

ARAŞTIRMA MAKALESİ

RESEARCH ARTICLE

The Effect of Macro Elements and Foliar Application of Micro Elements on the Yield and Quality of Damask Rose (*Rosa damascena* Mill)

Makro ve Mikro Elementlerin Yaprak Uygulamasının Isparta Güllü (*Rosa damascena* Mill.)'nün Kalite ve Verimi Üzerindeki Etkisi

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Abstract

Rosa damascena Mill. is one of the oldest and most valuable medicinal plants, widely utilized across the pharmaceutical, food, and cosmetic industries worldwide. The essential oil derived from this species is considered an important commercial raw material due to its high economic value and unique aromatic constituents. This study was conducted at the Alborz Research Station to evaluate the effects of macroelement fertilization and foliar application of iron-based microelements on the quantitative and qualitative characteristics of damask rose grown under field conditions. The experiment was arranged in a split-plot layout within a randomized complete block design with three replications. The main plots comprised 14 different fertilization treatments, including chemical fertilizers, cow manure, and various combinations of both. The subplots consisted of foliar spraying with nano iron chelate at four levels (0, 1, 2, and 3 applications). The findings revealed that macro- and microelement treatments significantly affected the number of flowers per plant, petal yield, essential oil content, and essential oil yield ($p \leq 0.01$). The highest essential oil yield (6711.6 g ha^{-1}) and essential oil content (0.078%) were obtained in treatments where N120P120K120 fertilization was combined with three foliar applications. This indicates that the combined supply of macro- and micro-nutrients substantially enhances essential oil biosynthesis by providing optimal nutritional conditions. Furthermore, the study demonstrated that fertilization regimes also caused notable alterations in essential oil composition. Key aromatic constituents such as citronellol, nonadecene, hexadecanol, and tricosene exhibited significant increases under high-input fertilization conditions. In particular, citronellol and nonadecene critical compounds determining fragrance quality reached their highest levels in treatments receiving both macro and microelement inputs. This highlights that nutrient management is not only a tool for improving yield but also a key factor influencing product quality through modulation of secondary metabolite profiles. Overall, the results of this research show that integrated nutrient management strategies are highly effective in enhancing both biomass production and the chemical quality of essential oil in damask rose cultivation. Nutrient optimization not only improves agricultural productivity but also enriches valuable constituents within the essential oil, thereby increasing the economic value of rose-based products.

Keywords: Secondary metabolites, Essential oil, Cow manure, Nano Iron chelate, Fragrance compound

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Öz

Rosa damascena Mill., dünya çapında farmasötik, gıda ve kozmetik endüstrilerinde geniş kullanım alanına sahip en eski ve en kıymetli tıbbi bitkilerden biridir. Bu türden elde edilen uçucu yağ, yüksek ekonomik değeri ve eşsiz aromatik bileşenleri nedeniyle önemli bir ticari hammadde olarak kabul edilmektedir. Bu çalışma, Alborz Araştırma İstasyonu'nda yürütülmüş olup, tarla koşullarında yetiştirilen Isparta gülünde makro element gübrelemesi ve demir temelli mikro elementlerin yapraktan uygulanmasının, niceliksel ve niteliksel özellikler üzerindeki etkilerini değerlendirmeyi amaçlamıştır. Deneme, tesadüf blokları deneme desenine dayalı bölünmüş parseller şeklinde ve üç tekerrürlü olarak düzenlenmiştir. Ana parseller; kimyasal gübreler, çiftlik gübresi ve bu iki kaynağın çeşitli kombinasyonlarını içeren toplam 14 farklı gübreleme uygulamasından oluşmuştur. Alt parsellerde ise dört farklı düzeyde (0, 1, 2 ve 3 kez) demir nano-şelat içeren yapraktan püskürtme uygulaması gerçekleştirilmiştir. Elde edilen bulgular, makro ve mikro element uygulamalarının bitki başına çiçek sayısını, taç yaprak verimini, uçucu yağ içeriğini ve uçucu yağ verimini istatistiksel olarak oldukça önemli düzeyde etkilediğini göstermiştir ($p \leq 0.01$). En yüksek uçucu yağ verimi ve yağ içeriği N120P120K120 gübreleme uygulamasının üç kez yapılan yaprak püskürtme ile birlikte kullanıldığı denemelerde sırasıyla 6711.6 g ha^{-1} ve %0.078 olarak elde edilmiştir. Bu sonuçlar hem makro besin elementlerinin hem de mikro besin takviyesinin optimum beslenme koşullarını sağladığını ve bitkide uçucu yağ sentezini önemli ölçüde artırdığını göstermektedir. Ayrıca çalışmada, gübreleme rejimlerinin uçucu yağ bileşimi üzerinde de belirgin değişikliklere yol açtığı ortaya konmuştur. Citronellol, nonadesen, hegzadekanol ve trikosen gibi temel aromatik bileşenler yüksek girdili gübreleme koşullarında dikkate değer artış göstermiştir. Özellikle koku kalitesinde belirleyici unsurlar olan citronellol ve nonadesen, hem makro hem mikro elementlerin birlikte uygulandığı gübreleme programlarında en yüksek seviyelerine ulaşmıştır. Bu durum, besin yönetiminin yalnızca verim artırıcı bir araç olmadığını, aynı zamanda ikincil metabolit profillerini düzenleyerek ürün kalitesini doğrudan etkileyen bir unsur olduğunu göstermektedir. Genel olarak bu araştırma, entegre besin yönetimi stratejilerinin Isparta gülü yetiştiriciliğinde hem biyokütle üretimini hem de uçucu yağın kimyasal kalitesini artırmada oldukça etkili olduğunu ortaya koymaktadır. Besin optimizasyonu, yalnızca tarımsal verimliliği artırmakla kalmayıp aynı zamanda uçucu yağ bileşimindeki değerli bileşenleri zenginleştirerek gül bazlı ticari ürünlerin ekonomik değerini artıran önemli bir uygulama olarak öne çıkmaktadır.

