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Rose productivity and physiological responses to different substrates for soil-less culture

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Abstract

Cultivation of roses in various soil-less media was studied with the aim to identify the optimum soil condition for rose production. Madelon roses grafted on rootstock of *Rosa indica* var. major were transplanted to polyethylene bags containing zeolite and perlite (at ratios of 25z:75p, 50z:50p, 75z:25p and 100z:0p, v/v) in a climate-controlled greenhouse. Net photosynthesis (A_{net}), stomatal conductance (g_s) and water use efficiency (WUE) of roses were followed for 5 months. Flower production and quality were recorded in three flowering flushes during a 5-month period. Analysis of variance of repeated measurements showed that even though the overall A_{net} did not differ among treatments (average 18.7 μmol m^{-2} s^{-1}), trends in A_{net} seasonality for roses in 25z:75p substrate differed significantly from those in 50z:50p, 75z:25p or 100z:0p. Stomatal conductance did not show any significant seasonality or trends in response to substrate mixtures, averaging 0.89 mol m^{-2} s^{-1}. Water use efficiency was significantly lower for roses in 25z:75p than in 100z:0p mixtures (1.8 ± 0.15 and 2.0 ± 0.13 μmol m^{-2} s^{-1} CO_2/mmol m^{-2} s^{-1} H_2O, respectively). Cumulative production of rose plants did not differ among substrate mixtures. Productivity significantly differed among flower stem classes. Stem class I (>70 cm) and class V (≤30 cm) exhibited the least production, contributing to only 7.6 and 3.7% of the total production, respectively. The highest productivity was observed in classes III (51–

60 cm) and IV (31–50 cm), contributing to the bulk of productivity (68.4%). Class II contributed a 20.3% of the production. Results showed that zeolite and perlite acted as inert materials. Zeolite did not exert any positive effect on productivity, in contrast to what has been reported in literature recently. Use of perlite resulted in a little improvement in photosynthesis, however this improvement was not reflected by a significant increase in production.

Keywords: Madelon rose, soil-less substrate, zeolite, perlite, gas exchange

1. Introduction

Soil-less cultures have been successfully used for several decades with the aim to intensify production and reduce cost (Maloupa et al., 1992). Cultivation of roses in various soil-less media is being achieved with promising commercial potentials. Roses have been produced in almerian sand culture, nutrient flow cultures (Takano, 1988), gravel culture (Sarro et al., 1989), volcanic materials (Raviv et al., 1999), organic substrates, mineral wool, aeroponics (Zieslin and Snir, 1989), rockwool (Kool and Van de Pol, 1991) and perlite (Katsoulas and Baille, 1999). The cost, local availability and experience in substrate use, are usually the determining factors for choosing a particular substrate type. Among the various soil-less culture practices, the use of substrate is the easiest to be adopted by growers.

Hydroponic cultivation in substrates containing zeolite has gained popularity in the last decade as an alternative to conventional soil-less production. Zeolite is reported to increase yields in several crops, i.e. wheat, eggplant, carrot, tomatoes, peppers (Mumpton, 1999). In floriculture, Issa et al. (2001) reported that gerbera performed better on zeolites than on perlite or rockwool. Zeolites are crystalline, hydrated alumino-silicate of alkali and alkaline earth cations, with an open three-dimensional structure, a unique adsorption capacity, and a high cation exchange and dehydration–rehydration ability (Mumpton, 1999). In contrast to the majority of production media which have a limited nutrient retaining capacity (Williams and Nelson, 1997), zeolite with its high cation exchange capacity (2–4 mequiv. g^{-1}), has the potential to be used in soil-less media as a slow release nutrient source, positively affecting yields.

Perlite on the other hand has been widely used in soil-less cultures. Perlite, an alumino-silicate of volcanic origin, is rather inert (low buffering and cation exchange capacities of 0–1 mg L^{-1}). In general, it has a closed cellular structure, with the majority of water being retained superficially and released slowly at a relatively low tension, providing excellent drainage of the medium and aeration of rhizosphere. Therefore, it requires frequent irrigation to prevent a fast developing water stress (Maloupa et al., 1992). Perlite also contains 6.9% aluminum which at low pH may be released into the solution and adversely affect the plants.

