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Araştırma Makalesi/*Research Article*

Response of Rose (*Rosa damascena Mill.*) Oil Components to Different Irrigation Water and Nitrogen Applications

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Abstract

In this study, the effects of different irrigation water amounts and nitrogen doses on the components of rose oil obtained from rose flowers harvested in different periods were investigated in oil rose (Rosa damascena Mill.). The experiment was set up in Süleyman Demirel University Agricultural Research and Application Center and carried out according to the randomized block factorial experimental design with 3 replications. The experiment trials were created as 4 irrigation water amounts created depending on Class A pan (T_0: 0.00, T_1: 0.40, T_2: 0.80, T_3: 1.20) and 4 nitrogen levels (N_0: 0 kg N da^{-1}, N_1: 8 kg N da^{-1}, N_2: 16 kg N da^{-1}, N_3: 24 kg N da^{-1}, pure substance). Irrigation was carried out at 10-day intervals by drip irrigation method. According to the study results, differences were observed in the ratios of citronellol, geraniol and nerol which are the important components of rose oil according to the trial subjects. Citronellol ratios were 19.41-38.25 (1st year: 25.35-34.40; 2nd year: 19.41-30.10; 3rd year: 24.16-38.25) and geraniol ratio was 9.62-35.36 (1st year: 27.86-33.87; 2nd year: 28.12 -35.36; 3rd year: 9.62-26.62). The C/G ratio was found to be 0.91, 1.00, 1.16, 1.61 and 1.40 in the 1st, 2nd, 3rd and 4th harvest periods, respectively.

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Farklı Sulama Suyu ve Azot Uygulamalarının Yağ Gülü (*Rosa damascena Mill.*)'nün Uçucu Yağ Bileşenlerine Etkisi

Öz

Farklı sulama suyu ve azot dozlarının, beş farklı dönemde hasat edilen yağ gülünden (Rosa damascene Mill.) elde edilen gül yağı bileşenleri üzerine etkisi araştırılan bu çalışma, Süleyman Demirel Üniversitesi Tarımsal Araştırma ve Uygulama Merkezi'nde, tesadüf blokları faktöriyel deneme desenine göre 3 tekrarlamalı olarak yürütülmüştür. Deneme konuları, Sınıf A sınıfı buharlaşma kabına bağlı olarak oluşturulan 4 sulama suyu miktarı (T0: 0.00, T1: 0.40, T2: 0.80, T3: 1.20) ve 4 azot dozu (N_0: 0 kg N da^{-1}, N_1: 8 kg N da^{-1}, N_2: 16 kg N da^{-1}, N_3: 24 kg N da^{-1}, saf madde) olacak şekilde oluşturulmuştur. Sulamalar, damla sulama yöntemi ile 10 günlük aralıklarla uygulanmıştır. Çalışma sonuçlarına göre, gül yağının önemli bileşenleri olan sitronellol, geraniol ve nerol oranlarında deneme konularına göre farklılıklar görülmüştür. Sitronellol oranları 19.41-38.25 (1.yıl: 25.35-34.40; 2.yıl: 19.41-30.10; 3.yıl: 24.16-38.25), geraniol oranı ise 9.62-35.36 (1.yıl: 27.86-33.87; 2.yıl: 28.12 -35.36; 3.yıl: 9.62-26.62) olarak bulunmuştur. C/G oranları 1., 2., 3. ve 4. hasat dönemlerinde sırasıyla 0.91, 1.00, 1.16, 1.61 ve 1.40 olarak bulunmuştur.

Anahtar Kelimeler
Azot
Isparta
Gül yağı bileşenleri
Sulama
Yağ gülü

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Introduction

Oil rose (Rosa damascena Mill.) is a scented rose species with the highest economic value for the perfume, cosmetics, pharmaceutical and food industries. Turkey is one of the most important oil rose production centers in the world, together with Bulgaria, with its 2500 hectare production area. In Turkey, where the first oil rose production started in 1888, Isparta (Baydar, 2006), Afyonkarahisar, Burdur and Denizli provinces, also known as the Lakes Region, are important production centers of oil rose. The most important products obtained from oil rose are rose oil, rose concrete, rose absolute and rose water.

Rose flower yield, content and quality of essential oil obtained from rose flower are affected by many parameters such as genotype, growing location, growing season, relative humidity, irrigation, fertilization, harvest time, fermentation period of leaves and distillation processes (Weiss, 1997). Baydar and Göktürk Baydar (2005) stated that the rose oil yield varies during the harvest period (May and June) and that the rose oil yield, which is 0.04% in May, is 0.03% in June. Kazaz (1997) stated that rose flower harvest should be done in the early morning hours to increase the essential oil yield.

Water deficit stress is one of the most important abiotic stresses and when combined with nitrogen deficiency in plant cultivation, its effect on yield and quality is higher. As in other plants, limited water and nitrogen applications in Rosa Damascena Mill. significantly affect rose flower yield, essential oil yield (Ucar et al., 2017) and some essential oil components (Ashourabadi et al., 2024). Water deficit reduces the growth and essential oil production of medicinal and aromatic plants in arid and semiarid regions (Farahani et al. 2021). Ashourabadi et al. (2024) reported that citronellol, and geraniol, which are important components of essential oil, increased due to water deficit stress and included 24.48 and 2.89%, respectively. On the other hand, Kiymaz et al. (2022) reported that water stress increased essential oil quality as water stress increased with diminished applied water. Farahani et al. (2021) showed that water stress resulted in 52.4, 46.4, and 43.2% increase in the concentrations of geraniol, citronellol, and nerol.

In this study, the effects of different irrigation water and nitrogen doses on the essential oil components of Rosa Damascena *Mill.* were investigated.

Material and Method

Plant material, planting, and experimental design

The research was conducted in the rose garden of the Rose and Rose Products Research Center in the Agricultural Research and Application Center of Süleyman Demirel University (Figure 1). The experimental area is located between latitude 37.83° and longitude 30.53° and the average altitude is around 1020 m above sea level. Isparta Province, where the research was conducted, is in the Mediterranean Region of southwestern Turkey. According to the long-term climate data of the research area, the average temperature is 11.97 °C, the average relative humidity is 61.1%, the average wind speed is 1.97 m s^{-1}, the annual average sunshine duration is 7.4 hours, and the annual total precipitation is 505.7 mm (Anonymous, 2009).

The study was set up in a randomized complete block design with 3 replications in a factorial arrangement. The plots were composed of 1×10 m rose rows, and a 2 m gap (unirrigated and unfertilized) was left between the plots. In the experiment, 4 different water levels (as Class A evaporation cup coefficient; T_0: 0.0, T_1: 0.40, T_2: 0.80, T_3: 1.20) and 4 different nitrogen levels (N_0: 0 kg da^{-1}, N_1: 8 kg da^{-1}, N_2: 16 kg da^{-1}, N_3: 24 kg da^{-1}; as pure substance) were used. The specified nitrogen doses were calculated as pure substance and ammonium nitrate (33% N) was used as the nitrogen fertilizer source.