Anahtar Kelimeler: Sekonder metabolitler, Uçucu yağ, Çiftlik gübresi, Nano şelatlı demir, Koku bileşenleri

1. Introduction

Rosa damascena Mill., commonly known as Damask rose, is a valuable aromatic and medicinal plant belonging to the Rosaceae family, characterized by its white, pink, and red flowers (Yildirim and Ozcelik, 2023; El Malahi et al., 2024). This species has long been appreciated for its therapeutic properties, including antidepressant, cardiogenic, anti-inflammatory, and analgesic effects. The essential oil extracted from its flowers is further known for its antibacterial, antimicrobial, antioxidant, and anti-HIV activities (Kant et al., 2023; Odyntsova et al., 2022). The nutritional status of medicinal plants is a key factor in maximizing both yield and the concentration of bioactive compounds. Essential elements for plant growth are broadly categorized into macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) and micronutrients including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni) (Monib et al., 2023; Chrysargyris et al., 2022). Optimizing the availability of these elements is fundamental in enhancing the quantitative and qualitative traits of medicinal plants. Among the diverse methods of nutrient application, foliar feeding has gained prominence for its efficiency in delivering nutrients directly to plant tissues. This technique ensures rapid absorption, particularly under field conditions where root uptake may be constrained by environmental factors (Kulkarni and Ghate, 2024; Johnson and Mirza, 2020). Moreover, foliar fertilization is associated with reduced chemical fertilizer usage and lower environmental risks (Nurzyńska-Wierdak et al., 2011). Recent studies emphasize the effectiveness of foliar application of micronutrients, especially iron, zinc, and manganese, in increasing plant yield and enhancing economic viability (Ashraf et al., 2025). Foliar spraying is particularly advantageous when nutrient availability in the soil is suboptimal, as it can directly influence physiological and morphological traits (Krishnasree et al., 2021). For example, in field trials conducted in Kashan, application of 20 tons ha⁻¹ of manure in combination with 200 kg ha⁻¹ nitrogen substantially increased the yield of *R. damascena* (Omidi et al., 2022). Several studies have demonstrated the specific effects of micronutrients on the growth and essential oil yield of various medicinal plants. In *Salvia*, iron application improved vegetative growth and flowering, while foliar application of 100 mg L⁻¹ zinc significantly enhanced plant height, branching, and leaf production (Mohamed and Ghatas, 2021; Ağamirzaoglu et al., 2024). Further investigations confirmed that optimal foliar zinc application, especially in the form of zinc sulfate, improved herb biomass and oil content (Ha-Tran et al., 2025; Fadala, 2024). In *Coriandrum sativum* L., foliar feeding with iron and zinc during critical developmental stages significantly enhanced plant height, number of branches, and essential oil production (Giang, 2025). Moreover, zinc and copper applications improved yield and phytochemical profiles in aromatic species closely related to coriander. Foliar feeding has also proven effective in preventing flower yield reduction during sensitive growth stages. For instance, foliar application of zinc and iron in *Matricaria chamomilla* (German chamomile) significantly enhanced floral yield and essential oil content, particularly when applied before flowering (Kumar et al., 2022). In *Achillea millefolium* (yarrow), potassium foliar application improved flowering and essential oil output (Mohamed and Ghatas, 2021). Furthermore, studies on *Satureja bachtiarica* demonstrated that zinc chelate application increased essential oil yield during the flowering phase (Khamushi and Nejadhabibvash, 2024). Collectively, these findings suggest that proper management of macro- and micronutrients especially through foliar application plays a vital role in optimizing the yield and phytochemical quality of medicinal plants. Based on this premise, the present study was designed to evaluate the impact of macronutrient application and foliar spraying of selected micronutrients on the growth parameters, yield, and essential oil content of *Rosa damascena* Mill.

2. Materials and Methods

This project was performed in Research Institute of Forest and Rangelands, Karaj, Iran (Latitude: 35° 38' N; Longitude: 51°E; Altitude: 1321 meter (m) in 2020-2023. In 2020 rooted cuttings in a greenhouse were prepared. In the winter of 2021 were transferred to the farm. In 2021, were few flowers, so picking flowers began in 2022 but the analysis of data related to the last two years of this experiment (2021 and 2023). The experiment was conducted in split-plot in the form of a randomized complete block design with three replications. The main factors were chemical fertilizer in 6 levels, manure in 3 levels, Combination of manure and chemical fertilizers in 4 levels and without use any fertilizers (Chemical properties of manure in *Table 1* and Physical, chemical properties of soil in *Table 2* and the amount and different levels of chemical fertilizers, manure and mix of them in *Table 3*). sub factor was spraying Khazra Iron Chelate 4 g p⁻¹ (*Table 4*) in 4 levels 0, 1, 2 and 3 times (*Table 5*).

