Turkish Journal of FIELD CROPS

Turk J Field Crops
2017, 22(1), 32-38
DOI: 10.17557/tjfc.301797

EFFECTS OF DIFFERENT PHOSPHORUS DOSES ON NUTRIENT CONCENTRATIONS AS WELL AS YIELD AND QUALITY CHARACTERISTICS OF LAVANDIN (*Lavandula* × *intermedia* Emeric ex Loisel. var. Super)

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Received: 18.04.2016

ABSTRACT

Lavandin (*Lavandula* × *intermedia* Emeric ex Loisel. var. Super) is cultivated in an area of about 320 ha in Isparta province of Turkey. This study was conducted to determine the effects of phosphorus fertilization at the levels of 0, 50, 100, and 150 kg ha^{-1} on the yield characteristics, essential oil content and composition, and nutrient concentrations of lavandin (*Lavandula* × *intermedia* Emeric ex Loisel. var. Super) in 2010 and 2011 growing season. With an increase in the levels of phosphorus, the P, N, K, Ca and Fe concentrations increased in the leaves, while the Mg, Mn and Zn concentrations ($p<0.01$) decreased. On the other hand, the characteristics of plant height, branch number, flower height and fresh, dry and drug flower yields increased up to the level of 100 kg ha^{-1} of phosphorus but decreased at the higher level. In comparison with the control application, the application of 100 kg ha^{-1} of phosphorus increased the essential oil content approximately by 16%. Linalyl acetate, the main component of the essential oil, rose from 25.07 to 30.72% on average from the control application to the highest phosphorus application, whereas the rate of linalool decreased from 41.82 to 38.54%. Phosphorus fertilization significantly affected the nutrient contents as well as yield and quality characteristics of lavandin. Therefore, application of 100 kg ha^{-1} of phosphorus may be suggested in lavandin to obtain the ideal yield and quality.

Keywords: lavandin, nutrients, P fertilization, quality, yield.

INTRODUCTION

Lavender (*Lavandula* sp.), a valuable essential oil plant of family *Lamiaceae*, has about 25 species, most of which are of Mediterranean origin (Guenther 1952). It is most distributed in Southern Europe and in the North African countries neighboring the Mediterranean Sea in the world (Weiss 1997). There are three important lavender species with a high commercial value in the world (Tucker 1985): Lavender (*Lavandula angustifolia* = *L. officinalis* = *L. vera*), Lavandin (*L. angustifolia* × *L. latifolia* = *Lavandula* × *intermedia* = *L. hybrida*), and Spike lavender (*Lavandula spica* = *L. latifolia*). Like other plants of *Lavandula* species, lavandin is mostly used as essential oils for perfumery, cosmetics, flavoring, and pharmaceutical industries thanks to its essential oil content and composition. Lavandin oil is commonly blended, either with lavender oil or other commercial essential oils, to create a pleasing fragrance (Lawrence 1993; Harborne and Williams 2002). Lavandin cultivars produce significantly higher oil yield as compared to the lavender cultivars, and linalool and linalyl acetate are the main components of lavandin and lavender oils (Marotti et al. 1989; Renaud et al. 2001). The essential oil of lavender is one of the 15 most produced essential oils in the world. About 200 tons of lavender oil and 1200 tons of lavandin oil are annually produced in the world (Karapandzova et al. 2012).

Lavender is densely cultivated in France, Bulgaria, Spain, Italy, Greece, England, Russia, the USA, Austria, and the North African countries worldwide (Tucker 1985). In Turkey, it is most cultivated in Keçiborlu district of Isparta province. Lavender has very well adapted particularly to the non-irrigated, arid, and sloping lands of this locality. The agriculture of lavender (*Lavandula* × *intermedia* var. Super) in the region, which commenced in 1970, has now reached a production area of about 320 ha. Lavandin plants start flowering in early July after the flowering season of oil-bearing rose (*Rosa damascena* Mill.), and they are generally harvested in the second half of July. Some of the fresh cut flowers are distilled and utilized in the production of lavandin oil at some rose oil factories, whereas some of them are dried and utilized as dry flowers. 3500 to 5000 kg of fresh flowers per hectare are obtained on average, and 750 to 1000 kg per ha of dry flowers are obtained on average by drying the fresh flowers and separating them from their stems. Of bunches of dried stemmed flowers, 65% comprise stems and 35% are comprised of flowers (Baydar 2016). About 1 kg of essential oil is obtained through the steam distillation of from 50 to 75 kg of fresh lavandin flowers at the factories. The fresh lavandin flowers contain 1.5 to 2.5% light yellow essential oil, while its dry flowers contain 5 to 6% light yellow essential oil (Erbaş and Baydar 2008). The main essential oil components in the lavandin oil are linalyl acetate (20 to 30%) and linalool (30 to 45%) (Lis-Balchin 2002; Woronuk et al. 2011).

