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Influence of Nutrient Concentrations and NaCl Salinity on the Growth, Photosynthesis, and Essential Oil Content of Peppermint and Lemon Verbena

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Abstract: Growth and essential oil content of peppermint (*Menhta piperita* var. officinalis) and lemon verbena (*Lipia citriodora* var. Verbena) were evaluated in response to salinity and nutrient solution concentrations, measured as electrical conductivity (EC 0.7, 1.4, 2.8, 5.6, and 5.6_{Na} dS m^{-1}). In peppermint, the highest fresh weight and dry weight were observed in the 1.4 dS m^{-1} treatment. The increased EC with either NaCl or all nutrients at 5.6 dS m^{-1} reduced the fresh weight of lemon verbena. The maximum fresh weight and dry weight in lemon verbena were obtained in both 1.4 and 2.8 dS m^{-1} treatments. Increasing EC level up to 2.8 dS m^{-1} increased leaf area but the leaf area was reduced by 5.6 dS m^{-1} treatment achieved by adding NaCl or all nutrients. The rate of photosynthesis (Pn) was higher in treatments with EC levels of 1.4 and 2.8 as compared to the other treatments. In both peppermint and lemon verbena, the concentrations of N, P, and K increased as the EC of the solution increased from 0.7 to 5.6 dS m^{-1} but in the 5.6_{Na} treatment their concentrations fell. The total content of essential oil was reduced by increasing the EC of the solution because of the reduction in total fresh weight of the plants. In peppermint, the essential oil content in the 1.4 dS m^{-1} treatment was 55.0% and 40.5% higher than those of both 5.6 and 5.6_{Na} treatments, respectively. The major constituents of the essential oil in peppermint were menthol and menthone and in lemon verbena they were geranial and neral in all treatments. The increased Pn and leaf area in moderate EC level led to improved plant growth. Consequently, 1.4-2.8 dS m^{-1} could be an optimum EC value in peppermint and lemon verbena production.

Key Words: Essential oil, lemon verbena, mineral nutrients, peppermint, photosynthesis

Introduction

The growth and biosynthesis of secondary metabolites in medicinal and aromatic plants are strongly influenced by environmental factors. Essential oil yield has been shown to be affected by nutrients (Stutte, 2006) and osmotic stress (Charles et al., 1990). Adjustment of nutrient solution concentration is useful to growers for modifying water and nutrient availability to the crop and hence the vegetative and reproductive vigour of the plant, which in turns influences the yield and growth of the plants (Massey et al., 1984; Cornish, 1992; Kang and Van-Iersel, 2004). Low to moderate levels of salinity achieved by adding NaCl or major nutrients are used to improve fruit quality (Rudich et al., 1981; Adams, 1991). In most cases, nutrient solutions used for growing plants in soilless culture usually have EC levels of 1-1.4 dS m^{-1} (Schwarz, 1995). Lower EC levels appear to limit plant growth due to the lack of sufficient nutrients, while higher EC levels may reduce plant growth because of osmotic deleterious impacts (Adams and Ho, 1989). High EC levels in the root zone achieved either by adding NaCl or all nutrients reduce the water uptake by the plant; hence dry matter content may increase. The combination of a high EC level and transpiration rate lowers water potential in the plant and leads to changes in some physiological aspects (Hsiao, 1973; Ho et al., 1993). Manipulation of nutrient solution by the modification of EC for improving a number of vegetables has been demonstrated (Adams, 1991; Cornish, 1992). However, research to determine the influence of nutrient solution on the growth and essential oil content of aromatic herbs appears to be lacking.