Rose cuttings, Kashan 93 genotypes were rooted in the greenhouse and in 2019 were transferred to the farm. First, the size of 70 × 70 pits was dug to a depth of 100 cm (6). Manure, with chemical fertilizers (N, P, K), based on treatments were mixed with soil and poured into the planting hole.

Ammonium sulfate, potassium sulfate and triple super phosphate, respectively, as a source of nitrogen, potassium and phosphorus was used. Plant spacing from each other, 3*3 m, Distance blocks, 4 m and for each treatment in each block, 3 seedlings were used. Also, for irrigation, a drip irrigation system was used, as recommended by researchers (Ahmadi et al., 2008; Mosavi and Feizi, 2002; Rahmani et al., 2013).

Table 1. Chemical properties of manure

pH	Ec (ds m ⁻¹)	Organic C (%)	N (%)	P (%)	K (%)
7.9	5.3	25.8	2.5	0.92	1.4

Table 2. Physical and chemical properties of soil

Text Hydrometer	Clay (%)	Silt (%)	Sand (%)	K (ave.) ppm	P (ave.) ppm	Zn (ave.) ppm	Fe (ave.) ppm	O.C (%)	O.M (%)	Nt (%)	pH of paste	EC
Cl	35.71	38.78	25.51	380	8.16	0.37	3.18	1.33	2.29	0.09	7.48	1.02

Table 3. The amount and different levels of chemical fertilizers, manure and mix of them

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N	0	40	40	80	80	120	120	0	0	0	40	40	80	120
P	0	40	40	80	80	120	120	0	0	0	40	40	80	120
K	0	0	40	40	80	80	120	0	0	0	0	40	40	80
M	0	0	0	0	0	0	0	15	30	40	15	15	30	40

Chemical fertilizer units are N, P and K (40, 80 and 120) kg ha⁻¹, M (15,30 and 40) ton ha⁻¹

Table 4. The elements in the Nano- iron Chelate Kh

Elements	Fe	Zn	Mg	Na	S
Wt. %	9	1	1	10	9.5

Fertilizer treatments were from Iron Chalat of Khazra with different amount of micro nutrients that were applied in harvesting flower years.

Table 5. Time and number of spraying with Iron Chelate

Timing of spray	Control	One time=1	Two times=2	Three times=3
Beginning of flowering		*	*	*
7 days after flowering				*
10 days after flowering			*	
14 days after flowering				*

* means spraying

With the onset of flowering, the amount of water used for spraying a plant with water on 30 plants was calculated. Then 4 g of iron chelated fertilizer for each plant (according to the manufacturer), Due to anticipated treatments (0, 1, 2 and 3 times) and as shown in Table 5, early morning or sunset and no wind conditions was sprayed. Start date spraying, May, and for every two years, coinciding with the beginning of flowering. During the harvest period, data were recorded on a daily basis and the following characteristics were measured.

2.1. The number of flowers per plant

Flowers of each plant were harvested on a daily basis during the flowering period and in the yield table was recorded. To collect flowers, paper envelopes that plant number, row and repeat was written on it was used.

2.2. Fresh flower weight in hectare

Each plant flowers after picking and counting were separated from other parts of the flower (Sepals, receptacle and part of the peduncle) and weight with a digital scale and on the table were recorded in gram. This work was

occurred on a daily basis, from the beginning of flowering until the end of it for each plant. In the end, the necessary calculations to determine the yield per hectare was carried out.

2.3. The essential oil extraction

After harvest, counting and separating from other parts of the flower petals, flowers related to distillation stored in the refrigerator at 4 °C and every 4-6 days, distillation was carried out. For distillation, 200-500 g of fresh flowers from each treatment poured into boilers and for every 100 grams of fresh petals, 1 liter of water were added to it and for two hours, using water distillation method, essential oils were extracted. Finally, the mean of total period was compared for different treatments.

2.4. Statistical analysis

The experiment was conducted in split-plot in the form of a randomized complete block design with three replications. The main factors were 14 macro fertilizers (chemical fertilizer in 6 levels, manure in 3 levels, Combination of manure and chemical fertilizers in 4 levels and without use any fertilizers. sub factor was spraying Khazra Iron Chelate in 4 levels (0, 1, 2 and 3 times). However, due to the implementation of the experimental design over two years, statistical analysis of the data was performed as a split-split plot in the form of a randomized complete block design with three replications. The main factors were two years, sub factor was chemical fertilizer, manure in 3 levels, Combination of manure and chemical fertilizers and without use any fertilizers (control). Sub-sub factor was spraying Iron Chelate in 4 levels.

Analyses of the statistics and data on the application components were done using SAS software and comparison of averages at $\alpha \geq 0.05\%$ level. Analyses of growth process data were done using excel software.