The field capacity of the soils in the study area is 429.03 mm/120 cm, the wilting point is 253.35 mm/120 cm, and the available water-holding capacity is 175.68 mm/120 cm. The bulk density in the 0-120 cm layer ranged from 1.30 g cm^{-3} to 1.42 g cm^{-3}, and the soil texture is classified as clay-loam. A 16 mm diameter in-line type lateral was used, and each plant row was irrigated with two lateral tubes. Based on the soil infiltration rate (15.5 mm h^{-1}), the emitter spacing was set at 0.50 m, and the emitter discharge was 4 l h^{-1} under pressure above 1 atmosphere. Consequently, the wetted area ratio was determined to be 33%, following the methodology of Keller and Bliesner (1990). Irrigation began at the beginning of May and ended at the end of September. In the first and second years of the experiment, irrigation was performed 15 times, while in 2012, it was performed 6 times.

Determination of main components in rose oil

In this study, the essential oil properties of Rosa damascena Mill., which is produced intensively in Turkey (especially in the Isparta, Burdur and Afyonkarahisar regions) and is also known as Isparta rose or oil

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rose, were investigated. Citronellol, geraniol, nerol, phenylethyl alcohol and linalool, which are the main active ingredients of rose oil and give rose oil its characteristic odor, were determined. The main components in rose oil were determined by GC/MS at Süleyman Demirel University, Experimental and Observational Research and Application Center according to Başer et al., (1990), Bayrak et al., (1994) and Baydar and Göktürk Baydar, (2005).

Figure 1. Experimental area.

Irrigation water

Class A Pan at the meteorological station located in the research area and used for agricultural purposes was used to determine the irrigation water applied to the experimental trials. Daily evaporation values measured from the Class A Pan were calculated cumulatively at 10-day intervals according to the rates specified in the trials using Equation 1 adapted from Ucar et al. (2017).

$$I = A \times T \times E_0 \times P \quad (1)$$

Where;

I: Irrigation water amount, liter, A: Plot area, m^2, T: Coefficient of Class A Pan, E_0: Cumulative evaporation amount in the irrigation interval, mm and P: Wetted area, %.

Harvest dates

Chemical component analyses of rose oils obtained from rose flowers harvested in 5 different periods in each of the three years of the experiment were carried out; in 2010; on 25 May (1st period), 29 May (2nd period), 05 June (3rd period), 11 June (4th period) and 17 June (5th period); in 2011; on 06 June (1st period), 13 June (2nd period), 17 June (3rd period), 21 June (4th period) and 26 June (5th period); in 2012; on 31 May (1st period), 05 June (2nd period), 11 June (3rd period), 15 June (4th period) and 20 June (5th period).

Results and Discussion

Although there are many components in the composition of rose oil, the most important ones are citronellol, geraniol, nerol, nonadecane, nonadecene, heneicosan, eicosan, tricosan, methyl eugenol, geranyl acetate and phenylethyl alcohol (Garnero, 1982; Baser, 1992; Bayrak and Akgul, 1994). However, among these components, the characteristic odor of rose oil is given especially by monoterpene alcohols (citronellol, geraniol and nerol), which are the main components of rose oil (Garnero, 1982; Baser, 1992; Bayrak and Akgul, 1994). Most of the international studies have focused on monoterpene alcohols such as citronellol, nerol and geraniol. Therefore, in our study, we focused on citronellol, geraniol and nerol. In addition, detailed information is given in the study about the citronellol/geraniol (C/G) ratio (Konur, 1990), which was first used in 1934 to simplify the comparison of oil components and to determine the quality of Bulgarian rose oil.

The components determined in rose oils obtained from rose flowers harvested according to the treatments in a total of 5 different harvest periods [(1st period; 25 May) (2nd period; 29 May) (3rd period; 05

 DOI: 10.54975/sduzfd.1597112

June) (4th period; 11 June), (5th period; 17 June)] in the 2010 rose flower harvest season are presented in Appendix (Table 1 and Table 6). Among all harvest periods, the highest citronellol rate was obtained in T_0N_2 with 47.71% on June 11, the 4th harvest period, followed by T_1N_2 in the last harvest period with 46.17%. The lowest citronellol rate was obtained in T_1N_1 in the first harvest period (May 25) with 19.74%. When the 2010 rose oil samples were evaluated only according to the treatments without considering the harvest periods in terms of average citronellol rates, the highest average citronellol rate among the treatments was determined in T_3N_3 with 34.40%, followed by T_0N_2 and T_3N_2 subjects with 32.72% and 32.25%, respectively (Figure 2). When the average citronellol rates of the harvest periods were evaluated without considering the treatments, the highest average citronellol rate was found in the 4th harvest (June 11) (32.78%), and the lowest average citronellol rate was found in the first harvest period (May 25) with a rate of 26.62% (Figure 2). Among all harvest periods, the highest geraniol content was obtained with 43.53% in T_2N_2 during the first harvest period (May 25), and the lowest geraniol content was obtained with 15.47% in T_1N_1 during the last harvest period (June 17). When the average geraniol content was evaluated only according to the treatments without considering the harvest periods, the highest average geraniol content was determined in T_2N_2 (33.87%), T_2N_3 (33.77%) and T_0N_3 (33.37%), while the lowest average geraniol content was determined in T_3N_3 (27.86%) treatments (Figure 2). When the average geraniol content in rose oils was evaluated in terms of harvest periods, the highest average geraniol content was obtained in the first harvest period, May 25 (38.43%), while the lowest average geraniol content was obtained with 23.33% in the last harvest period (June 17). Among all treatments, the highest nerol rate was determined in T_0N_3 (%20.22), and the lowest nerol rate was determined in T_0N_0 (%4.94). When the average nerol rates were evaluated only according to the trial subjects without considering the harvest periods, the highest average nerol rates were determined in T_2N_3, T_1N_3 and T_3N_1 with 14.43%, 14.40% and 14.06%, respectively, while the lowest average nerol rate was determined in T_0N_2 with 11.48% (Figure 2). When only the harvest periods were evaluated in terms of average nerol rate without considering the trial subjects, the highest average nerol rate (%17.76) was obtained from the 1st harvest period on 25 May, while the lowest average nerol rate (%8.78) was obtained from the 4th harvest period on 11 June.

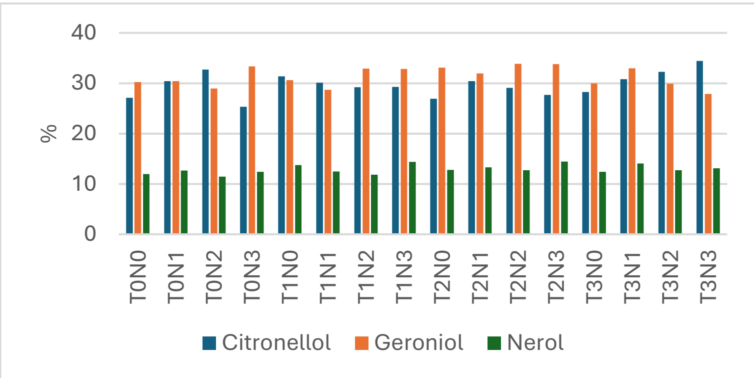

Figure 2. Citronellol, geraniol and nerol values in 2010.