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The interest in plant products has increased considerably all over the world because many herbal medicines are free from side effects (Groenewegen et al., 1992; Lipp, 1996). Since most medicinal plants are consumed raw, proper management of crop production is needed to achieve high quality plants. For this reason, the advantages offered by soilless culture for growing medicinal plants suggest that these cultivation systems could be a powerful tool for the medicinal products industry (Dorais et al., 2001; Hyden, 2006). Recently, both peppermint and lemon verbena have been produced extensively for the medicinal and food products industry; however, there is little information available about the optimum EC level of solution with respect to biomass and oil production. Among the many factors responsible for higher yield in soilless culture, adequate nutrient supply is considered one of the most effective tools (Munsi, 1992). Therefore, optimum nutrient concentrations for aromatic plants should be determined. The objective of this experiment was to determine the effects of a nutrient solution EC and NaCl salinity on the growth, photosynthesis, and essential oil content of peppermint and lemon verbena.

Materials and Methods

Growing conditions and treatments

Shoot tip cuttings of lemon verbena (7.5-10 cm long) were propagated under intermittent mist in March 2004. The propagation medium was perlite and sand (1:1) maintained at 21-24 °C by bottom heating. On 1 May, rooted cuttings were cut by removing 2 cm of the shoot apices, and they were transferred into slabs (bags) filled with perlite and vermiculite (1:1 v). At the same time, peppermint plants were planted in bags ($1 \times 0.25 \times 0.1$ m) filled with perlite and vermiculite (1:1). The peppermint plants were initiated from rhizome cuttings (10 cm long) supplied by Beheshti University. Initially, all plants were fed with a nutrient solution with half-strength Hoagland's solution and then when the plants developed 2 or 4 leaves the treatments were imposed. Seven bags were laid out on the floor of a glasshouse in 4 rows with 1 m between rows. Each bag containing approximately 6 plants was considered as a plot and each row as a block. The first and last plants of each row were used as guard plants. The treatments were randomised within rows to give a randomised complete block design with 4 replicates. Treatments consisted of 5 nutrient solutions differing in EC (0.7, 1.4, 2.8, 5.6, and 5.6_{Na} dS m^{-1}). The fifth treatment was 5.6_{Na} dS m^{-1} NaCl (45 mM) added to half-strength Hoagland's solution to attempt to find the effect of NaCl on the peppermint and lemon verbena growth. Standard nutrient solution was adapted from Hoagland and Arnon (1950) depending on the analysis of the local water and adjusting the EC of the solutions by either adding or subtracting all the macronutrients proportionally to the standard solution. Both frequency and duration of irrigation were controlled by a digital timer and extra solution was applied at each irrigation to prevent the building up of EC level in the root zone. The plants were kept under natural sunlight and the temperature was set at 28 ± 3 °C (day) and 20 ± 3 °C (night) during the entire experiment period. Relative humidity in the glasshouse was 60%-70% during the experiment. No pesticide or herbicide was applied to the plants.

Data collections

When the true leaves of the plant were fully expanded (30 days after treatment started), photosynthetic and stomatal conductance of the mid-lamina portion of the youngest fully expanded leaves of 2 plants from each treatment were measured using a portable photosynthesismeter (Walz, Model HCM-1000, Germany). The flow rate and PAR were set to 800 min and 1500 μmol m^{-2} s^{-1}, respectively. Reference CO_2 concentration was set to the inside of the glasshouse. The time of measurement was between 0900 and 1400 hours. A photosynthesismeter is able to measure photosynthesis and stomatal conductance at the same time. Fresh and dry weights of the plants were measured for each plant after harvesting in the flowering stage. Leaf area and chlorophyll index were measured by leaf area meter (LI-3100, LI-COR, Inc., Lincoln, NE, USA) and chlorophyll meter (SPAD, Minolta, Japan), respectively. Leaf chlorophyll index was estimated on the 5^{th}, 10^{th}, 15^{th}, and 20^{th} leaf (counted from the stems longer than 10 cm).