3. Results and discussion

3.1. The effect of fertilization treatments on rose yield and some yield characteristics

The analysis of variance revealed that both macro- and microelement fertilization had highly significant effects ($p \leq 0.01$) on key quantitative traits including the number of flowers per plant, petal yield per hectare, essential oil percentage, and essential oil yield. Year-to-year variation also significantly influenced all these traits, emphasizing the role of environmental factors. A significant interaction between year and macro fertilizer was observed for all the traits listed, while the interaction between year and micro fertilizer was only significant for the number of flowers per plant. Additionally, the triple interaction (year $\times$ macro $\times$ micro) was significant for the number of flowers per plant, petal yield per hectare, and essential oil percentage, but not for essential oil yield, suggesting that this latter trait is less influenced by complex interactions and may respond more consistently to specific nutrient regimes (Table 6)

The composition of rose essential oil was significantly influenced by fertilization treatments, as indicated in Table 6. Macro fertilizers had a statistically significant effect on all major oil constituents, including citronellol, heptadecane, hexadecanol, nonadecene, eicosene, heneicosene, docosane, and tricosene. Similarly, microelement foliar sprays significantly affected most of these compounds, with the exception of tricosene. Notably, treatments combining high doses of macro fertilizers with repeated microelement sprayings such as N120P120K120 applied alongside three foliar sprays resulted in enhanced concentrations of key aromatic compounds like citronellol and nonadecene. These compounds are known for their major contribution to the characteristic fragrance of *Rosa damascena* essential oil. Interestingly, year-to-year variation had no significant effect on any of the essential oil components. This suggests that the biosynthesis of these volatile compounds is more strongly governed by internal plant metabolic controls and nutrient availability than by external environmental factors (Table 6).

3.2. The effect of years on rose yield and some yield characteristics

The comparison of yearly means indicated that the first year significantly outperformed the second year across all measured traits. The highest number of flowers per plant ($4252 \text{ n plant}^{-1}$), petal yield per hectare ($3967.7 \text{ kg ha}^{-1}$), essential oil percentage (0.062%), and essential oil yield (2675 g ha^{-1}) were all recorded in the first year. These differences were statistically significant, as denoted by differing letters (a vs. b), underscoring the substantial influence of environmental conditions on *Rosa damascena* productivity (Table 7).

Table 6. Analysis of variance, the effect uses of macro and of spraying of micro fertilizers on rose flowering traits in two years

S.O.V	df	The number of flower in plant	The yield of petal in hectare	Essential oil percentage	Essential oil yield	Citronellol	Heptadecane	Hexadecanol	Nonadecene	Eicosene	Heneicosene	Tricosene
Year (Y)	1	49306188**	37019	0.04**	11776**	0.00	0.00	0.04	0.19	0.34	3.26	0.10
Error Y	4	205036	89463	0.0005	31	0.08	2.97	5.05	10.75	6.85	62.85	11.23
Ma	13	45166042**	2468660**	0.004**	3879	1.41**	20.52**	15.65**	62.33**	17.37**	135.34**	33.23**
Y*Ma	13	6286627**	529432**	0.0006**	232.8**	0.01	0.04	0.05	0.09	0.71	1.11	0.07
Error Ma	52	58306	6439	0.0001	93.26	0.12	0.71	1.03	3.61	1.3	10.75	1.53
Mi	3	18289089**	1565289**	0.001**	1656**	5.60**	1.29**	11.07**	179.01**	3.68**	15.65	25.96**
Y * Mi	3	851247**	92108	0.0001	27.4ns	0.00	0.08	0.14	0.07	0.03	0.36	0.10
Ma*Mi	39	1791085**	251719**	0.0002**	141.81*	1.83**	3.26**	5.93**	50.79**	2.88**	47.85**	14.19**
Y*Ma*Mi	39	1108679**	121578**	0.00009*	82.6ns	0.00ns	0.04	0.07	0.31	0.03	0.34	0.07
Error	168	142385	58790	0.0002	93.63	0.11	0.24	0.22	5.73	0.14	11.34	0.72
Cv%	-	9.75	12.56	29.91	22.62	21.30	14.55	7.46	5.30	7.03	10.63	10.14

Macro Fertilizer (Ma), Micro fertilizer (Mi), * & ** Significant at 0.05% and 0.01% level, respectively

Table 7. Mean comparisons of quality and quantity of Rosa in two years

Year	Traits	Mean		
	The number of flower in plant (n plant ⁻¹)	The yield of petal in hectare (kg ha ⁻¹)	Essential oil percentage (%)	Essential oil yield (g ha ⁻¹)
1st	4252a	3967.7a	0.06a	2675a
2nd	3486b	2709.8b	0.03b	1550b

Means with the same letter in the column are not significantly different

3.3. Means comparison of macro element fertilizer treatments

The mean comparison of macro fertilizer treatments revealed that the N120P120K120 combination resulted



Figure 1. Mean comparison effect of macro fertilizer on measurement traits

in the highest values across all evaluated traits. Specifically, this treatment produced an average of 7989.77 flowers per plant, a fresh petal yield of 8036.14 kg ha⁻¹, an essential oil content of 0.077%, and an essential oil yield of

6240 g ha⁻¹. These results indicate a strong positive response of *Rosa damascena* to high-input NPK fertilization, suggesting that full nutrient availability plays a critical role in maximizing both floral biomass and oil production (Figure 1).

3.4. Means comparison of microelement foliar spraying

According to mean comparisons, the highest performance across all measured traits was achieved with three foliar sprayings of microelements. This treatment resulted in the greatest number of flowers per plant (427.07 n plant⁻¹), the highest fresh flower yield per hectare (4598.68 kg ha⁻¹), the highest essential oil percentage (0.054%), and the maximum essential oil yield (2576 g ha⁻¹). These values were significantly greater than those observed in other spraying frequencies, as indicated by the different letters in the mean comparison, highlighting the strong positive impact of repeated microelement applications on *Rosa damascena* productivity (Table 8).