When the rose oil samples obtained in 2011 were evaluated only according to the treatments (different nitrogen and irrigation levels) in terms of average citronellol content, the highest average citronellol content was determined in T_1N_0 with 30.10%, followed by T_1N_3 and T_0N_0 subjects with 29.99% and 29.78%, respectively. The lowest average citronellol content was obtained from T_1N_1 with 19.41% [Appendix (Table 2 and Table 5)]. When the harvest periods are taken into consideration, the highest average citronellol content was determined in the first harvest period, June 06 (31.11%), and the lowest average citronellol content was determined in the last harvest period, June 26 (21.97%) (Figure 3). When the average geraniol rates in rose oils were evaluated in terms of harvest periods, the highest average geraniol rate was obtained in the second harvest period, June 13 (37.94%), while the lowest average geraniol rate was obtained in the 4th harvest period (June 21) with 25.33%. When the average geraniol rates were evaluated according to the treatments without considering the harvest periods, the highest average geraniol rates were determined in

T_0N_1 (35.83%) and T_2N_1 (35.36%), while the lowest average geraniol rates were determined in T_0N_2 (29.49%), T_1N_0 (29.70%) and T_0N_0 (29.90%) treatments (Figure 3). When the average nerol rates were evaluated only according to the treatments without considering the harvest periods in the study, the highest average nerol rates were determined as 13.80%, 13.74% and 13.01% in T_3N_2, T_1N_3 and T_3N_1, respectively, while the lowest average nerol rates were determined as 10.65% and 10.68% in T_3N_3 and T_0N_3, respectively. When the average nerol rates were evaluated only considering the harvest periods, the highest average nerol rate (14.38%) was obtained from the 2nd harvest period on June 13, while the lowest average nerol rate (9.33%) was obtained from the 4th harvest period on June 21 (Figure 3).

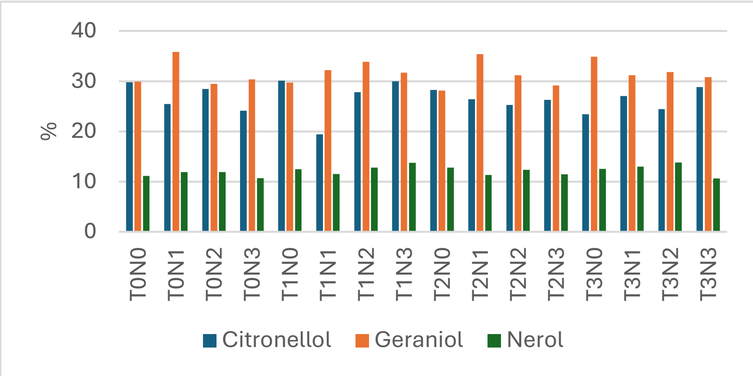

Figure 3. Citronellol, geraniol and nerol values in 2011.

Among all harvest periods in 2012, the highest citronellol rate was obtained in T_3N_2 with 58.59% on 20 June, the last harvest period, and this was followed by T_1N_3 and T_1N_1 subjects with 57.71% and 54.43%, respectively, in the same harvest period. The lowest citronellol rate was obtained in T_0N_1 subject with 11.00% on 05 June harvest. When the average citronellol rates were evaluated only according to the treatments, the highest average citronellol rate was determined in T_1N_1 with 38.25%, followed by T_3N_2 and T_1N_3 subjects with 37.08% and 36.34%, respectively (Figure 4). Among the harvest periods, the highest average citronellol rate was determined on 20 June (42.12%), the last harvest period, and the lowest average citronellol rate was determined in the second harvest period, 05 June (21.82%). Among all harvest periods, the highest geraniol content was obtained from T_2N_0 with 37.04% in the harvest period of June 15, and the lowest geraniol content was obtained from T_3N_0 with 2.14% in the harvest period of June 11. When the average geraniol content in rose oils was evaluated in terms of harvest periods, the highest average geraniol content was obtained in the first harvest period of May 31 (23.34%), followed by the harvest of the last harvest period of June 20 (19.83%). The lowest average geraniol content was obtained in the 3rd (June 11) and 4th (June 15) harvest periods with 13.38% and 13.88%, respectively. When the average geraniol rates were evaluated according to the treatments, the highest average geraniol rates were determined in T_2N_0 (26.62%) and T_3N_3 (25.87%), while the lowest average geraniol rates were determined in T_0N_2 (11.76%) and T_1N_1 (11.92%) experimental subjects (Figure 4). When the harvest periods and experimental subjects were evaluated together in terms of nerol rate, the highest nerol rate was determined with 15.89% in T_3N_3 during the last harvest (June 20) period, and the lowest nerol rate was determined with 0.39% in T_1N_1 during the 3rd harvest (June 11) period [Appendix (Table 6)]. When the treatments were evaluated in terms of average nerol rate, the highest average nerol rates among the treatments were determined with 10.26% and 8.88% in T_3N_3 and T_1N_0, respectively, while the lowest average nerol rate was determined with 3.62% in T_0N_2 (Figure 6). When the harvest periods were evaluated in terms of average nerol content, the highest average nerol content (8.81%) was obtained from the 3rd harvest period on June 15, while the lowest average nerol content (3.95%) was obtained from the 3rd harvest period on June 11.

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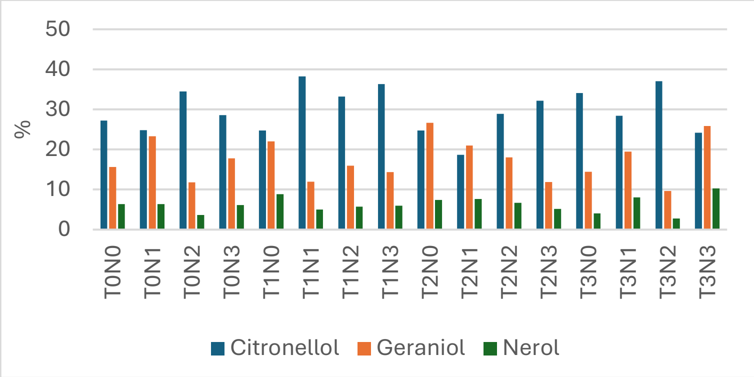

Figure 4. Citronellol, geraniol and nerol values in 2012.

Citronellol/Geraniol (C/G) ratio, which is an important criterion in determining the quality of rose oil, showed differences in rose oils obtained from rose flowers harvested from different periods and different treatments. In 2010, the highest average S/G ratio among the treatments was determined as 1.23 (T_1N_3), 1.01 (T_1N_0) and 3.85 (T_3N_2) in 2011 and 2012, respectively, while the lowest C/G ratios in the same years were determined as 0.76 (T_0N_3), 0.60 (T_1N_1) 0.93 (T_2N_0, T_3N_3), respectively. When the harvest periods are considered, the highest C/G as an average of 3 years was determined as 1.61 in the 4th period, while the lowest C/G was determined as 0.91 in the first harvest period (Figure 5).