The concentration of total N, Na, and K in the youngest fully expanded leaves on the main stem was determined by the Kjeldahl method (for N) and atomic absorption spectrometer (for Na and K) (Perkin Elmer, Model 110, USA). Essential oil was measured by the distillation of 500 g fresh mass. The composition of essential oil was analysed by GC-MS using a Shimadzu

GCMS-QP5050A gas chromatograph mass spectrometer, DB-5 capillary column. The operating conditions were as follows: carrier gas, helium with a flow rate of 0.9 ml/min; column temperature, 3 min in 60 °C, 60-230 °C at 4 °C/min, and finally 22 min in 230 °C, injector temperature, 220 °C; detector temperature, 250 °C; volume injected, 1 ml of the oil in chloroform (0.1%); split ratio, 1:45. The identification of the GC peaks corresponding to the components of the essential oil was based on direct comparison of the retention times (RT) and mass spectral data with those for standard compounds. At the end of the experiment (in October 2005), all the plants within each plot were harvested for the study of their growth characteristics and oil contents. Analysis of variance was carried out using generalised linear models in the SAS program. Differences between treatments were tested by Student's t-test ($P \leq 0.05$) and differences between means were compared by the LSD test.

Results

The results showed that EC levels of the various solutions had significant effects on the vegetative characteristics (Table 1). In peppermint, the highest fresh and dry weight was observed in the 1.4 dS m^{-1} treatment. Increasing the solution EC with either NaCl or all nutrients at 5.6 dS m^{-1} reduced the fresh weight of the plants; however, the extent of fresh weight reduction became more pronounced in the 5.6 dS m^{-1} treatment by adding all nutrients. The increased EC with either NaCl or all nutrients at 5.6 dS m^{-1} reduced the fresh weight of lemon verbena. The highest dry weight in peppermint was obtained in the 1.4 dS m^{-1} treatment while in lemon verbena it was in both 1.4 and 2.8 dS m^{-1} treatments. Both high and low EC solutions reduced the leaf area so that the highest leaf area was observed in both 1.4 and 2.8 dS m^{-1} treatments (Figure 1). In peppermint increasing EC to 1.4 dS m^{-1} had no effect on the chlorophyll index; however, supplying higher EC to the plant tended to produce a deep green colour (Figure 2). In lemon verbena, increasing EC reduced the chlorophyll index. The EC of the nutrient solutions significantly affected Pn and stomatal conductance (Figure 3A and B). The Pn increased up to 2.8 dS m^{-1}, but thereafter decreased. The reduction in Pn and stomatal conductance in 5.6 dS m^{-1} became more severe, as compared to the 5.6_{Na} treatment. The data of leaf ion concentration of the plants in relation to EC levels are presented in Table 2. In both plants, the concentration of N was higher in the EC values from 1.4 to 2.8 dS m^{-1} whereas it was reduced in both 0.7 and 5.6_{Na} dS m^{-1} treatments. Increasing EC of solution by all nutrients increased the concentration of K in both plants. However, adding NaCl to the solution led to a significant decrease in K in the plant tissue. The lower concentrations of K occurred in the treatments with the highest NaCl. Various levels of solution EC by adding all nutrients had no significant effect on Na concentration, but its concentration increased in the 5.6_{Na} treatment. No detrimental visible toxicity symptoms such as dead leaf edge or drop were observed in the 5.6_{Na} treatment.

Table 1. The effect of different EC levels on the vegetative characteristics of peppermint and lemon verbena.

EC (dS m^{-1})	leaves Fwt (g $plant^{-1}$)		leaves Dwt (g $plant^{-1}$)		Dry matter content (%)		Leaves no. (per plant)	
	mint[1]	lemon[2]	mint	lemon	mint	lemon	mint	lemon
0.7	714.9b	401.0b	100.2b	101.0b	14.0b	25.2b	1214.6b	806.6b
1.4	863.8a	480.2a	129.2a	132.0a	15.0b	27.5b	1756.0a	971.0a
2.8	498.2c	441.8ab	77.5c	125.3a	15.6b	28.4b	1163.0b	1003.0a
5.6	395.7c	300.0c	77.3c	109.1b	19.5a	36.4a	1169.6b	990.2a
5.6_{Na}[1]	548.0bc	262.2c	88.5bc	80.1c	16.1ab	30.5ab	1848.3a	464.3c
Significance	**	**	*	**	**	**	*	*