Table 8. Mean comparisons of spraying micro fertilizer on *Rosa* traits

Spraying micro fertilizers	The number of flower in plant (n plant ⁻¹)	The yield of petal in hectare (kg ha ⁻¹)	Essential oil percentage (%)	Essential oil yield (g ha ⁻¹)
Control	3281d	3268c	0.04b	1716b
One time	3709c	3656bc	0.04b	1829b
Two times	4216.5b	4223ab	0.05a	2331a
Tree times	4270.7a	4598a	0.05a	2576a

Means with the same letter in the column are not significantly different

3.5. Treatment comparisons and optimal fertilization regimes

As shown in Table 9, the combined application of N120P120K120 macro fertilizer with three foliar sprayings of microelements resulted in the highest performance for key traits: flower number per plant (8475), essential oil content (0.078%), and essential oil yield (6711.6 g ha⁻¹). In contrast, the highest petal yield per hectare (10117.74 kg ha⁻¹) was achieved under a lower-input macro regime (N40P40M15), also combined with three microelement sprayings. This divergence highlights that optimal petal biomass does not necessarily coincide with the highest flower count or essential oil production. It suggests that different yield components in *Rosa damascena* respond uniquely to nutrient regimes, possibly due to physiological and biochemical allocation patterns. Therefore, fertilization strategies should be tailored to production objectives: high-input treatments such as N120P120K120 with repeated microelement sprays are suitable for maximizing oil yield and concentration, while moderate-fertilizer application like N40P40M15 may be more efficient for producing bulk petal biomass at potentially lower cost.

3.6. Means Comparison of the Year × Macro × Micro Interaction

According to mean comparisons, the most pronounced responses across key traits were observed in the first year under specific fertilization regimes. The highest number of flowers per plant (8946.1 n plant⁻¹) was recorded with the N120P120K120 macro fertilizer combined with three foliar sprayings of microelements. The maximum petal yield per hectare (15621.41 kg ha⁻¹) occurred under the N40P40M15 treatment, also with three sprayings. Interestingly, the highest essential oil content (0.096%) was obtained in the first year under the N120P120K120 regime without any microelement spraying. This suggests that while microelement spraying enhances flower and biomass production, essential oil concentration may peak under high macro element availability alone, possibly due to shifts in plant metabolic allocation. These results emphasize the complexity of nutrient-environment interactions and underscore the importance of fine-tuning fertilization strategies to match specific production objectives under varying seasonal conditions (Table 10).

Table 9. Mean comparisons of the consumption of macro and spraying micro fertilizers

Traits (Macro*Micro)	The number of flowers in plant (n plant ⁻¹)	The yield of petal in hectare (kg ha ⁻¹)	Essential oil percentage (%)	Essential oil yield (g ha ⁻¹)
Control	1118b	1433j	0.034l-p	511l
One time=1	2507xyz	3017d-j	0.031m-p	961h-l
Two times=2	3346o-u	3690d-j	0.046g-p	1687e-l
Tree times=3	2582xyz	3345d-j	0.04j-p	1370f-l
N40P40K0	3501n-s	3468d-j	0.043h-p	1528e-l
N40P40K0*1	2658w-z	2496f-j	0.042i-p	1086h-l
N40P40K0*2	4540fgh	4525c-h	0.051d-m	2339d-k
N40P40K0*3	3943i-n	5005c-f	0.053c-l	2676d-h
N40P40K40	2423yz	3167d-j	0.053c-l	1727e-l
N40P40K40*1	3567m-r	4085d-j	0.047f-o	1997e-l
N40P40K40*2	3580m-r	3730d-j	0.062a-i	2337d-k
N40P40K40*3	3523n-r	3571d-j	0.068a-f	2410d-j
N80P80K40	2572xyz	2585e-j	0.07a-e	1782e-l
N80P80K40*1	2920t-y	2882d-j	0.057b-k	1585e-l
N80P80K40*2	3217q-v	3338d-j	0.063a-i	2227d-l
N80P80K40*3	3608l-r	3841d-j	0.071a-d	2539d-i
N80P80K80	3793j-o	3507d-j	0.064a-h	2328d-k
N80P80K80*1	2758v-z	2707d-j	0.059a-j	1802e-l
N80P80K80*2	3257p-v	3147d-j	0.071a-d	2293d-k
N80P80K80*3	5084cde	4648c-h	0.076ab	3745cd
N120P120K80	4202g-j	4268d-i	0.066a-g	3101def
N120P120K80*1	4518fgh	4577c-h	0.06a-g	3072def
N120P120K80*2	4307.7ghi	4309d-i	0.073abc	3253cde
N120P120K80*3	4988def	4390d-i	0.053c-l	2415d-j
N120P120K120	6882b	6987bc	0.078ab	5455ab
N120P120K120*1	8307a	8073ab	0.075ab	6099a
N120P120K120*2	8293a	8556ab	0.078ab	6693a
N120P120K120*3	8475a	8527ab	0.078a	6711a
M15	4676efg	3987d-j	0.027op	1076h-l
M15*1	4103h-l	3998d-j	0.049e-n	1966e-l
M15*2	5255cd	5295cde	0.041i-p	2217d-l
M15*3	5507c	5340cd	0.044h-p	2362d-k
M30	2500xyz	2507f-j	0.036k-p	850i-l
M30*1	4143h-k	4126d-j	0.039j-p	1602e-l
M30*2	4070h-l	3925d-j	0.039j-p	1543e-l
M30*3	4517fgh	4220d-i	0.046g-p	1956e-l
M40	4553fgh	5141c-f	0.044h-p	2321d-k
M40*1	3733j-q	3640d-j	0.057a-j	2113d-l
M40*2	5049cde	4901c-g	0.059a-j	2871d-g
M40*3	4370ghi	3841d-j	0.062a-i	2384d-j
N40P40M15	2310za'	2264g-j	0.047f-o	1049h-l
N40P40M15*1	3395o-s	3317d-j	0.033l-p	1102h-l
N40P40M15*2	3679k-n	4118d-j	0.03m-p	1238h-l
N40P40M15*3	4440ghi	10117a	0.04j-p	4620bc
N40P40K40M15	2987s-x	2562f-j	0.032l-p	809i-l
N40P40K40M15*1	3099r-w	2744d-j	0.025p	606kl
N40P40K40M15*2	3129r-w	2688d-j	0.035l-p	900i-l
N40P40K40M15*3	2307za'	1982hij	0.038j-p	734jkl
N80P80K40M30	1953a'	1769ij	0.048f-o	816i-l
N80P80K40M30*1	3343o-u	2801d-j	0.033l-p	900i-l
N80P80K40M30*2	3522n-r	3213d-j	0.049e-n	1560e-l
N80P80K40M30*3	3314o-u	2861d-j	0.043h-p	1184h-l
N120P120K80M40	2458yz	2111hij	0.034l-p	666jkl
N120P120K80M40*1	2876u-y	2720d-j	0.029nop	710jkl
N120P120K80M40*2	3779j-p	3681d-j	0.041i-p	1470f-l
N120P120K80M40*3	3124r-w	2686d-j	0.037j-p	953h-l