Because of their complementary properties, zeolite and perlite might be used together in substrates for soil-less cultivation and could potentially provide optimum growth conditions for roses. To test this hypothesis, we have studied the physiology, productivity, growth and flower quality of Madelon roses grown in zeolite (z) and perlite (p) substrates at various ratios (25z:75p, 50z:50p, 75z:25p and 100z:0p) in a climate and drip fertigation controlled greenhouse.

2. Materials and methods

2.1. Growth conditions

Madelon rose plants grafted on rootstock of *Rosa indica* var. major were grown in a climate-controlled greenhouse (Agricultural Research Center of Macedonia and Thrace, Thessaloniki, Greece). Plants were transplanted in January, into 71 L black inside and white outside polyethylene bags (2 m length, 60 cm perimeter, 19 μm thickness). Bags were filled with zeolite:perlite mixtures with ratios of 25z:75p, 50z:50p, 75z:25p and 100z:0p (v/v). Particle sizes of zeolite and perlite were 3–6 mm and 3–5 mm, respectively.

Sixteen slabs placed on 16 PVC gullies were formed and supported by polystyrene blocks placed 30 cm above the ground. Each slab represented one treatment, each treatment was replicated 4 times and carried 16 plants (total of 64 plants/treatment). Plants were spaced 12 cm apart. The rate of the irrigation (fertigation) was electronically controlled to obtain an average of 30% drainage. Irrigation was applied between 8 and 16 times per day for 10 to 20 min. The final concentrations in the nutrient solution (mequiv. L^{-1}) were 9.6 N-NO_3^-, 0.8 N-NH_4^+, 4.0 K^+, 6.8 Ca^{2+}, 1.6 Mg^{2+}, 1.6 $H_2PO_4^{2-}$, 1.6 SO_4^{2-}, while the concentrations of microelements (μequiv. L^{-1}) were 93.6 B, 2.32 Cu, 144.67 Fe, 2.02 Mn, 1 Mo, 11.4 Zn. The pH was adjusted to 5.8 with the addition of 65% HNO_3 (this addition was taken into account when measuring the final N-concentration), and the electrical conductivity (EC) was 1.9 mS cm^{-1}.

Winter and summer temperatures in the greenhouse were set at 13 and 25 °C, respectively. Summer temperatures were controlled using automatic fans and cooling system, and excessive radiance was controlled using a shading net applied in June. The shading net allowed a maximum photosynthetic active radiation (PAR) of 700–900 μmol m^{-2} s^{-1}. These PAR values were adequate to saturate photosynthesis in roses (Jiao et al., 1991). Yellow sticky traps, vaporized sulphur and spider mites predators (*Ambliseious california* and *Phytoseiulus persimilis*) were used in conjunction with Vendex and Pyrimor to control black and green aphids, white flies, spider mites and powdery mildew.

2.2. Gas exchange measurements

Seasonal oscillations in gas exchange were followed on a monthly basis from May (when rose production started) till September using a portable photosynthetic system (LI-6250, LI-COR Inc. Lincoln NE, USA). A fully developed, five-leaflet compound leaf (the fourth or fifth from the top of the flowering shoot) was chosen for the measurement. Three variables were determined: net photosynthetic rates (A_{net}, μmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}) and water use efficiency (WUE, μmol m^{-2} s^{-1} CO_2/mmol m^{-2} s^{-1} H_2O). Measurements were conducted on clear sunny days between 10 am and 1 pm (time of highest photosynthetic rates). Difference between air and leaf temperatures in the chamber were maintained close to air temperature (difference between 1 and 2 °C) by manipulating the fan speed in the chamber. Vapor pressure deficit (VPD, mbar) between the leaf and the air was maintained near ambient (Awada et al., 2003). A total of 20 plants was selected per treatment (five plants per replication) for gas exchange measurements, the remaining plants were used for productivity measurements.