Many factors such as growing conditions, climatic conditions, the growth period of plants, and agricultural practices are effective on herb yield, drug yield, and essential oil content and composition in aromatic plants, along with genetic modifications (Lawrence 1993; Perry et al. 1999; Grausgruber-Gröger et al. 2012). Of agricultural practices, especially the application of phosphorus is a nutrient with an important role in the essential oil synthesis and assimilation in aromatic plants. Farnesyl diphosphate compresses to geranyl diphosphate and linalool diphosphate, and these components are precursors of essential oil production (Ramezani et al. 2009). Although it was reported that the essential oil content and yield were increased with the application of phosphorus in such aromatic plants as cumin, fennel, sage, oregano, basil, and coriander (Tunçturk and Tunçturk 2006; Moslemi et al. 2012; Nell et al. 2009; Meena et al. 2015), only the effect of application of foliar phosphorus on yield and quality was examined in lavender by Hussein et al. (1996) whose reported that application of 1% phosphorus twice before flowering might be suggested to increase the essential oil content and the flower yield. The present study aims to investigate the influence of phosphorus (P) fertilization on yield and quality characteristics as well as the nutrient concentrations of lavandin under field conditions.

MATERIALS AND METHODS

In the study, lavandin (*Lavandula* × *intermedia* Emeric ex Loisel. var. Super) was used as the material plant. The study was carried out in a trial field located at the Department of Field Crops, Faculty of Agriculture, Suleyman Demirel University, Isparta (latitude 37º47' N, longitude 30º30' E, elevation 1122 m) in the 2010-2011 growing season. The soil of the research field was loamy in texture with pH 7.9 (1:2.5 water extract), 19% $CaCO_3$, and 1.7% organic matter (Jackson 1973). Extractable P (0.5 M $NaHCO_3^-$) was 30 kg ha^{-1} and exchangeable K (NH_4OAC^-) was 600 kg ha^{-1} (Olsen et al. 1954; Knudsen et al. 1982). The DTPA extractable Fe, Zn and Mn concentrations in leaves were 3.0, 0.7, and 4.4 mg kg^{-1}, respectively. The climatic data for the research area are given in Table 1.

Table 1. Total precipitation, mean humidity and mean temperatures values of research area

Month	Precipitation, mm			Mean temperature, ºC			Mean humidity, %		
	1970-2011	2010	2011	1970-2011	2010	2011	1970-2011	2010	2011
January	76.7	68.0	34.6	2.1	4.2	2.9	75.0	76.9	78.2
February	69.2	136.8	51.8	3.1	5.7	3.7	67.0	75.3	75.6
March	63.2	33.2	50.4	6.8	8.7	6.3	52.1	59.6	70.2
April	60.0	47.0	42.8	11.7	11.9	10.3	56.3	61.0	68.5
May	47.7	32.4	42.5	16.5	17.1	14.4	46.3	55.1	64.8
June	31.0	64.5	61.8	21.1	19.2	19.8	28.7	61.8	56.6
July	17.0	40.1	1.8	24.3	24.8	25.0	12.6	49.0	42.3
August	16.2	0.2	0.6	24.0	27.0	22.9	12.5	38.0	40.7
September	25.2	15.7	14.8	19.9	20.7	18.3	49.9	52.2	51.6
October	57.4	79.1	31.4	14.4	12.7	12.8	64.8	70.2	65.9
November	72.9	13.6	0.2	8.4	10.8	0.4	63.2	64.6	54.5
December	87.7	84.2	4.2	4.1	6.8	2.5	75.1	80.1	66.7