*significant ($P < 0.05$), **significant ($P < 0.01$); 1 and 2 are peppermint and lemon verbena, respectively
[1]5.6 dS m^{-1} + 45 mM NaCl supply

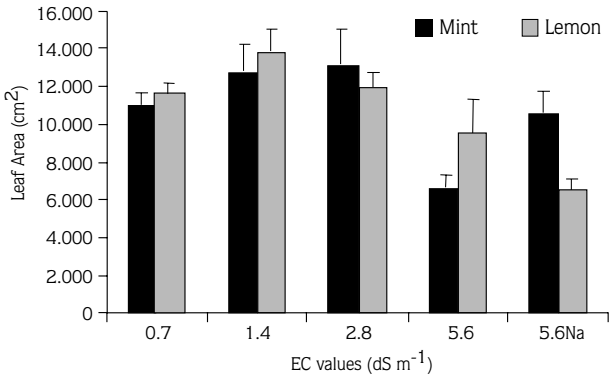

Figure 1. The effects of nutrient solutions and salinity on leaf area in peppermint and lemon verbena.

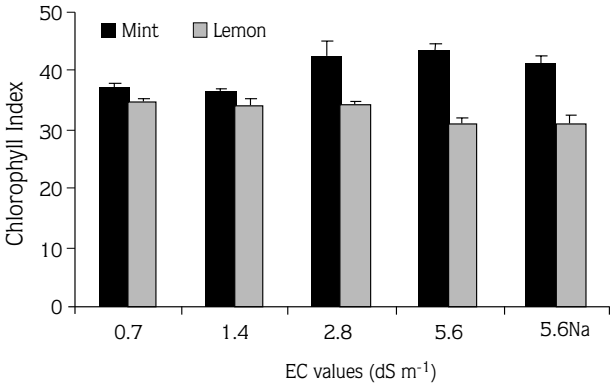

Figure 2. The effects of nutrient solutions and salinity on chlorophyll index in peppermint and lemon verbena.

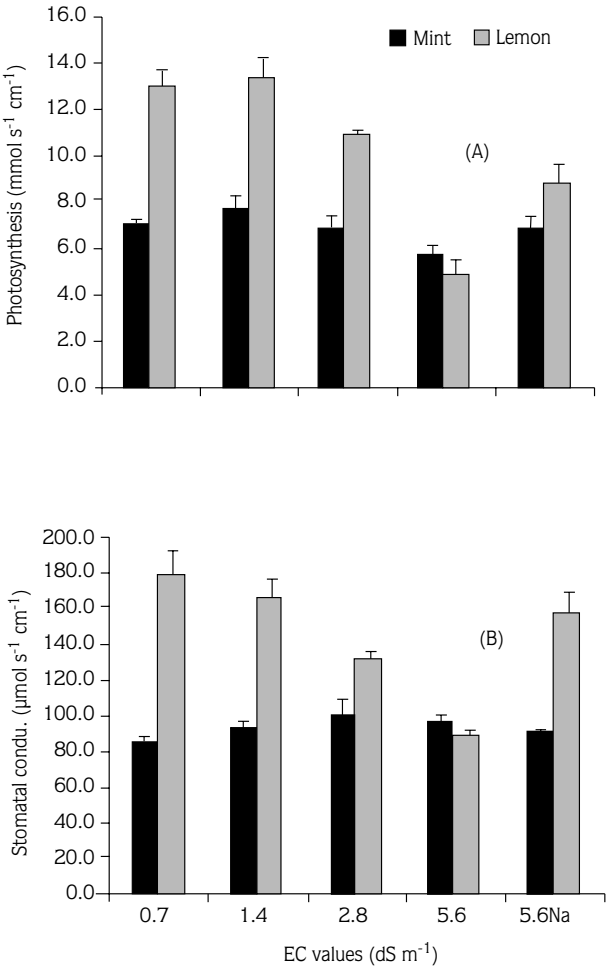

Figure 3. The effects of nutrient solutions and salinity on Pn (A) and stomatal conductance (B) in peppermint and lemon verbena.