2.3. Flower production and quality measurements

Flower production and quality were recorded between May and September in three flowering flushes (from May 9th to June 10th, June 11th to July 18th, and July 19th to September 7th). Stem length, thickness (at both top and bottom) and mass were measured. To evaluate quality, flowers were separated into five classes: class I (flowering stem length >70 cm), II (61–70 cm), III (51–60 cm), IV (31–50 cm), and class V (≤30 cm).

2.4. Data analysis

Repeated measures analyses of variance were performed using the Mixed Model Procedure in SAS statistical package to evaluate seasonal trends in gas exchange and the effect of substrate mixtures on gas exchange. Linear and/or quadratic contrast analyses for treatment (substrate mixture) effects were also performed. Treatment and month were considered fixed factors, while plants within replications were random (Steel et al., 1996). Rose productivity, stem width and weight were analyzed using the General Linear Model in SAS. Pairwise mean comparisons were performed using the probability of difference ($P = 0.05$) (Steel et al., 1996).

3. Results

3.1. Gas exchange measurements

Seasonal and diurnal trends of photosynthetic active radiation (PAR), air temperature (TA) and vapor pressure deficit (VPD) are presented in Figure 1. Environmental variables did not differ among treatments within sampling dates, and therefore, data were pooled together. There was a drop in total PAR received in July compared to June, due to the installation of the shading system. The lack of differences between treatments suggests that differences in gas exchange should be mainly attributed to differences in substrate characteristics and seasonality. Analysis of variance of repeated measurements over the 5-month period (May–September, Table 1) showed that roses exhibited significant sea-

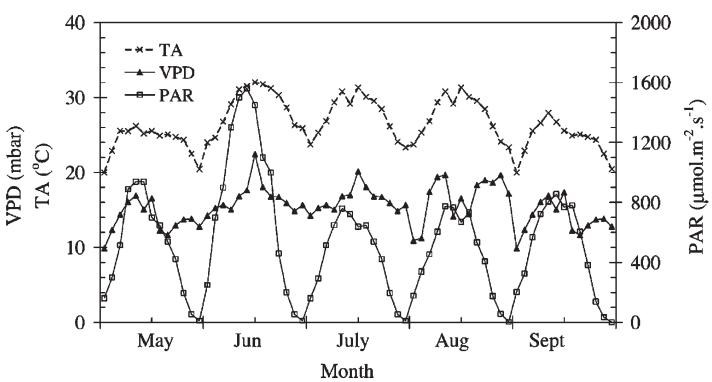

Figure 1. Average monthly course of photosynthetic active radiation (PAR, µmol m^{-2} s^{-1}), air temperature (TA, °C), and vapor pressure deficit (VPD, mbar) between 8:00 and 20:00 h in the greenhouse.

Table 1. Analysis of variance of repeated measurements and orthogonal contrasts of seasonal changes (May–September)

Analysis of variance	d.f.	A_{net} (*F*-value)	g_s (*F*-value)	WUE (*F*-value)
Month	4	44.27**	1.69 *ns*	138.4**
Treatment	3	2.54 *ns*	0.67 *ns*	7.55**
Treatment × month	12	3.49**	1.00 *ns*	3.93**
Orthogonal contrasts				
25z:75p vs. 50z:50p	1	96.7**	0.01 *ns*	85.9**
25z:75p vs. 75z:25p	1	95.3**	3.21 *ns*	17.2**
25z:75p vs. 100z:0p	1	54.5**	0.02 *ns*	139.3**
50z:50p vs. 75z:25p	1	2.55 *ns*	3.6 *ns*	42.9**
50z:50p vs. 100z:0p	1	4.99*	0.01 *ns*	443.6**
75z:25p vs. 100z:0p	1	1.51 *ns*	3.49 *ns*	315.9**
25z:75p vs. (50z:50p, 75z:25p and 100z:0p)	1	20.59**	1.42 *ns*	174.5**

Net photosynthesis (A_{net}, µmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}) and water use efficiency (WUE, µmol m^{-2} s^{-1} CO_2/mmol m^{-2} s^{-1} H_2O) in hydroponic roses grown in four substrates (treatments) of zeolite:perlite (z:p) mixtures.
ns denotes not significant at 0.05.
* *F*-values significant at 0.05.
** *F*-values significant at 0.01.