*Turkish State Meteorological Service

Propagation of plants was normally accomplished by taking cuttings on 15 March 2007. The cuttings were planted at 1-meter plant spacing and 1.5-meter row spacing. The plot length was 10 m, and each plot contained 5 rows. Individual plots (50 plants) were 10×1.5×5 = 75 m^2. In order to determine the effects of P on the yield and quality parameters of lavandin, four levels of P (0, 50, 100, and 150 kg ha^{-1}) were applied as triple superphosphate (42% P_2O_5) in March for both years. Fertilization was performed in the form of a surface application in the lines and then mixed by means of a hoe. No other fertilization was performed in the trial field and drip irrigation was applied when needed, between 2007-2010 years. Lavandin flowers were harvested by hand on 15 July 2010 and 17 July 2011. The characteristics under examination were determined using 10 randomly selected plants. The following observations were made: plant height (cm), branch height (cm), flower height (cm), floret number per flower, fresh flower yield (kg ha^{-1}), dry flower yield (kg ha^{-1}), drug flower yield (kg ha^{-1}), essential oil content (%), and essential oil composition (%).

To make a nutrient analysis, leaf samples were collected from the middle of the shoots at the beginning of the flowering periods (Özcan 2004). Later on, the samples were washed thoroughly with tap water, dilute acid (0.2N HCl), and distilled water to remove surface residues and then kept at 65 ± 5 °C until they reached a stable weight. Afterwards, the leaf samples were dried and ground. The phosphorus concentrations of the samples were determined by means of a spectrophotometer (Shimadzu UV-1208) at 430 nm according to the vanadomolybdophosphoric acid method. The nitrogen concentrations of the samples were determined according to the Kjeldahl methods. Other nutrients such as K, Ca, Mg, Mn, Fe, and Zn concentrations were determined using an atomic absorption spectrophotometer (Jones et al. 1991).

The essential oils of fresh flowers (100 g) were extracted by distillation for 3 hours under continuous steam using a neo-Clevenger apparatus according to the standard procedure described in European Pharmacopoeia (1975) so as to determine the oil content (% v/w). After the oils had been dried over anhydrous sodium sulphate, they were stored at 4 ºC until they were used for gas chromatography-mass spectrometry (GC-MS) analyses. The oil samples were weighed (7.5 mg) and diluted in 1.5 mL of dichloromethane, and 1 µL of this sample was injected into GC-MS, and the constituents of the oil samples were detected. The GC-MS analysis was performed on QP5050 GC-MS equipped with a Quadrapole detector. The GC-MS analysis was carried out as follows: capillary column, CPWax 52 CB (50 m × 0.32 mm i.d., film thickness, 0.25 µm); oven temperature was kept at 60 °C for 10 min and programmed to 220 °C at a rate of 10 °C min^{-1}, and then kept constant at 220 °C for 10 min; total run time, 60 min; injector temperature, 240 °C; detector temperature, 250 °C; and flow rate for helium, 20 mL min^{-1}. Identification of the constituents was carried out by the help of the retention times of standard substances by composition of mass spectra with the data given in the NIST library (Stein 1990) and our created library.

The results obtained in the two years were evaluated both individually and in combined form according to the randomized complete block design with three replications. All data were analyzed with the analysis of variance (ANOVA) using GLM producers of SAS (1999) program, and the differences among treatments were compared with the LSD test ($p<0.05$).

RESULTS AND DISCUSSION

The effect of P application on nutrient concentrations

According to the results obtained, it was seen that P doses significantly affected leaf P concentrations for both years ($p<0.01$). As seen from Table 2, the highest P concentrations were determined at the highest P doses for both years. When compared with the control application, increases in leaf P concentrations were approximately by 40.9% in the first year and 59.1% in the second year. Similar results can be seen when the averages of both years are considered. This could be due to the increases in the available P concentrations in the root zone of the plant. Although the amount of soil P concentration seems to be sufficient, the application of high available P containing fertilizers to the soil can increase the plant nutrient concentrations (Nell et al. 2009; Rahimi et al. 2013; Khalid 2012, 2015; Kumar et al. 2015).

The plant nutrient concentrations did not vary by year, and the average values of leaf N concentrations significantly increased depending on the P application doses ($p<0.01$). While the lowest N value (1.44%) was determined in the control (0) treatment, the highest value (1.56%) was obtained from the highest P doses according to the two-year average (Table 2). The increases in the N concentration of the plants with the P applications might be related to better shoot and root growth (Sharma et al. 2008). In our study, it might have resulted from the overall improvement seen in the growth and development of the plant depending on the increase in the plant biomass in the lavandins treated with phosphorus.