The increased EC level had no effect on the oil concentration in peppermint (Figure 4A). In lemon verbena, the concentration of oil progressively increased as the solution EC increased. When the data for oil concentration were transformed into per plant fresh weight, there was a significant reduction in oil content due to both increased and decreased EC of solution, which was more marked in the 5.6 and 5.6_{Na} treatments (Figure 4B). The essential oil content in the 1.4 dS m^{-1} treatment was 55.0% and this was 40.5% higher than those of the 5.6 and 5.6_{Na} dS m^{-1} treatments. In peppermint, the major constituents of the essential oil were menthone and menthol, which together accounted for approximately 60%-65% of total oil composition in each treatment (Table 3). The highest and lowest proportion of menthone was observed in 1.4 and 0.7 dS m^{-1} treatments, respectively. Significantly higher levels of menthone were observed in the 5.6_{Na} treatment. However, the proportion of menthol was reduced in that treatment. The increased Na concentration in the solution significantly reduced the menthofuran. In lemon verbena, the major constituents of the essential oil were geranial and neral, which together accounted for 50%-55% of total oil composition in each treatment (Table 3). Increased solution EC by adding either NaCl or all macronutrients slightly increased the proportion of geranial and had no significant effect on the neral proportion.

Table 2. The effect of different EC levels on the nutrient concentration of peppermint and lemon verbena.

EC (dS m^{-1})	N (mg g^{-1})		P (mg g^{-1})		K (mg g^{-1})		Na (mg g^{-1})	
	mint	lemon	mint	lemon	mint	lemon	mint	lemon
0.7	29.9b	30.6b	6.2a	6.7a	45.8b	37.8b	1.4b	1.6b
1.4	38.1a	35.5a	6.6a	7.5a	47.8b	42.1ab	1.4b	1.6b
2.8	37.1a	35.6a	6.6a	7.1a	54.8a	54.8a	1.2b	1.3b
5.6	36.8a	35.3a	8.2a	7.4a	51.5a	54.5a	1.2b	1.3b
5.6_{Na}	28.4b	29.0b	6.4a	6.5a	37.8c	37.1b	3.8a	4.7a
Significance	**	*	**	Ns	**	**	**	**

ns = nonsignificant, * significant (P < 0.05), ** significant (P < 0.01)

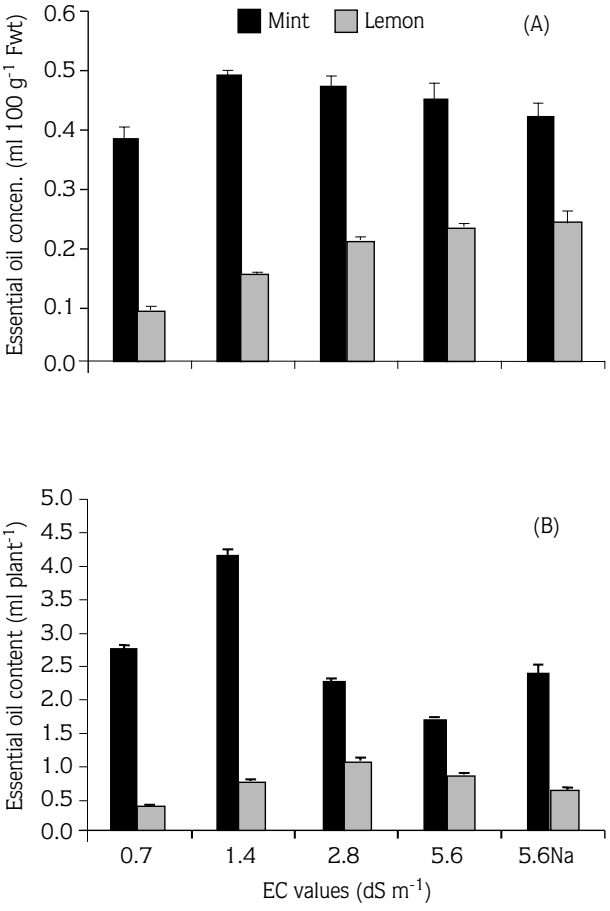

Figure 4. The effects of nutrient solutions and salinity on essential oil concentration (A) and oil content (B) in peppermint and lemon verbena.