sonality in net photosynthesis (A_{net}), and that this trend in seasonality was to some extent influenced by substrate mixture treatments. More specifically, even though the overall A_{net} rates (values ranging between 18.36 and 19.11 µmol m^{-2} s^{-1}) were not significantly influenced by substrate treatment, orthogonal contrasts (Table 1) showed that trends in A_{net} for roses grown in 25z:75p differed significantly from those grown in 50z:50p, 75z:25p and 100z:0p. Significantly higher A_{net} values for roses grown in 25z:75p than in 100z:0p were observed in May, August and September (Figure 2A). These differences in A_{net} were not reflected by differences in stomatal conductance. Stomatal conductance did not show any significant seasonality or trends in response to substrate mixtures, averaging 0.89 mol m^{-2} s^{-1} (Table 1, Figure 2B). Water use efficiency on the other hand, exhibited significant variability among treatments and seasons. Roses in 25z:75p mixtures had significantly lower WUE than roses in 100z:0p mixtures (1.8 ± 0.15 and 2.0 ± 0.13, respectively). WUE in 50z:50p and 75z:25p mixtures averaged 1.9 and values were not significantly different from either 25z:75p or 100z:0p mixtures (Figure 2C).

3.2. Production and quality

Analysis of variance (Table 2) showed that cumulative production of rose plants (n = 10) did not differ among substrate mixtures. The average cumulative production per plant ranged from 50 to 55 for 100z:0p and 25z:75p substrate mixtures, respectively (Figure 3). Productivity significantly differed among classes (Table 2, Figure 3). Stem class I (>70 cm) and class V (≤30 cm) exhibited the least production, averaging 4.1 and 2 flowers per plant and contributing to 7.6 and 3.7% of the total production, respectively. The highest productivity was observed in classes III (51–60 cm) and IV (31–50 cm), with 17 (31.4%) and 20 (37%) flowering stems per plant. Classes III and IV did not differ be-

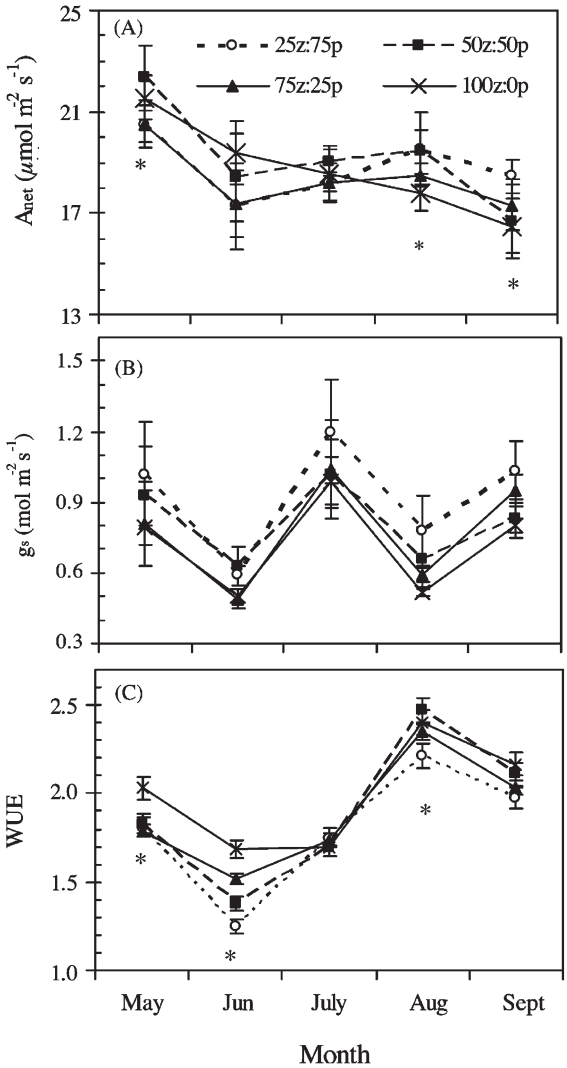

Figure 2. Seasonal variation of (A) net photosynthesis (A_{net}, μmol m^{-2} s^{-1}), (B) stomatal conductance (gs, mol m^{-2} s^{-1}) and, (C) water use efficiency (WUE, μmol m^{-2} s^{-1} of CO_2/mmol m^{-2} s^{-1} of H_2O) and respective standard error bars in hydroponic roses, grown in four zeolite:perlite (z:p) mixtures in the greenhouse. An asterisk indicates significant differences between treatments within a month at $P = 0.05$, $n = 20$.