Whilst the effect of application of phosphorus on the K concentration of lavandin was insignificant by year, the K concentration of the plants increased with an increase in the level of P according to the average of the 2 years ($p<0.01$). Based on the two-year average, the K concentration detected to be 2.01% in the plants in the control (0) group rose to 2.63% in the highest P application. Khalid (2012) reported that phosphorus fertilization significantly increased the K concentration in anise, coriander, and fennel.

Table 2. The effect of phosphorus treatment on nutrition concentrations in lavandin leaves

P levels	**P (%)**			**N (%)**			**K (%)**			**Ca (%)**		
(kg ha^{-1})	**2010 ****	**2011 ****	**Mean ****	**2010**	**2011**	**Mean ****	**2010**	**2011**	**Mean ****	**2010 ****	**2011 ****	**Mean ****
0	0.22 c	0.22 b	0.22 C	1.44	1.45	1.44 C	1.73	2.30	2.01 B	0.58 c	0.59 c	0.58 C
50	0.27 b	0.25 b	0.26 B	1.48	1.50	1.49 BC	1.80	2.46	2.12 AB	0.82 b	0.57 c	0.69 BC
100	0.27 b	0.26 b	0.27 B	1.57	1.50	1.53 AB	1.80	2.63	2.21 AB	0.85 b	0.76 b	0.80 B
150	0.31 a	0.35 a	0.33 A	1.62	1.51	1.56 A	2.03	2.50	2.63 A	1.17 a	0.95 a	1.06 A

P levels	**Mg (%)**			**Mn** (mg kg^{-1})			**Fe** (mg kg^{-1})			**Zn** (mg kg^{-1})		
(kg ha^{-1})	**2010 ****	**2011**	**Mean ****	**2010 ****	**2011**	**Mean ****	**2010 ****	**2011 ****	**Means ****	**2010**	**2011 ***	**Mean ****
0	0.35 c	0.31	0.33 C	34.7 bc	24.0	29.4 C	104.7 c	112.0 b	108.3 D	17.3	19.3 a	18.4 A
50	0.52 a	0.35	0.43 A	45.0 a	26.0	35.4 A	116.7 bc	120.3 b	118.5 C	14.5	16.3 b	15.4 B
100	0.41 b	0.33	0.37 B	38.3 b	26.3	32.5 B	123.3 b	122.0 b	122.6 B	16.6	16.3 b	16.5 B
150	0.41 b	0.31	0.36 BC	32.7 c	24.7	28.5 C	143.7 a	142.0 a	142.9 A	16.0	16.3 b	16.2 B

Means with identical letters in the same column are not statistically significant; * $p<0.05$; ** $p<0.01$

The Ca and Fe concentrations of the plants significantly differed in both years depending on the P application ($p<0.01$). While the Ca and Fe concentrations of the plants were 0.58% and 108.3 mg kg $^{-1}$ on average in the control application, they rose to 1.06% and 142.9 mg kg $^{-1}$ in the highest phosphorus application. The P application showed significant effects on the Mg and Mn contents of the plants in 2010 and according to the average of both years ($p<0.01$). The highest Mg and Mn concentrations were found at 50 kg ha^{-1} in 2010, whereas the lowest values were detected in the control application. The Mg and Mn concentrations of the plants were observed to have decreased at the higher doses. This might have been because the K concentration in the plants increased depending on the increased phosphorus dose and K caused toxicity, thereby reducing the Mg and Mn uptake (Heenan and Campbell 1981).

Similarly, the differences in the Zn concentrations of the plants were found significant in 2011 and according to the average of both years. The Zn concentration in the plants decreased to 16.2 from 18.4 with an increase in the dose of phosphorus according to the average of both years. This is due to the antagonistic effect between phosphorus and zinc. Even though a similar case is also reported in the plants of *Trachyspermum ammi* L. (El-Wahab and Mohammed 2007) and *Trachyspermum cucumeria* L. (Karthikeyan et al 2008), there is no information on this subject concerning lavender. Only Hussein et al. (1996) reported that the application of foliar phosphorus to *Lavandula angustifolia* positively affected the uptake of such macronutrients as N, P, and K.