Discussion

The concentration of nutrient solution is the most controllable cultural factor affecting the growth and quality of greenhouse plants. In peppermint, treatments with EC of 1.4 dS m^{-1} and in lemon verbena treatments with EC of both 1.4 and 2.8 dS m^{-1} led to the production of higher fresh and dry weight of the plants (Table 1). In our study, both fresh and dry weight were reduced by the high EC solution (5.6 and 5.6_{Na} treatments), suggesting that this EC level suppressed plant growth. The growth suppression in the 5.6 dS m^{-1} treatment was due to in part to high osmotic potential in the solution and in 5.6_{Na} to both high salinity and ion toxicity. Leaf area decreased in both high and low EC treatments (Figure 2), which is an important factor for plant growth. The decrease in leaf area in high EC conditions is associated with leaf water status (Marschner, 1995) and is reported by many researchers (Cramer, 2002; Kang and Van-Iersel, 2004). The reduction in leaf growth rate in high EC conditions is likely to be caused by reduced cell turgor. In the increased osmotic potential, the rate of water supply to the shoot becomes restricted so that leaf growth falls. The reduction in leaf area in the low EC treatment is likely to be the result of sub-optimal nutrient supply. Low rates of net photosynthesis or insufficient cell expansion or both can limit leaf area. This is particularly evident with sub-optimal supply of nitrogen and phosphorus. Chapin et al. (1987) indicated that elongation of leaves might decline before there is any reduction in net photosynthesis. Leaf area of the 1.4 and 2.8 EC treatments were more than

Table 3. The effect of different EC levels on composition (%) of essential oils (EO) of peppermint and lemon verbena.

	Peppermint						Lemon verbena				
	EC (dS m^{-1})						EC (dS m^{-1})				
EO constituent	0.7	1.4	2.8	5.6	5.6_{Na}	EO constituent	0.7	1.4	2.8	5.6	5.6_{Na}
Menthone	29.8	44.68	35.2	31.5	48.0	Geranial	27.4	30.4	31.7	32.7	33.2
L-(-)Menthol	33.6	19.6	25.6	26.5	20.8	Neral	22.5	20.0	23.0	23.5	23.0
Menthofuran	16.8	15.0	15.2	15.8	1.5	α-curcumene	8.5	10.5	3.6	5.4	6.0
Pulegone	5.7	7.0	8.5	10.0	11.2	Spathulenol	4.5	6.7	4.7	4.5	4.3
Eucalyptol	5.6	6.0	6.7	6.7	6.0	Caryophllenoxide	4.5	-	2.5	1.7	-
Isomenthone	-	-	-	-	5.8	6-Methyl-5-hepten-2 ol	5.5	4.8	3.5	2.4	2.0
Trans-sabinenehydrate	2.0	0.1	1.4	2.0	2.0	D-limonene	3.8	4.0	4.8	4.3	6.0
D-limonene	1.7	2.6	2.0	2.0	1.8	Eucalyptol	3.3	3.6	3.4	2.7	3.4
(Z)-β-farnesene	1.0	-	-	-	-	β-caryophyllene	2.9	2.1	3.1	3.8	5.0
β-pinene	0.5	0.7	1.0	0.6	0.4	Trans-Geraniol	2.8		1.6	0.1	2.0
Menthyl acetate	0.4	0.2	0.3	0.3	-	1-Octen-3-ol	2.0	2.5	2.1	0.1	0.1
Isopulegone	0.3	0.1	0.5	0.1	1.0	Nerol	-	-	2.9	2.2	1.5
Terpineol-4	0.3	0.2	0.6	0.6	0.5	Nerolidol	1.9	3.3	1.4	1.5	1.4
Germacrene D	0.3	0.1	0.4	0.6	-	Cis-Geraniol	1.8	2.6	0.1	0.1	0.1
α-pinene	0.3	0.5	0.5	0.4	0.2	Gerannyl acetate	1.8	2.4	1.8	1.5	-
Sabinen	0.2	0.3	0.3	0.3	-	Geraniol	-	2.4	-	3.0	0.1
(+)-somenthol	0.2	0.2	0.1	0.1	-	(+)-α-teroineol	1.6	3.4	3.5	2.7	2.4
Piperitone	0.3	0.2	0.2	0.2	-	(+)-Calarene	1.1	1.5	0.1	0.1	0.8
Ethyloctynol	0.2	0.1		0.2	0.1	α-elemene	0.8	0.1	-	-	1.5
(+)-α-terpineol	0.1	0.1	0.2	0.2	0.1	β-cubebene	0.8	0.1	-	0.1	2.5
β-caryophyllene	0.1	0.1	0.3	0.5	0.1	Terpinene-4-ol	0.6	-	0.5	-	0.1
Myircene	0.1	-	0.1	0.2		L-linalool	0.5	-	0.6	0.1	0.1
Farnesol	-	0.3	-	0.1	0.1	Trans-β-ocimene	0.5	-	2.2	1.0	1.3
Viridiflorol	-	-	0.1	0.3	-	Germacrene D	-	-	2.2	2.4	-
						(-)-methol	-	-	-	3.2	1.9
						Cemirene	-	-	-	-	1.0

