress conditions. These findings were in parallel with a previous report by Şimşek, Kaçıra, and Tonkaz (2004); Doorenbos and Kassam (1979); Şehirali et al. (2005); Kiymaz and Ertek (2015a, 2015b); De Azevedo et al. (2016); Kıymaz and Beyaz (2019). In addition, the researchers reported that *Ky* may be affected by other factors besides soil water deficiency, namely soil properties, climatic conditions, length of growing period, irrigation methods and schedules, and inefficiencies of production technology (Ucan and Gencoglan 2004; Kiymaz and Ertek 2015b).

Physiological characteristics

Our study showed that both I and N levels on *Rosa damascena* Mill. significantly ($p < .01$) affected leaf chlorophyll a content RWC and leaf both in 2017 and 2018 (Table 6). Generally, chlorophyll contents (chlorophyll a, chlorophyll b, and the total chlorophyll) and RWC trends to decrease depend on I and N levels in flowering period in oil rose.

Based on the overall results of this study showed that the treatments of the highest water stress and the lowest N application ($I_{0.50}N_1$) were achieved the highest chlorophyll content and leaf

Table 7. The effect different water and nitrogen levels on main chemical constituents of the essential oil of *Rosa damascena* Mill. in the third experiment year of flower harvesting (2017).

			Chemical constituents (%)								
S. number	RI	Chemical constituents	$I_{1.00}N_1$	$I_{1.00}$ N_2	$I_{1.00}$ N_3	$I_{0.75}$ N_1	$I_{0.75}N_2$	$I_{0.75}$ N_3	$I_{0.50}N_1$	$I_{0.50}N_2$	$I_{0.50}N_3$
1	1032	α-Pinene	0.15	0.20	0.14	0.72	0.96	0.66	0.45	0.48	0.26
2	1079	Myrcene	–	–	–	–	–	0.32	0.20	0.18	–
3	1080	β-Pinene	–	0.09	0.06	0.33	0.34	0.15	0.10	0.10	0.14
4	1146	γ-Terpinene	–	–	–	0.11	0.07	0.07	–	–	–
5	1179	Phenethyl alcohol	1.37	1.60	1.15	1.81	1.72	1.70	1.43	1.42	1.12
6	1193	Rose oxide	0.11	0.08	0.14	0.34	0.29	0.35	0.31	0.32	0.23
7	1260	4-Terpineol	0.17	0.15	0.21	0.48	0.47	0.44	0.33	0.34	0.28
8	1271	α-Terpineol	–	–	0.09	0.30	0.26	0.26	0.21	0.20	0.15
9	1311	Citronello + nerol	21.39	21.15	23.55	28.77	28.07	27.79	22.65	24.11	42.67
10	1315	Neral	–	–	–	0.30	0.42	0.11	0.16	–	–
11	1327	Phenethyl acetate	–	–	–	0.16	–	0.17	–	–	–
12	1336	Geraniol	6.32	8.32	5.55	11.67	11.41	11.46	9.44	9.56	11.95
13	1435	Eugenol	0.50	0.62	0.50	0.57	0.46	0.57	0.50	0.47	0.31
14	1443	Citronellyl acetate	0.41	0.45	0.49	0.61	0.54	0.89	0.64	0.61	0.43
15	1471	Neryl Acetate	0.28	0.40	0.20	0.43	0.54	0.67	0.51	0.48	0.29
16	1480	Methyl eugenol	2.30	2.15	2.45	2.89	2.51	3.50	2.65	2.59	1.95
17	1499	β-elemene	0.12	0.15	0.14	0.16	0.09	0.13	0.14	0.13	–
18	1531	β-Caryophyllene	0.60	0.64	0.57	0.83	0.51	0.59	0.63	0.62	0.28
19	1551	α-Guaiene	0.59	0.60	0.63	0.72	0.52	0.59	0.61	0.58	0.30
20	1566	α-Humulene	0.49	0.49	–	0.59	0.38	0.42	0.48	0.46	0.12
21	1593	Germacrene D	1.88	2.29	2.13	3.17	1.04	1.14	1.80	1.32	0.57
22	1613	α-Gurjunene	0.10	–	–	–	–	–	–	–	–
23	1620	δ-Guaiene	0.76	0.85	0.81	–	0.43	0.52	0.56	0.54	0.24
24	1838	Heptadecane	3.43	3.35	3.29	3.44	3.16	2.96	3.44	3.24	1.82
25	1947	Eicosane	0.27	0.23	0.25	0.13	0.27	0.14	0.18	0.17	0.10
26	2025	Heptadecanol	7.14	6.05	5.66	3.60	3.93	3.90	5.10	4.96	2.90
27	2056	Nonadecane	23.40	21.37	19.96	14.71	14.84	15.74	18.36	19.15	15.11
28	2164	Eicosane	3.99	4.00	4.14	2.37	2.74	2.58	3.48	3.18	1.74
29	2266	Citronellyl valerate	0.08	0.35	0.42	–	0.26	0.28	0.39	–	–
30	2273	Heneicosane	15.73	16.08	15.36	11.55	12.89	12.31	14.30	14.63	10.40
31	2381	Tetracosane	0.69	0.75	0.90	0.55	0.66	0.55	0.79	0.68	0.22
32	2483	Citronellyl propionate	0.09	0.12	0.19	0.12	0.14	0.11	0.16	0.14	0.10
33	2490	Pentacosane	5.10	5.72	6.37	4.79	5.54	4.96	5.75	5.50	3.47
34	2707	n-Dotriacontane	2.76	1.73	4.65	3.78	4.54	3.74	4.25	3.84	2.77
		Total	100	100	100	100	100	100	100	100	100