The effect of P application on yield and quality characteristics

When the agronomic and quality characteristics were examined, it was seen that the application of phosphorus significantly affected plant height, the flower height, fresh, dry, and drug flower yields, and the essential oil content in 2010 and 2011 as well as according to the average of both years. Nevertheless, the differences in branch height were not significant in 2010, but significant in 2011 and according to the average of both years. The number of flower spikes of the plants was statistically insignificant. All characteristics were positively affected from the control application to the application of 100 kg ha^{-1} of phosphorus, whereas the characteristics were negatively affected at the higher dose. According to the phosphorus doses, the plant height, the branch height and the flower height were 92.6 cm, 47.2 cm, and 10.5 cm on average in the control application, respectively, while the highest values of these characteristics were recorded as 104.3, 53.0, and 15.7 cm with the application of 100 kg ha^{-1} of phosphorus, respectively (Table 3). In the results obtained from our study, the increase in the phosphorus dose up to the dose of 100 kg ha^{-1} was observed to have improved such characteristics as the flower length and the number of florets in plants. The P found at a limited level in soil is reported to slow down the development of the floral structures of plants (Ma et al. 2001). However, the P application enables the flowers to reach the maximum size but does not increase the number of flowers. This was also observed in the flowers of *Calendula officinalis* and *Pimpinella anisum* (Steward and Lovett-Doust 2003; Meena et al. 2015).

The P application had a positive effect on the fresh flower yield, dry flower yield, and drug flower yield of lavandin up to the dose of 100 kg ha^{-1}. The highest fresh and dry flower yields were obtained in 2011. The mean fresh flower yield ranged from 7520 to 11390 kg ha^{-1}, the dry flower yield from 3216 to 5022 kg ha^{-1}, and the drug flower yield from 1513 to 2357 kg ha^{-1}. The highest fresh, dry and drug flower yields were obtained from the application of 100 kg ha^{-1} of P (Table 3). Given the nutrient uptake by the plants, the increase in yield characteristics is an expected case. Likewise, phosphorus is an element which is directly related to photosynthesis. It affects many metabolic events primarily such as chlorophyll, protein, carbohydrate, and oil syntheses, thereby contributing to the increase in yield. It is reported that phosphorus fertilization increases the chlorophyll content (Rathore et al. 1985; Ramezani et al. 2009) and the leaf area index (Maurya 1989) in basil and African marigold. Khalid (2012) reported that phosphorus fertilization in some *Apiaceae* (*Umbelliferaceae*) species increased total carbohydrate, total soluble sugar, total oil, and the vegetative productivity of plants. Similar results were also found in chamomile (Naderidarbaghshahi et al. 2011), feverfew (Saharkhiz and Omidbaigi 2008), sweet basil (Sharafzadeh et al. 2011), marigold (Ahmad et al. 2011), indigenous mint (Alsafar and Al-Hassan 2009), and sage (Lu et al. 2013).

Table 3. The effect of phosphorus treatment on yield and quality characters in lavandin

P levels (kg ha^{-1})	**Plant height (cm)**			**Branch height (cm)**			**Flower height (cm)**			**Floret number per flower**		
	2010 *	**2011 ****	**Mean ****	**2010**	**2011 ***	**Mean ****	**2010 ****	**2011 ****	**Mean ****	**2010**	**2011**	**Mean**
0	92.2 c	93.0 b	92.6 B	46.2	48.3 b	47.2 C	10.7 c	10.3 b	10.5 C	8.6	8.5	8.6
50	100.3 ab	101.9 a	101.1 A	50.6	49.9 b	50.3 AB	13.6 b	13.8 a	13.7 B	8.6	8.7	8.7
100	104.0 a	104.7 a	104.3 A	51.7	54.3 a	53.0 A	15.7 a	15.7 a	15.7 A	8.7	8.7	8.7
150	96.5 bc	94.3 b	95.4 B	48.3	47.6 b	47.9 BC	10.4 c	11.3 b	10.9 C	8.5	8.6	8.6