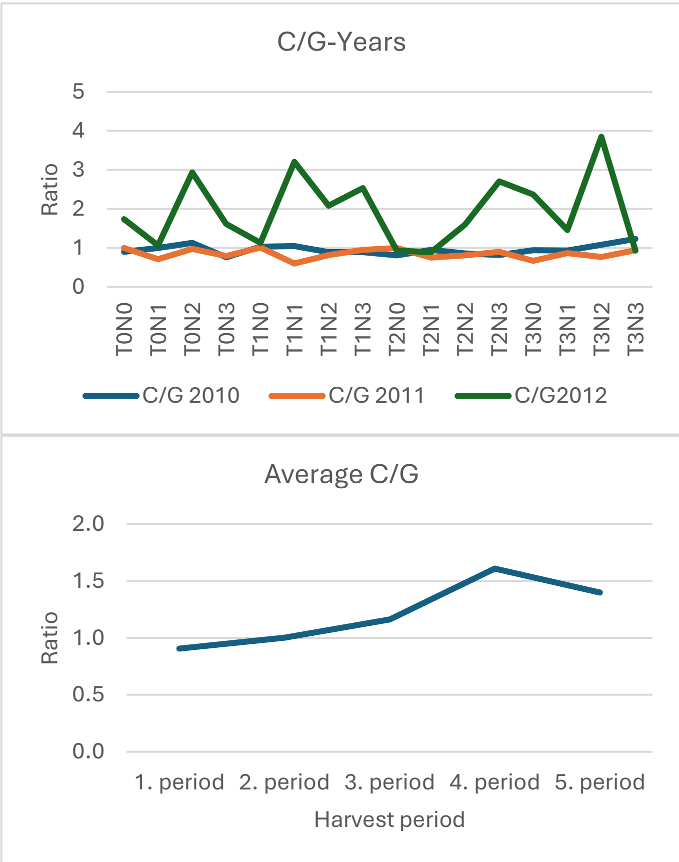

Figure 5. C/G ratios according to treatments and harvest periods.

It has been reported that the basic rose character of rose oil is determined by its citronellol content and that higher citronellol content increases sweetness and main odor when combined with equal amounts of geraniol, whereas when geraniol is low, the main odor and sweetness persist (Kürkçüoğlu, 1995). Also, nerol, one of the important components of volatile oils, not only increases the rose character but also gives a freshness character to rose oil, but when the geraniol content is low, the freshness character of nerol

 DOI: 10.54975/sduzfd.1597112

appears as a very little citrus character, and when the geraniol content is high, the combination of citronellol, geraniol, farnesol and nerol gives it a strong, sweet, floral, fresh and rose character (Kürkçüoğlu, 1995). The citronellol, geraniol and nerol ratios in Turkish rose oils vary between 25-50%, 8-16% and 3-12% (Başer, 1992; Bayrak and Akgül, 1994), and in Bulgarian rose oils they vary between 22-55%, 14-18% and 5-10% (Garnero, 1982; Kürkçüoğlu, 1988). In our study, it was determined that citronellol ratios varied between 19.74-47.71%, geraniol ratios varied between 19.91-43.53% and nerol ratios varied between 4.94-20.22% among the harvest periods and treatments. It was determined that the values obtained for citronellol were generally in accordance with the lower and upper limit values of the previously reported values in Turkish rose oils, although the lower and upper limits showed differences. It was determined that the lower and upper limit values of geraniol ratios were considerably higher than both Turkish and Bulgarian rose oils. It was determined that nerol ratios were generally consistent with both Turkish and Bulgarian rose oils, but the upper limit values were higher. It is thought that the differences in the lower and upper limit values of both geraniol and nerol ratios may be due to cultural processes, ecological conditions and differences in the application in the study. It has been reported by various researchers that the differences in the essential oil components in rose oil are due to various factors such as plant species and variety, region, ecological conditions, cultural processes, harvest time and form, the time from harvesting to processing of rose flowers, differences in flower parts used in oil production, transportation, pretreatments, distillation techniques, packaging and storage (Guenther, 1952; Garnero et al., 1976; Anaç, 1984; Tucker and Maciarello, 1988; Yılmaz and Mengüç, 1991; Başer, 1992; Bayrak et al., 1994). One of the important criteria in determining the quality of rose oil is the citronellol/geraniol (C/G) ratio (Başer, 1992). This ratio was first used in 1934 to determine the quality of Bulgarian rose oil to simplify the comparison of oil components (Konur, 1990). The desired odor quality in rose oil can be achieved when the C/G ratio is between 1.25-1.30 (Başer, 1992). Since the C/G ratio in oil obtained from fermented flowers exceeds these limits, the quality deteriorates. In this study, it was determined that the C/G ratio gradually increased towards the later harvest periods. The results obtained in the study in terms of harvest periods are consistent with the findings of Baydar and Göktürk Baydar (2001), who reported that the S/G ratio increased until the last harvest period in type 1 oils (light green oil obtained as a result of the first distillation; direct oil, fresh oil). In our study, the C/G ratio varied between 0.89-3.85 according to the treatments (water and nitrogen). Kürkçüoğlu (1995) reported that the C/G ratio of the 1st oil obtained from fresh rose flowers by hydro-distillation in the Clevenger apparatus was 1.36, while it was 3.17 in the 1st oil obtained from fermented flowers.

In the Figure 6, in order to understand the effect of irrigation and nitrogen individually, the citronellol, graniol and nerol rates in the treatments to which nitrogen was not applied (T_0N_0, T_1N_0, T_2N_0 and T_3N_0) and in the treatments to which irrigation water was not applied (T_0N_0, T_0N_1, T_0N_2, T_0N_3) are given. In the subjects to which nitrogen was not applied, although it generally varies according to the experimental years, the highest citronellol and geraniol rates were obtained in T_2 or T_3 subjects. When the nerol rate is evaluated in terms of irrigation, it is seen that the nerol values are similar in all irrigation applications except for 2012. More variable results were obtained in terms of nitrogen applications. In terms of nitrogen doses, although it varies according to the years, the highest values in terms of citronellol, geraniol and nerol were obtained from N_1, N_2 and N_3 nitrogen applications. From here, it is possible to say that nitrogen and irrigation applications have a positive effect on the increase in citronellol, geraniol and nerol rates and that irrigation applications are more effective than nitrogen.