Table 9. Continued (Percentage of essential oil compounds)

Traits (Macro*Micro)	Citronellol	Heptadecane	Hexadecanol	Nonadecene	Eicosene	henicosene	ricosene
Control	1.29p-t	2.72g-k	7.36c-h	43.25m-r	0.57b-g	29.05i-o	6.57k-o
One time=1	1.62m-t	2.83f-k	6.9f-k	41.73o-s	1.13b	29.72i-o	9.11ef
Two times=2	2.85j-o	2.77f-k	6.78f-l	43.75l-p	0.35c-g	22.10q	8.58fgh
Tree times=3	4.87e-h	2.61h-k	6.13k-p	44.48i-o	0.93c-g	28.94k-p	6.66k-o
N40P40K0	1.7m-t	2.82f-k	7.73cde	44.43j-o	0.55b-g	30.33g-n	7.26hi
N40P40K0*1	1.27p-t	2.61h-k	5.74n-t	47.90a-h	0.38c-g	31.80e-m	6.76k-o
N40P40K0*2	1.25p-t	2.34jkl	5.15s-x	40.65qrs	0.53b-g	37.94abc	9.45ef
N40P40K0*3	2.35k-t	3.10f-k	5.36q-v	46.32c-m	0.52b-g	33.24c-g	8.40fgh
N40P40K40	1.48p-t	3.17e-j	6.54h-n	45.93d-m	0.45b-g	30.26g-n	7.22hi
N40P40K40*1	4.35f-j	3.25e-i	6.15k-p	44.62i-n	0.25efg	37.71abc	9ef
N40P40K40*2	2.19k-t	3.31e-h	6.88f-l	41.24qrs	0.48b-g	29.75i-o	11.11bc
N40P40K40*3	1.52n-t	3.12f-k	6.63h-m	44.63i-n	0.60b-g	31.22e-m	8.90fgh
N80P80K40	1.23p-t	3.31e-h	6.65g-m	46.30c-m	0.58b-g	31.30e-m	7.26hi
N80P80K40*1	6.8c	3.33e-h	5.57o-u	44.35k-p	0.48b-g	28.52k-p	6.39l-q
N80P80K40*2	3.03i-p	3.01f-k	5.03t-x	40.27rs	0.57b-g	34.08b-f	9.48ef
N80P80K40*3	2.9j-r	2.98f-k	5.55p-u	46.24c-m	0.52b-g	33.14c-g	8.01fgh
N80P80K80	1.57m-t	3.59ef	6.11k-r	48.77a-d	0.58b-g	32.79d-h	7.94hi
N80P80K80*1	6.24ce	2.98f-k	5.99l-s	45.08h-n	0.46b-g	29.68i-o	6.39l-q
N80P80K80*2	2.82j-r	3.74e	6.9e-k	45.67e-m	0.52b-g	28.85k-p	7.20hi
N80P80K80*3	2.2k-t	3.59ef	7.07d-i	45.45f-n	0.60b-g	30.45g-n	8.14fgh
N120P120K80	4.66e-i	4.95bcd	8.92a	49.31abc	1.01bc	34.33b-f	10.34cd
N120P120K80*1	1.54n-t	3.79e	8.01bc	46.56b-l	0.63b-g	33.32c-g	8.84fgh
N120P120K80*2	1.9m-t	3.31e-h	6.42j-o	49.63ab	0.29efg	32.34d-h	7.98hi
N120P120K80*3	0.98r-t	2.67g-k	6.85f-l	42.32n-q	0.66b-g	38.25ab	12.14ab
N120P120K120	2.1t	3.35efgh	4.66vwx	47.12a-k	0.62b-g	34.29b-f	10.38cd
N120P120K120*1	1.98l-t	4.75d	7.81cd	48.50a-f	0.52b-g	32.41d-h	7.77hi
N120P120K120*2	5.15efg	2.82f-k	5.23r-w	43.12m-r	0.68b-g	28.65k-p	9.88ef
N120P120K120*3	1.33p-t	2.77f-k	6.66g-m	39.18s	0.81b-f	33.15c-g	13.36a
M15	1.51n-t	3.57ef	6.85f-l	48.51a-f	0.78b-g	33.35c-g	9.29ef
M15*1	2.87j-r	4.83cd	6.96d-j	49.23abc	0.98bcd	34.56b-f	9.49ef
M15*2	9.77a	5.84a	7.74cde	48.14a-h	2.64a	37.74abc	7.08hi
M15*3	3.76g-l	2.42jkl	4.41wx	39.27s	0.72b-g	39.40a	12.34ab
M30	3.27i-n	4.56d	7.34c-i	50.28a	0.65b-g	36.61a-d	9.10ef
M30*1	2.87j-o	3.30e-h	7.52c-g	48.64a-e	0.68b-g	35.27-a-e	9.88ef
M30*2	9.76a	5.54abc	6.45i-o	45.33f-n	0.50b-g	30.17g-n	7.42hi
M30*3	3.14i-o	5.58ab	8.85a	48.50a-f	0.65b-g	31.31e-m	8.79fgh
M40	3.4h-m	4.77d	8.66ab	47.55a-k	0.83b-f	32.51d-h	8.94fgh