P levels (kg ha^{-1})	**Fresh flower yield (kg ha^{-1})**			**Dry flower yield (kg ha^{-1})**			**Drug flower yield (kg ha^{-1})**			**Essential oil content (%)**		
	2010 **	**2011 ****	**Mean ****	**2010 ****	**2011 ****	**Mean ****	**2010 ****	**2011 ****	**Means ****	**2010 ****	**2011 ****	**Mean ****
0	7669 c	7370 c	7520 D	3281 c	3152 c	3216 D	1544 c	1483 c	1513 C	1.80 c	1.80 b	1.80 C
50	8481 b	8879 b	8680 C	3778 b	3940 b	3864 C	1806 b	1888 b	1847 B	1.96 b	2.00 b	1.97 B
100	10861 a	11920 a	11390 A	4786 a	5258 a	5022 A	2245 a	2469 a	2357 A	2.09 a	2.10 a	2.10 A
150	9163 b	9578 b	9371 B	4076 b	4258 b	4167 B	1845 b	1927 b	1886 B	2.02 a	2.09 a	2.06 A

Means with identical letters in the same column are not statistically significant; * $p<0.05$; ** $p<0.01$

The essential oil content of lavandin flowers significantly increased with phosphorus fertilization. Whilst the essential oil content in the unfertilized plants was determined as 1.80% on average, the essential oil content increased up to the application of 100 kg ha^{-1} of P and rose to 2.10% on average. On the other hand, it decreased to 2.06% in the application of 150 kg ha^{-1} of P. However, there is no statistical difference between these two applications (100 and 150 kg ha^{-1}) (Table 3). Phosphorus fertilization increased the essential oil content in the flowers. This might have been due to the increase in the synthesis of tricycle-glycerol from glycerol-3-phosphate – the precursor to the syntheses of mevalonic acid and isoprene that constituted the building blocks of the essential oil. In addition, now that phosphorus makes up the building blocks of the phosphoenolpyruvate (PEP) molecule it plays a significant role in the formation of aromatic compounds (Qadry 2010). Our results are in agreement with Hussein et al. (1996), who reported that the essential oil content increased with the application of 1% foliar phosphorus in lavender. Although the rates of increase also differed in the plants belonging to different families, the application of phosphorus was observed to have had a positive effect on the essential oil content. The application of phosphorus increased the essential oil content in basil (Ramezani et al. 2009), chamomile (Nikolova et al. 1999), chrysanthemum (Alvarez-Castellanus and Pascual-Villalobos 2003), fennel (Kapoor et al. 2004), cumin (Tuncturk and Tuncturk 2006), parsley (Kandeel 1991), coriander (Khalid 2015), and sage (Abaas 2014).

The averages concerning the effect of the P application on the essential oil composition of lavandin are presented in Table 4. The essential components of lavandin varied upon P fertilization in comparison with the control application. A total of 36 components were detected in the essential oil of lavandin; however, a total of 18 major components with total amounts ranging from 98.35 to 99.65% were evaluated. The rates of the 18 remaining micro components varied between 0.35 and 1.65%. The oxygenated monoterpenes constituted the main group of the essential oil (92.25-93.86%), followed by the monoterpene hydrocarbon group (3.07-3.76%). On the other hand, ketone and esters ranged from 2.03 to 2.38% but sesquiterpene hydrocarbons from 0.34 to 0.52% in lavandin oil (Table 4). The fact that lavandin oil comprised the primary monoterpenes (C_{10}) was also reported by Lis-Balchin (2002). In the study, the main components of the essential oil of lavandin consisted of monoterpene compounds such as linalool>linalyl acetate>borneol>α-terpineol>geranyl acetate>1,8-cineole. The rate of linalool was 41.82% on average in the control application, whereas it decreased to 38.54% in the highest P application. On the other hand, the rate of linalyl acetate rose to 30.72% from 25.07% on average with the increased P application.

Table 4. The effect of phosphorus treatment on essential oil composition in lavandin