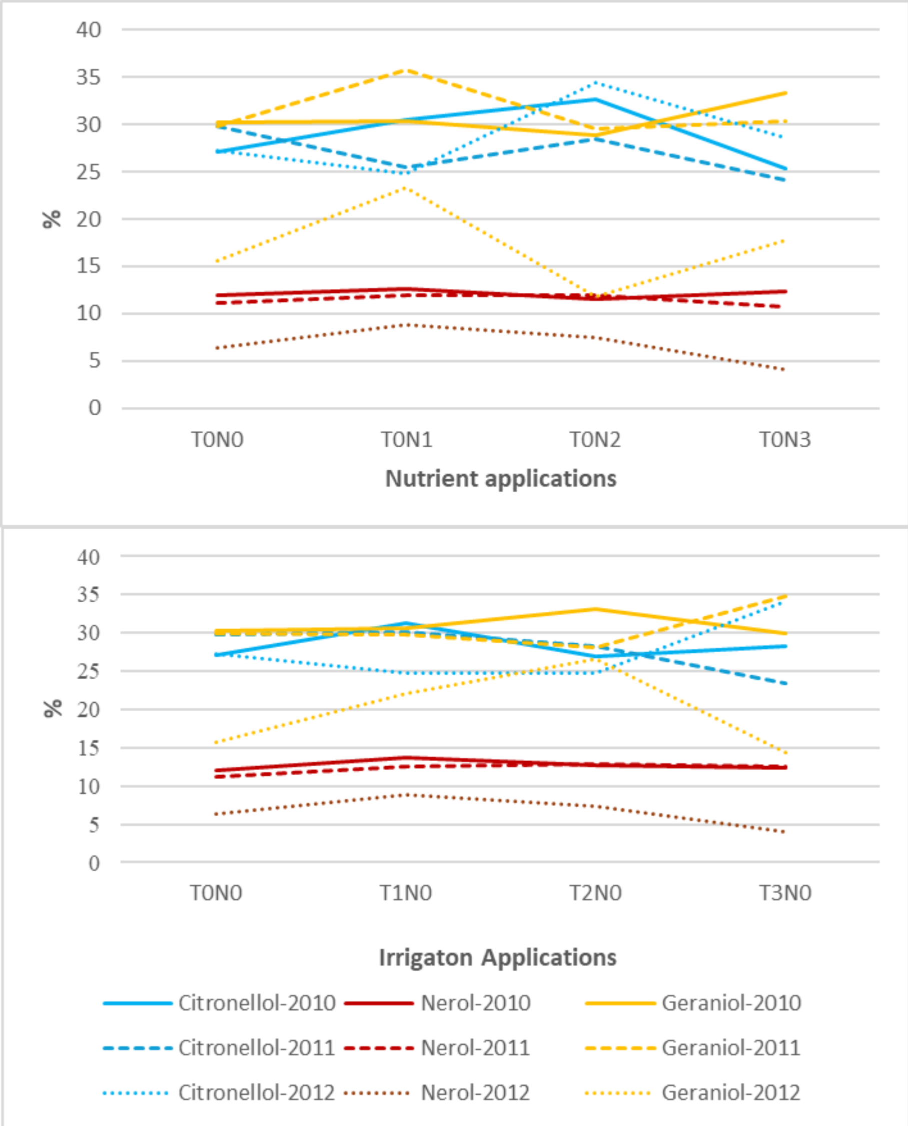

Figure 6. Citronellol, geraniol and nerol ratios in the treatments without water and nitrogen application.

Conclusion

In this study, which was carried out to determine the effects of different irrigation water and nitrogen amounts on citronellol, geraniol and nerol, which are the components of the essential oil obtained from Rosa Damescana *Mill*. The composition of essential rose oil obtained from Rosa Damascena *Mill*. grown under different irrigation water and nitrogen treatments was found to be highly compliant with oil standards. According to results, although these three important components vary depending on the treatments, nitrogen and irrigation applications generally increased the rates of citronellol and geraniol. When the experimental treatments applied only nitrogen or only irrigation water were evaluated separately, it was seen that the irrigation effect was higher than the nitrogen effect. When the C/G ratios, which are important quality parameters, were examined, the highest C/G ratio was determined in the harvest period in 4 periods.

Undoubtedly, Rosa Damascena Mill, which is mostly grown in rainfed conditions, will be able to achieve essential oil quality by applying appropriate irrigation and nitrogen programs. For this, it will be possible to develop and implement the mentioned programs by considering the ecological conditions of the fields where Rosa Damescana Mill is grown.

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Author Contributions

The authors equally contributed to the preparation of this paper.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Committee Approval

As the authors of this study, we confirm that we do not have any ethics committee approval.

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APPENDIX

Table 1. Oil content (%) and composition in 2010

Chemical constituents	Treatments															
	T_0N_0	T_0N_1	T_0N_2	T_0N_3	T_1N_0	T_1N_1	T_1N_2	T_1N_3	T_2N_0	T_2N_1	T_2N_2	T_2N_3	T_3N_0	T_3N_1	T_3N_2	T_3N_3
Mirsen	-	-	0.03	0.08	-	-	-	-	-	0.09	-	-	-	-	0.04	-
Linalool	0.48	0.32	0.36	0.46	0.28	0.25	0.26	0.39	0.40	0.38	0.40	0.40	0.30	0.49	0.42	0.40
Aromadendrene	0.59	0.40	0.52	0.50	0.65	0.59	0.65	0.63	0.73	0.76	0.65	0.63	0.51	0.61	0.50	0.62
Citronellyl acetate	0.73	0.57	0.81	0.76	0.76	0.70	0.78	0.81	0.83	0.85	0.64	0.69	0.57	0.51	0.51	0.72
Caryophyllene/farnesene	0.71	0.69	0.53	0.68	0.76	0.65	0.60	0.33	0.30	0.53	0.71	0.43	0.69	0.73	0.56	0.65
Hexadecane	1.42	1.40	1.01	1.34	0.90	1.28	1.23	1.03	1.17	0.94	1.06	0.97	1.22	0.91	1.10	1.13
Germakren D	1.29	0.70	0.90	0.76	0.96	0.75	1.11	0.96	1.17	0.92	1.18	0.82	0.85	0.69	0.80	0.98
Farnesol	0.07	0.23	0.67	0.33	0.53	0.58	0.18	0.18	0.19	0.30	0.28	0.55	0.38	0.34	0.36	0.51
Neryl acetate	0.22	0.03	0.07	0.23	0.12	0.11	0.15	0.09	0.16	0.05	0.23	0.14	0.21	0.30	0.15	0.09
Citral	0.39	1.14	0.39	0.33	0.39	0.29	0.20	0.43	0.37	0.37	0.51	0.61	0.47	0.50	0.60	0.43
Geranyl acetate	5.06	3.77	3.54	4.94	3.67	4.05	3.89	4.39	4.17	3.67	4.02	5.07	4.76	3.52	4.14	3.57
Citronellol	27.0	30.4	32.7	25.35	31.35	30.11	29.21	29.27	26.94	30.45	29.08	27.66	28.25	30.78	32.25	34.40
Nerol	11.9	12.6	11.4	12.41	13.77	12.45	11.85	14.40	12.78	13.32	12.73	14.43	12.40	14.06	12.70	13.10
Geraniol	30.2	30.3	28.9	33.37	30.58	28.68	32.89	32.85	33.08	31.94	33.87	33.77	29.98	32.95	29.93	27.86
Nonadecane	8.68	8.07	7.61	8.35	6.26	9.64	7.15	5.99	7.13	6.09	5.92	5.56	8.71	5.21	6.62	6.54
9-nonadeken	2.17	1.82	1.91	1.96	1.60	1.97	1.69	1.02	1.67	1.34	1.43	1.30	1.80	1.18	1.58	1.63
Phenylethyl alcohol	1.20	1.16	1.08	1.07	1.11	1.02	0.96	1.06	1.02	1.17	0.97	1.10	1.22	1.16	1.03	1.02
Eikosan	0.50	1.63	0.62	0.61	0.78	0.56	0.45	0.38	0.43	0.51	0.44	0.44	0.62	0.34	0.50	0.47
Methyl eugenol	1.09	1.25	1.51	1.34	1.60	1.59	1.10	1.25	1.15	1.35	1.31	1.28	1.18	1.71	1.25	1.31
Heneikosan	3.83	2.57	3.01	3.34	2.33	3.21	2.99	2.54	3.23	2.57	2.33	1.95	3.47	2.26	2.63	2.66
Eugenol	1.12	0.79	1.06	1.10	0.89	0.77	1.09	1.06	1.15	1.06	1.10	1.00	1.03	3.04	1.18	0.99
Phenylethyl acetate	-	-	0.18	0.28	0.08	-	0.15	-	0.05	0.15	0.19	0.06	0.18	0.29	0.15	0.04