RI: retention indices

RWC. Similarly, the results agree with those reported by Hassan, Bazaid, and Ali (2013) in *Rosmarinus officinalis* L.

Chemical composition of essential oil

From the GC-MS analysis of hydrodistilled essence from *Rosa damascena* Mill., we identified a total of 34 (Table 7) and 33 (Table 8) compounds, representing 100% of the volatile part in this study. The present results indicated that the major constituents were found citnonellol + nerol, nonadecane, heneicosane, geraniol, pentacosane, and *n*-dotriacontane. Citronellol can be prepared by hydrogenation of geraniol or nerol. Therefore, the result of the analysis is given as citnonellol + nerol (Marris 2007; Ait Ali et al. 1995).

As shown in Tables 7 and 8, the yield in 2017 and 2018 of citronellol + nerol, geraniol, heptadecanol, nonadecane, heneicocane, pentacosane, and n-dotriacontane under water stress conditions caused little change in essential oil constituents.

Our results indicated that the differences in essential oil ratio changes between harvest dates may be due to plant age and climate parameters (precipitation and temperature, see Table 1). Similar to our results, it was reported in previously studies that the most important compounds have been found citronellol, geraniol, nerol and linalool, nonadecane, heneicosane, heptadecane,

Table 8. The effect different water and nitrogen levels on main chemical constituents of the essential oil of *Rosa damascena* Mill. in the fourth experiment year of flower harvesting (2018).