those of the low and high EC treatments. This implies that this range of EC can be applied to lemon verbena and peppermint plants grown in hydroponics.

Addition of different salts to the nutrient solution (NaCl or all nutrients) appeared to have unequal effects on biomass and essential oil production. This discussion is supported by the reduction in leaf water content in response to increasing EC level. Numerous studies have shown that K concentration in plant tissue declines as the Na salinity in the root zone increases, because of a competitive uptake process, and results in growth and yield reductions (Munns, 1993; Lopez and Satti, 1996; Grattan and Grieve, 1999). The presence of other nutrients may also influence the effect of salinity on K uptake and accumulation as shown in Table 2. Nitrogen uptake can be affected by high Na salinity (Tabatabaei, 2006). In this experiment N uptake was lower in the 0.7 and 5.6_{Na} treatments.

The decrease in Pn and stomatal conductance with increasing solution EC was expected, as it was reported by previous researchers (Kang and Van-Iersel, 2004; Tabatabaei, 2006). According to Shannon and Grieve

(1999), the plant responds to salt stress by decreased growth rate with corresponding formation of small and fewer leaves and reduced plant height. Root systems respond to salinity not only with a reduced growth rate but also with reduced water and nutrient uptake. Reduced water uptake results in reduced turgor in leaves and subsequently closure of stomata, leading to the reduction in stomatal conductance and Pn rate (Ball and Farquhar, 1984).