Table 2. Oil content (%) and composition in 2011

Chemical constituents	Treatments															
	T_0N_0	T_0N_1	T_0N_2	T_0N_3	T_1N_0	T_1N_1	T_1N_2	T_1N_3	T_2N_0	T_2N_1	T_2N_2	T_2N_3	T_3N_0	T_3N_1	T_3N_2	T_3N_3
Linalool	0.43	0.47	0.29	0.33	0.37	0.33	0.47	0.42	0.54	0.58	0.40	0.33	0.53	0.46	0.37	0.55
Citronellyl acetate	0.45	0.53	0.56	0.53	0.64	0.40	0.44	0.57	0.61	0.52	0.61	0.75	0.47	0.65	0.59	0.53
Hexadecane	1.45	1.31	1.44	1.52	1.27	1.85	1.28	1.12	1.40	1.41	1.54	1.40	1.36	1.29	1.26	1.49
Geranyl acetate	1.61	2.48	2.43	2.72	2.10	2.85	1.89	1.89	2.04	2.27	2.58	3.02	2.51	2.66	2.56	2.40
Citronellol	29.78	25.46	28.47	24.10	30.10	19.41	27.81	29.99	28.25	26.40	25.25	26.30	23.39	27.03	24.47	28.82
Nerol	11.15	11.92	11.88	10.68	12.50	11.49	12.80	13.74	12.79	11.35	12.37	11.44	12.52	13.01	13.80	10.65
Geraniol	29.90	35.83	29.49	30.33	29.70	32.20	33.83	31.73	28.12	35.36	31.20	29.14	34.87	31.17	31.81	30.82
Nonadecane	11.79	9.85	9.69	14.71	10.60	15.94	9.46	8.76	11.42	9.98	12.22	11.54	11.55	10.52	11.49	11.16
9-Nonadeken	2.55	2.19	4.38	3.11	2.24	3.35	2.05	1.97	2.42	2.13	2.89	2.94	2.27	2.16	2.43	2.32
Phenylethyl alcohol	0.78	0.82	0.90	0.79	0.91	0.82	1.00	0.99	1.05	0.82	0.88	0.97	0.91	1.02	0.90	0.90
Eikosan	0.86	0.70	0.85	1.01	0.76	1.10	0.63	0.61	1.03	0.66	0.88	0.96	0.83	0.73	0.85	0.74
Methyl eugenol	0.83	0.87	1.24	0.73	1.20	0.53	1.03	1.07	1.25	0.72	0.74	0.96	0.78	1.08	0.87	0.96
Heneikosan	4.19	3.47	4.16	5.39	3.80	5.36	3.05	2.99	4.33	3.22	4.36	4.93	4.05	3.50	4.46	3.51
Eugenol	0.95	1.04	1.00	0.85	0.91	1.12	1.04	0.91	1.12	1.01	0.90	0.97	1.04	1.07	0.93	1.23

Table 3. Oil content (%) and composition in 2012

Chemical constituents	Treatments															
	T_0N_0	T_0N_1	T_0N_2	T_0N_3	T_1N_0	T_1N_1	T_1N_2	T_1N_3	T_2N_0	T_2N_1	T_2N_2	T_2N_3	T_3N_0	T_3N_1	T_3N_2	T_3N_3
α-pinene	-	-	-	0.13	-	-	-	0.14	-	0.01	-	0.12	-	0.01	-	-
β-mirsen	-	-	-	-	-	-	-	0.06	-	0.02	-	0.05	-	-	-	-
Linalool	0.23	0.32	0.24	0.30	0.42	0.22	0.29	0.30	0.30	0.31	0.30	0.29	0.27	0.24	0.26	0.25
α-quaien	0.29	0.27	0.46	0.29	0.34	0.34	0.36	0.34	0.39	0.17	0.29	0.35	0.41	0.29	0.28	0.26
Trans-caryophyllene	0.48	0.77	0.73	0.45	0.76	0.46	0.53	0.57	0.70	0.67	0.71	0.62	0.59	0.46	0.53	0.54
Terpinen-4-ol	0.05	0.15	0.05	0.01	0.16	-	-	0.07	0.17	0.09	0.04	0.06	0.01	0.05	-	0.12
Citronellyl acetate	0.39	0.30	0.66	0.57	0.52	0.38	0.62	0.75	0.44	0.30	0.51	0.56	0.55	0.56	0.68	0.46
α-humulene	0.07	0.36	0.33	0.14	0.20	0.20	0.25	0.31	0.20	0.23	0.33	0.28	0.23	0.26	0.33	0.21
Hexadecane	1.42	1.12	1.30	1.42	1.43	1.19	1.00	1.25	1.42	1.65	1.38	1.40	1.35	0.87	1.58	1.29
(Z)-Citral	0.08	-	-	-	0.15	-	0.01	0.02	-	0.04	-	0.07	-	0.06	-	0.19
Germakren D	1.15	1.21	1.28	1.14	1.35	0.99	1.17	1.21	1.35	1.00	1.39	1.05	1.44	0.98	1.15	1.23
(E)-Citral	0.23	0.21	0.16	0.12	0.35	0.10	0.12	0.28	0.23	0.24	0.15	0.21	0.06	0.16	0.06	0.46
Geranyl acetate	1.29	1.61	0.92	1.58	2.24	0.48	1.34	1.09	2.02	1.98	1.39	0.82	0.82	1.60	0.58	2.18
Citronellol	27.23	24.78	34.46	28.61	24.77	30.60	33.22	36.34	24.74	18.70	28.86	32.17	34.07	22.73	37.08	24.16
Nerol	6.37	6.38	3.62	6.14	8.88	3.99	5.76	5.93	7.42	7.64	6.68	5.18	4.04	6.45	2.80	10.26
Geraniol	15.66	23.34	11.76	17.77	22.00	9.53	15.94	14.35	26.62	20.97	18.06	11.85	14.40	15.57	9.62	25.87
Eicosane	19.57	16.04	17.61	16.74	15.79	13.60	16.95	15.29	15.01	20.60	16.40	18.05	18.43	11.81	19.19	14.17
9-Nonadekan	4.61	3.62	4.57	4.24	3.86	3.31	4.23	3.74	3.29	4.11	4.17	4.41	3.84	2.66	4.86	3.31
Phenylethyl alcohol	0.40	0.31	0.47	0.60	0.57	0.40	0.58	0.58	0.50	0.37	0.54	0.42	0.37	0.48	0.50	0.64
Eicosane	1.96	1.78	2.04	1.76	1.56	1.38	1.68	1.59	1.38	2.11	1.78	2.03	1.79	1.29	1.94	1.29
Methyl eugenol	1.43	0.96	1.83	1.35	1.21	1.31	1.42	1.91	1.16	0.85	1.70	1.68	1.92	1.20	2.30	1.17
Heneikosan	12.13	11.14	11.94	10.66	8.69	7.93	9.71	9.44	8.03	12.34	10.39	12.00	10.56	7.37	11.16	7.51
Eugenol	1.14	1.62	1.18	2.37	1.97	0.84	1.18	0.98	2.19	1.64	1.27	2.02	1.47	2.47	1.47	2.17
Trikosan	4.15	3.63	4.33	3.56	2.93	2.70	3.21	3.44	2.58	3.89	3.55	4.29	3.32	2.40	3.59	2.25