			Chemical constituents (%)								
S. number	RI	Chemical constituents	$I_{1.00}N_1$	$I_{1.00}N_2$	$I_{1.00}N_3$	$I_{0.75}N_1$	$I_{0.75}N_2$	$I_{0.75}N_3$	$I_{0.50}N_1$	$I_{0.50}$ N_2	$I_{0.50}N_3$
1	1032	α-pinene	0.15	0.19	0.18	0.23	0.34	0.32	0.13	0.11	0.10
2	1079	Myrcene	–	–	–	–	–	–	0.20	–	–
3	1080	β-pinene	–	–	0.09	0.15	0.06	0.25	0.06	0.05	0.06
4	1146	γ-Terpinene	–	–	–	–	0.07	–	–	–	–
5	1180	Linalool	0.48	0.25	0.52	0.99	0.51	0.55	0.28	0.42	0.40
6	1193	Rose oxide	0.04	0.14	0.24	0.32	0.16	0.22	0.25	0.24	0.23
7	1260	4-Terpineol	0.14	0.08	0.16	0.30	0.16	0.36	0.11	0.11	0.10
8	1271	α-Terpineol	0.08	0.03	0.09	0.14	0.09	0.09	–	0.06	0.05
9	1311	Citronellol + nerol	18.44	9.01	21.25	32.02	19.27	16.30	17.96	23.03	22.07
10	1336	Geraniol	1.55	1.19	3.27	7.97	2.53	3.39	0.70	2.69	1.97
11	1435	Eugenol	0.07	0.04	0.18	0.20	0.10	0.06	0.05	0.05	0.04
12	1443	Citronellyl acetate	0.20	–	0.34	0.15	0.15	0.07	0.08	0.13	0.14
13	1471	Neryl Acetate	0.10	0.05	0.12	0.10	0.07	0.03	–	0.14	0.14
14	1480	Methyl eugenol	0.90	0.51	2.09	1.17	1.20	0.89	1.41	1.25	1.29
15	1499	β- elemene	–	0.04	0.14	0.19	0.16	0.21	0.10	0.11	0.09
16	1531	β-Caryophyllene	0.36	0.23	0.46	0.80	0.52	0.72	0.40	0.38	0.41
17	1551	α-guaiene	0.36	0.24	0.48	0.76	0.54	0.77	0.50	0.46	0.47
18	1568	α-humulene	0.21	0.15	0.28	0.47	0.38	0.52	0.23	0.22	0.20
19	1593	Germacrene D	0.65	0.41	0.99	1.67	1.02	1.46	0.73	0.70	0.71
20	1613	α-gurjunene	0.09	0.10	0.06	0.16	0.12	0.10	0.24	0.34	0.22
21	1620	δ -guaiene	0.36	0.14	0.57	0.60	0.24	0.78	0.12	0.07	0.07
22	1838	Heptadecane	1.45	0.81	1.70	2.40	1.52	1.36	1.17	1.66	1.53
23	1947	Eicosane	2.90	3.15	3.36	2.25	3.22	3.06	3.26	3.05	2.98
24	2025	Heptadecanol	2.17	1.19	2.94	1.75	1.81	1.64	1.92	2.20	1.97
25	2056	Nonadecane	27.75	20.67	24.85	17.23	19.09	19.51	24.15	23.19	22.20
26	2263	Pentadecanol	–	–	–	–	0.18	–	–	0.16	0.15
27	2273	Heneicosane	25.51	31.05	20.89	16.67	24.01	25.17	25.26	22.35	23.19
28	2381	Tetracosane	0.45	1.17	0.92	0.49	1.05	1.23	0.98	0.92	0.90
29	2483	Citronellyl propionate	–	0.03	0.18	0.04	0.15	0.17	0.22	0.13	0.11
30	2490	Pentacosane	8.79	15.19	7.43	5.99	11.44	10.88	10.50	8.49	9.66
31	2695	Heptadecanol	–	–	0.14	–	–	–	–	–	–
32	2707	*n*-Dotriacontane	6.83	13.94	6.0	4.79	10.15	9.79	9.19	7.18	7.17
33	2915	Heptadecyl alcohol	–	–	0.08	–	–	0.07	–	–	–
		Total	100	100	100	100	100	100	100	100	100

RI: retention indices

eicosane, tricosane, humulene, murolene, methyl eugenol, geranyl acetate, geranial, and eugenol (Anaç 1984; Kovats 1987; Başer 1992; Bayrak and Akgül 1994; Picone et al. 2004; Rusanov et al. 2011; Rusanov, Kovacheva, and I. Atanassov 2011; Koksal et al. 2015). Results of the study are also supported by the findings of Nunes and Miguel (2017), who explained that the reasons for this may be depending on several factors depending on several factors, such as varieties, agronomic characteristics, plant propagation techniques, cultivation date, harvesting, pruning, transportation and storage of practices, and method of distillation.

Conclusions

This study was conducted to investigate the effect irrigation and N fertilization on growth, yield, and quality parameters of *Rose damascena* Mill. The results of our experiment revealed that applied irrigation water affected several plant growth parameters and plant physiological characteristics.

However, there was little tradeoff between reductions in applied water and fresh flower yield. Furthermore, the GC-MS results in Tables 7 and 8 reveal little change in essential oil quality as water stress increases with diminished applied water. The yield response and essential oil quality are the direct result of the relatively invariant WUE shown in Figure 2.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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