Essential oil composition (%)	RT* (min)	0 kg ha^{-1}		50 kg ha^{-1}		100 kg ha^{-1}		150 kg ha^{-1}	
		2010	2011	2010	2011	2010	2011	2010	2011
Myrcene	13.4	0.95	0.99	0.83	0.82	0.83	0.78	0.70	0.71
Limonene	15.6	0.63	0.66	0.64	0.59	0.57	0.52	0.45	0.49
1.8-cineole	16.2	3.55	3.96	3.33	3.26	3.26	3.24	2.96	3.02
p-cymene	17.2	2.18	2.08	2.04	1.95	2.00	1.85	2.00	1.87
3-octanone	18.8	0.64	0.70	0.68	0.70	0.50	0.62	0.51	0.49
Hexyl acetate	19.5	0.66	0.64	0.63	0.59	0.57	0.55	0.56	0.55
1-octen-3-yl acetate	25.9	0.29	0.32	0.31	0.28	0.27	0.29	0.30	0.28
Hexyl butanoate	28.4	0.72	0.72	0.68	0.65	0.70	0.66	0.76	0.71
Camphor	35.8	4.48	4.66	3.45	4.01	4.36	4.45	4.42	4.31
Linalool	36.7	42.19	41.45	40.48	39.00	39.68	39.45	38.56	38.52
Linalyl acetate	37.4	24.87	25.26	25.84	26.41	29.78	28.13	30.94	30.50
Neryl acetate	40.5	3.01	2.95	3.26	3.50	3.39	3.65	3.30	3.42
β-farnesene	44.1	0.34	0.35	0.38	0.42	0.49	0.52	0.42	0.50
α-terpineol	46.6	4.04	4.41	3.86	3.99	3.15	3.68	3.87	4.00
Borneol	46.7	3.61	3.90	5.29	5.42	3.84	4.00	3.90	4.12
Geranyl acetate	47.9	4.10	4.15	3.90	4.12	3.40	3.62	3.51	3.65
Nerol	52.0	0.70	0.50	0.68	0.52	0.53	0.53	0.77	0.67
Geraniol	54.9	2.30	1.95	2.16	2.12	1.98	2.12	0.49	1.65
Monoterpene hydrocarbons		3.76	3.73	3.51	3.36	3.40	3.15	3.15	3.07
Oxygenated monoterpenes		92.85	93.19	92.25	92.35	93.37	92.87	92.72	93.86
Ketons and esters		2.31	2.38	2.30	2.22	2.04	2.12	2.13	2.03
Sesquiterpene hydrocarbons		0.34	0.35	0.38	0.42	0.49	0.52	0.42	0.50

RT: Retention time (minute)

Similar to other terpenoids, these biochemicals with low molecular weights result from the condensation of isopentenyl diphosphate (IPP, C_5) and dimethylallyl diphosphate (DMAPP, C_5) – the universal terpene precursors. While monoterpenes are generally synthesized from geranyl diphosphate (GPP), sesquiterpenes are synthesized from farnesyl diphosphate (FPP) (Woronuk et al. 2011). Linalyl diphosphate is the precursor to the production of linalool. Linalyl acetate is modified by adding an acetyl CoA group to linalool (Zaks et al. 2008). In our study, the P application increased the synthesis of linalool from the GPP and the concentration of the acetyl CoA enzyme, one of whose building blocks was P, and the rate of linalyl acetate might have increased upon the intensive catalyzation of these two molecules. With the P application, the myrcene, *p*-cymene, limonene, 1,8-cineole, geranyl acetate and geraniol components of the essential oil relatively decreased, whereas its β-farnesene and neryl acetate contents increased, although slightly. On the other hand, the variations in 3-octane, hexyl acetate, 1-octen-3-yl acetate, hexyl butanoate, camphor and nerol contents were unaffected by the levels of P. Borneol was higher at the first P application dose, but it was decreased at the other doses. α-terpineol was decreased by P application. Borneol and camphor are synthesized from bornyl diphosphate and contain phosphate in their structures. While the concentrations of borneol and camphor are expected to increase in reality like linalool and linalyl acetate, the presence of these compounds at a proportionately low concentration might cause the variations of increases and decreases to remain at a low level. Camphor is reported to range from 4 to 12% in lavandin oil and to reduce quality and the market value (Lawrence 1994; Lis-Balchin 2002). Similar results about the compounds found at low rates in our study were also obtained by Khalid (2015). Rioba et al. (2015) reported that the application of phosphorus in sage reduced the 1,8-cineole content but did not affect the camphor or borneol content.

In the study, phosphorus fertilization significantly affected the nutrient contents as well as yield and quality characteristics of lavandin. The P application increased the P, N, K, Ca, and Fe concentrations in lavandin, and this increase was positively reflected in the yield characteristics of the plant and in its essential oil content and composition. All yield characteristics other than the floret number increased up to the level of 100 kg ha^{-1} of P. Thus, 100 kg ha^{-1} of P fertilization in lavandin will be useful to obtain the ideal yield and quality.

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