M40*1	2.7j-s	6.27a	5.66o-t	49.28abc	0.61b-g	33.38c-g	10.56cd
M40*2	2.1k-t	5.72a	7.82cd	48.42a-g	0.52b-g	31.33e-m	8.77fgh
M40*3	5.92def	5.73a	6.58h-n	45.33f-n	2.28a	31.54e-m	9.85ef
N40P40M15	1.14q-t	3.76e	7.56c-f	43.60l-q	0.42c-g	29.39i-o	6.82k-o
N40P40M15*1	3.83g-k	2.29kl	5.23r-w	47.69a-i	0.20efg	30.52g-n	5.85n-t
N40P40M15*2	2.34k-t	1.66l	4.46wx	39.23s	0.38c-g	35.34a-e	9.20ef
N40P40M15*3	1.66m-t	2.27kl	4.64vwx	45.30f-n	0.31d-g	30.29g-n	7.57hi
N40P40K40M15	1.07q-t	2.77f-k	5.82m-t	45.23g-n	0.22efg	29.48i-o	6.74k-o
N40P40K40M15*1	5.32efg	2.88f-k	5.24r-w	43.09n-r	0.09g	25.49pq	8.82fgh
N40P40K40M15*2	1.34p-t	2.64h-j	6.80f-l	39.37s	0.52b-g	30.15g-n	11.48bc
N40P40K40M15*3	1.22p-t	2.59h-k	5.82m-t	45.42f-n	0.29efg	30.38g-n	6.30l-q
N80P80K40M30	0.88st	2.69g-k	6.07k-r	45.43f-n	0.38c-g	30.52g-n	6.53l-q
N80P80K40M30*1	9.08a	2.85f-j	4.74u-x	45.25f-n	0.13fg	25.77n-q	5.12n-t
N80P80K40M30*2	1.76m-t	1.44m	3.45y	35.71t	0.33c-g	35.27a-e	9.62ef
N80P80K40M30*3	1.24p-t	2.53h-k	4.33x	49.35abc	0.20efg	29.42i-o	5.85n-t
N120P120K80M40	0.66t	2.61h-k	5.55p-u	45.36f-n	0.28efg	30.11g-n	6.95k-o
N120P120K80M40*1	7.65c	2.55h-k	5.44q-v	43.17m-r	0.21efg	27.34lp	5.47n-t
N120P120K80M40*2	1.13q-t	3.51efg	6.88f-l	45.39f-n	0.35c-g	28.30k-p	6.80k-o
N120P120K80M40*3	2.47k-t	2.79f-k	5.73n-t	44.17k-p	0.32d-g	29.33i-o	6.94k-o

Means with the same letter in the column are not significantly different, not spraying with Iron Chelate=control, one time spraying with Iron Chelate=1, two times spraying with Iron Chelate=2, three times spraying with Iron Chelate=3

3.7. Correlations between rose yield and yield traits

Correlation analysis showed significant positive relationships among key agronomic and biochemical traits of *Rosa damascena*. The number of flowers per plant exhibited strong correlations with petal yield ($r = 0.61^{**}$), essential oil percentage ($r = 0.45^{**}$), and particularly with essential oil yield ($r = 0.75^{**}$). Petal yield was also significantly correlated with oil percentage ($r = 0.21^{**}$) and oil yield ($r = 0.83^{**}$). Moreover, a substantial correlation was found between essential oil percentage and oil yield ($r = 0.66^{**}$). These results suggest that enhancing flower production tends to increase both petal biomass and oil yield. However, the relatively lower correlation between flower or petal yield and oil concentration indicates that essential oil percentage may be influenced by more complex physiological and biochemical processes, including potential saturation effects or nutrient partitioning dynamics (Table 10).