Table 4. Citronellol, geraniol and nerol ratios according to harvest periods in 2010

Treatments	May.25			May.29			June 5			June 11			June 17			Avg C	Avg G	Avg N
	C	G	N	C	G	N	C	G	N	C	G	N	C	G	N			
T_0N_0	32.12	32.84	15.41	25.5	34.31	14.25	30.48	29.8	15.24	23.05	25.17	4.94	24.27	28.95	9.93	27.08	30.21	11.95
T_0N_1	23.86	39.23	18.49	41.43	24.53	12.02	24.08	36.85	15.93	31.00	33.10	10.02	31.87	18.25	6.94	30.45	30.39	12.68
T_0N_2	31.12	34.15	15.25	21.18	39.43	10.53	36.27	26.38	12.65	47.71	21.57	9.16	27.34	23.15	9.82	32.72	28.94	11.48
T_0N_3	24.88	40.26	20.22	24.18	40.52	11.11	23.75	36.07	13.97	20.63	26.68	6.51	33.33	23.32	10.26	25.35	33.37	12.41
Average	**28.00**	**36.62**	**17.34**	**28.07**	**34.70**	**11.98**	**28.65**	**32.28**	**14.45**	**30.60**	**26.63**	**7.66**	**29.20**	**23.42**	**9.24**	**28.90**	**30.73**	**12.13**
T_1N_0	28.64	38.16	19.43	36.75	29.96	15.2	28.58	31.13	15.83	26.68	35.95	10.68	36.1	17.71	7.72	31.35	30.58	13.77
T_1N_1	19.74	39.11	15.83	30.11	33.79	14.41	26.78	35.11	17.66	43.91	19.91	8.61	30	15.47	5.76	30.11	28.68	12.45
T_1N_2	22.9	41.16	16.87	22.28	38.02	11.09	25.68	33.95	15.97	29.03	34.06	8.12	46.17	17.26	7.18	29.21	32.89	11.85
T_1N_3	24.5	41.00	19.68	34.38	27.93	13.08	30.16	32.83	15.64	34.92	27.98	11.39	22.41	34.49	12.22	29.27	32.85	14.40
Average	**23.95**	**39.86**	**17.95**	**30.88**	**32.43**	**13.45**	**27.80**	**33.26**	**16.28**	**33.64**	**29.48**	**9.70**	**33.67**	**21.23**	**8.22**	**29.99**	**31.25**	**13.12**
T_2N_0	23.4	42.33	19.24	37.27	28.25	14.22	21.15	36.37	12.86	27.4	33.2	7.46	25.48	25.25	10.11	26.94	33.08	12.78
T_2N_1	23.96	41.25	17.29	35.05	30.83	14.98	27.9	34.51	18.06	26.22	32.1	7.15	39.12	20.99	9.12	30.45	31.94	13.32
T_2N_2	21.88	43.53	18.32	32.57	30.71	14.95	22.19	40.06	13.45	28.53	33.77	7.22	40.24	21.26	9.7	29.08	33.87	12.73
T_2N_3	24.69	40.23	19.04	34.37	31.25	16.16	24.69	37.12	16.62	31.88	34.55	10.46	22.69	25.71	9.89	27.66	33.77	14.43
Average	**23.48**	**41.84**	**18.47**	**34.82**	**30.26**	**15.08**	**23.98**	**37.02**	**15.25**	**28.51**	**33.41**	**8.07**	**31.88**	**23.30**	**9.71**	**28.53**	**33.16**	**13.32**
T_3N_0	26	38	17.28	30.87	29.27	13.2	32.28	29.39	14.17	27.69	31.77	9.67	24.41	21.48	7.7	28.25	29.98	12.40
T_3N_1	27.2	37.11	16.47	23.86	42.39	13.87	30.82	31.36	17.45	36.53	29.25	12.08	35.48	24.62	10.41	30.78	32.95	14.06
T_3N_2	35.18	33.36	16.65	31.13	30.51	14.11	23.08	34.88	12.44	46.4	20.54	8.08	25.47	30.37	12.24	32.25	29.93	12.70
T_3N_3	35.81	33.17	17.04	27.97	32.31	14.83	30.26	28.74	14.03	42.95	20.17	8.94	35.03	24.92	10.66	34.40	27.86	13.10
Average	**31.05**	**35.41**	**16.86**	**28.46**	**33.62**	**14.00**	**29.11**	**31.09**	**14.52**	**38.39**	**25.43**	**9.69**	**30.10**	**25.35**	**10.25**	**31.42**	**30.18**	**13.07**

C: Citronellol, G: Geraniol, N: Nerol, Avg: Average

Table 5. Citronellol, geraniol and nerol ratios according to harvest periods in 2011