Essential oils are a mixture of various compounds, also known as secondary metabolites, with a peculiar taste, useful in modern industry including the pharmaceutical, tobacco, and food industries. For example, menthol found in peppermint oil is a terpenoid compound originating in the mevalonic acid cycle (Aflatuni, 2005), which is a long biochemical pathway with many enzymes acting on it. Changes in enzymes activity modify the content of their substrate or product, improving essential oil quality (Maia et al., 2001). Research to determine the influence of nutrient solution on the growth and essential oil content of aromatic herbs appears to be lacking. As shown in Figure 4, the concentration of nutrients in the solution exerted a greater influence on essential oil content. Essential oil content was the highest in plants receiving the moderate EC solution (Figure 3). Although increasing solution EC resulted in a higher oil concentration per 100 g leaf fresh weight, it did not result in greater total oil production by leaves when evaluated on a per plant basis. These results suggest that a high rate of fertilisation suppresses essential oil biosynthesis in peppermint. The high NaCl concentration in the nutrient solution has a negative impact on the oil content in both plants as expected. In some vegetables, such as tomatoes, enhanced fruit quality is the result of the increased sugar content, which is correlated with the dry matter content (Adams, 1991). However, organic constituents involve both enzymatic and metabolite changes caused by ion concertinos and/or osmotic effects (Greenway and Munns, 1980; Staples and Toenniessen, 1984). One explanation for the increased oil concentration in the high EC could be the accumulation of dry matter in the plants grown in the increased EC solutions. The increase in essential oil yield due to higher solution EC depended not only on the increase in leaf biomass, but also on the increase in leaf essential oil concentration, presumably indicating an enhancement in oil biosynthesis (Sangwan et al., 2001). Additionally, the plants might produce secondary metabolites to cope with stressful conditions (Taiz and Zeiger, 2002). Leaves produced by plants grown at higher levels of EC may have had a higher oil gland density as a result of a stress-induced reduction in leaf area. Such a change in gland frequency could provide a partial explanation for the observed high oil concentration per unit leaf fresh weight. Alternatively, higher EC may increase the absolute number of glands produced prior to leaf emergence (Charles et al., 1990). Higher EC may also have affected essential oil accumulation indirectly through its effects on either net assimilation or the partitioning of assimilates among growth and differentiation processes. The reduction in growth induced by lower osmotic potential may have resulted in a new pattern of resource partitioning, perhaps providing additional carbon skeletons for terpene biosynthesis and accumulation. On the other hand, the benefit of increased essential oil concentration because of the increased EC would be offset by any reduction in biomass production in high EC treated plants. Although oil concentration was affected due to higher EC levels (5.6 dS m^{-1}), a significant adverse effect of high EC was observed when data for oil concentration were transformed into per plant fresh weight. Therefore, total yield of oil in higher EC fell due to the production of the reduced fresh weight. A high reduction in total yield of oil of these crops could imply maintaining the EC of solution at an appropriate level.

In peppermint, the site of terpene biosynthesis has been localised in the secretory cells of the glandular trichomes, which are mainly located on the leaf and stem surfaces (Gershenzon et al., 1989). The bulk of the monoterpenes of peppermint essential oil is produced by and stored in the peltate glandular trichomes (Turner et al., 2000). From a qualitative point of view, menthol and menthone are the main constituents of the peppermint essential oil (Maffei and Sacco, 1987). The commercial importance of peppermint essential oil depends on the percentage of these 2 components as well as the low percentages of other undesirable compounds such as menthofuran (Maffei and Mucciarellib, 2003). The increase in menthone and the decrease in menthofuran in the 5.6_{Na} treatment improved the commercial quality of the distilled essential oil. This result is consistent with those reported by Charles et al. (1990) for peppermint grown in different levels of osmotic stress.

In lemon verbena, the commercial importance of essential oil depends on the percentages of geranial and neral. The increased EC slightly increased the geranial, but a minor change was induced in neral proportion. The physiological factors regulating compositional changes in lemon verbena are poorly known. At least, the results suggest that growth of lemon verbena or peppermint could be manipulated to improve essential oil yield without adversely affecting oil composition by adding NaCl to the solution.

Conclusion

The results led to the conclusion that for high economic yields, particularly of biomass, which is a basic raw material for medicinal use, moderate EC levels are beneficial for cultivation in a controlled environment. Increased EC either by adding all nutrients or NaCl to the solution increased the total oil content of peppermint, but it was reduced in lemon verbena. Therefore, application of higher EC in some species does not increase essential oil content. Our data indicated that increasing the EC of the solution by adding NaCl had deleterious effects on biomass production in lemon verbena, but in peppermint NaCl could be a suitable salt to increase the EC of solution. The optimum value of EC in the root zone at which no yield reduction occurred in peppermint and lemon verbena was 1.4 and 2.8, respectively.

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