Table 10. The correlation between the traits of *Rosa damascena* affected macro and micro fertilizers

Traits	The number of flowers per plant	Flower yield per hectare	Essential oil percentage	Essential oil yield
The number of flowers per plant	1			
Flower yield per hectare	0.61**	1		
Essential oil percentage	0.45**	0.21**	1	
Essential oil yield	0.75**	0.83**	0.66**	1

**significant correlation at 1% level

4. Discussion

The pronounced inter-annual variation in key traits namely flower number, petal yield, essential oil content, and oil yield highlights the substantial influence of environmental conditions on the productivity of *Rosa damascena*. As shown in Table 7, the first year outperformed the second across all major traits, underscoring the year-specific impact of climatic variability. Interestingly, although plant height and branching increased in the second year, this did not translate into greater floral or oil yields, possibly reflecting stress-related resource reallocation or nutrient imbalances (Abbaszadeh et al., 2014).

Analysis of variance (Table 6) and comparative trait analysis (Tables 7–9) confirmed that both macro- and microelement fertilization significantly influenced floral and essential oil traits. Among the tested treatments, the combination of N120P120K120 with three foliar microelement sprayings produced the most favorable results, achieving the highest flower number (8475 n plant⁻¹), essential oil content (0.078%), and oil yield (6711.6 g ha⁻¹). This synergy supports the effectiveness of integrated nutrient management strategies, in line with findings by Rahmani et al. (2013), who also reported interaction effects between fertilization regimes and seasonal variation.

Microelement foliar applications notably enhanced both floral and oil-related traits, particularly with repeated application. This confirms the efficacy of foliar feeding in directly targeting metabolically active tissues, thereby bypassing potential soil-based uptake limitations or antagonistic interactions (Jeevaa et al., 2025; Pannico et al., 2023; Aktepe et al., 2019). The benefits of foliar nutrition are especially pronounced under conditions of potential root zone limitations or stress, such as those potentially induced by soil pathogens like *Fusarium* or *Pythium* (Rajendran et al., 2025), where rapid and localized nutrient delivery becomes essential.

Correlation analysis (Table 10) further substantiates these findings, revealing strong positive associations between flower number, petal yield, essential oil content, and oil yield. Notably, the robust correlation between flower number and oil yield ($r = 0.75^{**}$) highlights floral productivity as a key determinant of oil output. However, the essential oil percentage itself exhibited more modest correlations, suggesting that its regulation involves more complex, possibly saturation-limited biochemical pathways.

Importantly, maximum petal biomass did not necessarily coincide with peak oil production. The N40P40M15 treatment combined with three microelement sprays, for example, yielded the highest petal biomass (10117.74 kg/ha) but did not produce the highest essential oil yield. This divergence illustrates the distinct physiological underpinnings of primary growth (biomass accumulation) and secondary metabolism (essential oil biosynthesis). Ali et al. (2023) similarly reported that while potassium and zinc foliar treatments enhanced both flower and oil metrics in *Rosa damascena*, peak flower yield did not always align with peak oil content. These findings emphasize

the need to tailor fertilization strategies based on targeted production goals whether prioritizing biomass for floral products or maximizing oil quality and quantity.

The essential oil composition was also significantly modulated by fertilization regimes. As presented in *Table 6*, high-input macro element treatments (especially N120P120K120) in combination with multiple foliar sprays significantly enhanced the concentrations of key aromatic compounds such as citronellol and nonadecene. These constituents are critical for the fragrance quality of rose oil, and their enhancement through nutrient management supports the role of fertilization in value-added trait optimization. Interestingly, year-to-year variation did not significantly influence essential oil composition, suggesting that internal plant regulatory mechanisms and nutrient availability exert stronger control over secondary metabolite biosynthesis than external environmental factors. These results align with findings by Ghavam (2021) and Izgi (2022), who demonstrated nutrient-dependent modulation of essential oil profiles, especially in relation to potassium and phosphorus availability.

In conclusion, this study demonstrates that the quantity and quality of *Rosa damascena* products can be strategically optimized through carefully designed macro- and microelement fertilization regimes. High-input systems such as N120P120K120 combined with triple foliar applications of microelements are most effective for maximizing oil yield and composition. In contrast, moderate-input regimes like N40P40M15 may be more suitable for producers focused on petal biomass. These results, consistent with findings by Kant et al. (2023), reinforce the importance of context-specific nutrient management strategies that are tailored to specific production objectives and responsive to environmental variability. Future research should consider integrating these agronomic insights with economic analyses to guide sustainable and cost-effective rose cultivation practices.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Abbaszadeh, B.; Design: Abbaszadeh, B., Ağamirzaoğlu, M., Valizadeh, N.; Data Collection or Processing: Valizadeh, N., Abbaszadeh, B., Ağamirzaoğlu, M.; Statistical Analyses: Abbaszadeh, B., Valizadeh, N., Ağamirzaoğlu, M.; Literature Search: Valizadeh, N., Ağamirzaoğlu, M., Baran, M. F.; Writing, Review and Editing: Valizadeh, N., Abbaszadeh, B., Ağamirzaoğlu, M., Baran, M. F.

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