Treatments	June 6			June 13			June 17			June 21			June 26			Avg C	Avg G	Avg N
	C	G	N	C	G	N	C	G	N	C	G	N	C	G	N			
T_0N_0	40.83	21.52	11.12	31.59	29.82	13.08	24.89	36.43	10.07	21.73	38.39	8.70	29.86	23.33	12.76	29.78	29.90	11.15
T_0N_1	20.92	46.56	9.13	21.25	37.19	15.01	31.41	38.91	8.55	22.49	31.66	13.63	31.21	24.83	13.27	25.46	35.83	11.92
T_0N_2	19.63	32.09	12.21	17.48	46.89	13.95	28.97	35.42	16.46	51.55	4.88	1.77	24.72	28.19	15.02	28.47	29.49	11.88
T_0N_3	26.67	35.04	11.69	19.24	47.67	13.75	28.03	27.00	12.10	37.02	22.23	10.48	9.56	19.72	5.39	24.10	30.33	10.68
Average	**27.01**	**33.80**	**11.04**	**22.39**	**40.39**	**13.95**	**28.33**	**34.44**	**11.80**	**33.20**	**24.29**	**8.65**	**23.84**	**24.02**	**11.61**	**26.95**	**31.39**	**11.41**
T_1N_0	40.06	21.40	9.08	17.62	43.17	11.92	30.09	33.43	16.28	36.66	20.38	9.06	26.09	30.14	16.16	30.10	29.70	12.50
T_1N_1	22.96	37.12	13.52	18.76	38.75	16.73	24.11	34.95	15.13	20.52	39.49	8.33	10.71	10.71	3.75	19.41	32.20	11.49
T_1N_2	23.03	46.46	9.60	21.98	41.15	14.47	27.84	33.82	14.79	40.05	16.97	7.26	26.16	30.77	17.87	27.81	33.83	12.80
T_1N_3	39.13	19.49	8.25	31.98	35.44	16.05	24.90	37.63	12.37	23.53	34.87	15.83	30.43	31.20	16.19	29.99	31.73	13.74
Average	**31.30**	**31.12**	**10.11**	**22.59**	**39.63**	**14.79**	**26.74**	**34.96**	**14.64**	**30.19**	**27.93**	**10.12**	**23.35**	**25.71**	**13.49**	**26.83**	**31.87**	**12.63**
T_2N_0	30.01	21.37	12.05	23.14	32.18	17.01	32.57	39.24	9.08	34.01	13.14	6.54	21.51	34.69	19.26	28.25	28.12	12.79
T_2N_1	39.75	20.83	9.24	24.27	40.47	15.24	31.14	40.12	8.15	18.46	32.34	7.08	18.38	43.06	17.06	26.40	35.36	11.35
T_2N_2	28.06	30.17	10.46	31.02	27.03	9.96	25.80	34.92	14.81	26.49	27.82	13.45	14.89	36.05	13.16	25.25	31.20	12.37
T_2N_3	28.90	32.90	12.81	18.77	37.96	10.75	26.89	24.52	8.57	31.81	15.28	6.66	25.12	35.04	18.42	26.30	29.14	11.44
Average	**31.68**	**26.32**	**11.14**	**24.30**	**34.41**	**13.24**	**29.10**	**34.70**	**10.15**	**27.69**	**22.15**	**8.43**	**19.98**	**37.21**	**16.98**	**26.55**	**30.96**	**11.99**
T_3N_0	22.83	42.39	10.13	24.10	34.96	15.67	28.93	36.21	8.15	19.46	31.22	13.40	21.65	29.59	15.25	23.39	34.87	12.52
T_3N_1	27.77	34.90	13.13	18.20	39.69	13.06	26.08	34.69	14.46	42.19	14.37	6.19	20.90	32.18	18.20	27.03	31.17	13.01
T_3N_2	25.78	34.00	12.60	23.19	36.13	16.89	25.14	37.50	15.78	25.89	29.58	13.23	22.34	21.85	10.51	24.47	31.81	13.80
T_3N_3	61.42	8.65	2.77	21.86	38.48	16.61	22.72	33.62	11.01	20.04	32.64	7.62	18.04	40.69	15.25	28.82	30.82	10.65
Average	**34.45**	**29.99**	**9.66**	**21.84**	**37.32**	**15.56**	**25.72**	**35.51**	**12.35**	**26.90**	**26.95**	**10.11**	**20.73**	**31.08**	**14.80**	**25.93**	**32.17**	**12.50**

C: Citronellol, G: Geraniol, N: Nerol, Avg: Average

Table 6. Citronellol, geraniol and nerol ratios according to harvest periods in 2012

Treatments	May.31			June 5			June 11			June 15			June 20			Avg	Avg G	Avg N
	C	G	N	C	G	N	C	G	N	C	G	N	C	G	N			
T_0N_0	34.97	14.72	5.71	15.83	9.05	3.78	27.81	2.18	0.53	36.41	16.58	8.14	21.12	35.79	13.71	27.23	15.66	6.37
T_0N_1	27.53	24.28	9.88	11.00	18.34	2.32	18.30	34.91	7.06	18.64	30.29	9.03	48.45	8.88	3.62	24.78	23.34	6.38
T_0N_2	19.37	30.11	7.27	25.87	12.10	4.45	43.85	2.61	0.71	36.31	10.21	4.41	46.89	3.77	1.24	34.46	11.76	3.62
T_0N_3	15.93	27.06	6.29	22.20	19.92	7.51	18.72	16.21	5.75	36.99	20.24	9.30	49.23	5.41	1.87	28.61	17.77	6.14
Average	**24.45**	**24.04**	**7.29**	**18.73**	**14.85**	**4.52**	**27.17**	**13.98**	**3.51**	**32.09**	**19.33**	**7.72**	**41.42**	**13.46**	**5.11**	**28.77**	**17.13**	**5.63**
T_1N_0	21.41	22.51	8.37	17.14	16.29	5.92	24.69	21.04	8.87	40.95	15.85	8.37	19.64	34.32	12.85	24.77	22.00	8.88
T_1N_1	26.05	21.47	8.62	18.92	16.08	6.91	-	-	-	53.59	5.79	2.83	54.43	4.33	1.59	38.25	11.92	4.99
T_1N_2	17.91	27.99	7.03	25.42	7.69	3.07	24.41	20.82	9.05	49.63	11.15	4.61	48.72	12.06	5.02	33.22	15.94	5.76
T_1N_3	23.58	30.64	11.47	28.13	5.41	1.73	34.97	5.58	2.01	37.31	25.84	13.08	57.71	4.26	1.35	36.34	14.35	5.93
Average	**22.24**	**25.65**	**8.87**	**22.40**	**11.37**	**4.41**	**28.02**	**15.81**	**6.64**	**45.37**	**14.66**	**7.22**	**45.13**	**13.74**	**5.20**	**32.63**	**16.25**	**6.47**
T_2N_0	31.27	15.76	6.08	19.41	32.60	5.40	17.45	32.55	7.27	17.34	37.04	11.73	38.24	15.16	6.63	24.74	26.62	7.42
T_2N_1	23.54	20.99	8.47	19.08	26.74	4.38	2.19	2.54	0.39	29.48	22.29	12.51	19.23	32.29	12.43	18.70	20.97	7.64
T_2N_2	26.05	29.09	11.65	20.35	17.53	6.48	34.89	3.07	0.93	16.01	36.18	12.86	47.00	4.43	1.48	28.86	18.06	6.68
T_2N_3	20.25	21.11	7.88	26.08	12.36	5.70	28.24	4.33	1.43	40.54	18.63	9.84	45.73	2.80	1.04	32.17	11.85	5.18
Average	**25.28**	**21.74**	**8.52**	**21.23**	**22.31**	**5.49**	**20.69**	**10.62**	**2.51**	**25.84**	**28.54**	**11.74**	**37.55**	**13.67**	**5.40**	**26.12**	**19.37**	**6.73**
T_3N_0	26.39	15.96	5.58	19.63	32.97	4.95	33.20	2.14	0.53	47.40	11.10	5.00	43.75	9.82	4.14	34.07	14.40	4.04
T_3N_1	-	-	-	28.67	11.25	4.46	18.87	17.65	7.33	17.89	35.99	14.99	48.24	12.96	5.49	28.42	19.46	8.07
T_3N_2	14.58	21.32	4.19	28.84	13.82	5.32	36.53	4.92	1.71	46.84	4.60	1.85	58.59	3.45	0.95	37.08	9.62	2.80
T_3N_3	22.00	27.13	10.26	22.55	15.65	7.11	13.72	27.20	5.70	35.62	23.16	12.36	26.93	36.20	15.89	24.16	25.87	10.26
Average	**20.99**	**21.47**	**6.68**	**24.92**	**18.42**	**5.46**	**25.58**	**12.98**	**3.82**	**36.94**	**18.71**	**8.55**	**44.38**	**15.61**	**6.62**	**30.56**	**17.44**	**6.22**

C: Citronellol, G: Geraniol, N: Nerol, Avg: Average

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