tween each other, but differed significantly from the remaining classes. They contributed to the bulk of the production with 70% of the total. Class II contributed to an average of 11 flowering stems per plant, or 20.3% of total production.

Stem width at the top and base, and average mass did not differ among substrate treatments (Table 2), therefore data were pooled together (Figure 4). Stem width and weight declined, as expected, significantly with decline in stem length (classes I–V). The decline was steeper, mass and width-wise, at the base than with the width at top. The latter was the least affected by the decline in stem length.

Table 2. Analysis of variance table of stem production

Analysis of variance	d.f.	Production (*F*-value)	Width (T) (*F*-value)	Width (B) (T) (*F*-value)	Weight (T) (*F*-value)
Class	4	95.6**	145.6**	305.3**	518.4**
Treatment	3	0.06 *ns*	2.24 *ns*	0.28 *ns*	0.86 *ns*
Class × treatment	12	0.17 *ns*	1.16 *ns*	1.13 *ns*	1.42 *ns*

Stem width at the top (T) and base (B), and stem weight in five stem length classes (I–V) of hydroponic roses, grown in four zeolite:perlite mixtures (treatments).
ns denotes not significant at 0.05.
** *F*-values significant at 0.01.

4. Discussion

Data on the physiology of roses, including water use and photosynthesis and their impact on growth and yield, are either scarce (Jiao and Grodzinski, 1998) or unreliable (Raviv and Blom, 2001). The importance of radiation and temperature on the other hand, has been studied by Zieslin and Mor (1990) and Jiao et al. (1991) among others. Jiao et al. (1991) reported that irradiance accounts for 70% of the total variability in assimilation rate in roses. A decrease in light intensity below the saturation point due to either seasonal changes or shading is believed to reduce yield in roses (Zieslin and Mor, 1990). In the Mediterranean area, however, the high light intensity during summer reduces yield and flower quality in the greenhouse due to its direct effect on temperature, relative humidity and the resulting vapor pressure deficit, transpiration and stomatal conductance (Bredmose, 1993). Decreased length and mass of rose stems following supplementary lighting have been reported (Jiao et al., 1988). Partial shading and greenhouse ventilation are therefore, common practices in this region in an effort to decrease temperature, reduce vapor pressure deficit, and to control insects and diseases.

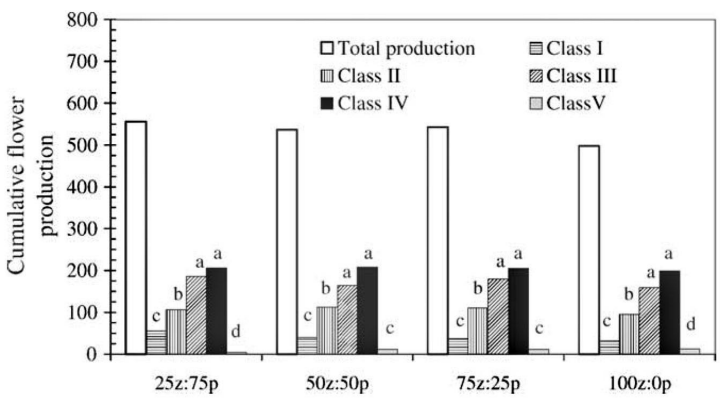

Figure 3. Cumulative flower production of hydroponic roses (n = 10 plants) in five stem classes (I–V), grown in four zeolite:perlite (z:p) mixtures in the greenhouse. All treatments (25z:75p, 50z:50p, 75z:25p and 100z:0p) within the same class are not statistically different at P = 0.05. Means with the same letter within a treatment are not statistically different at P = 0.05.

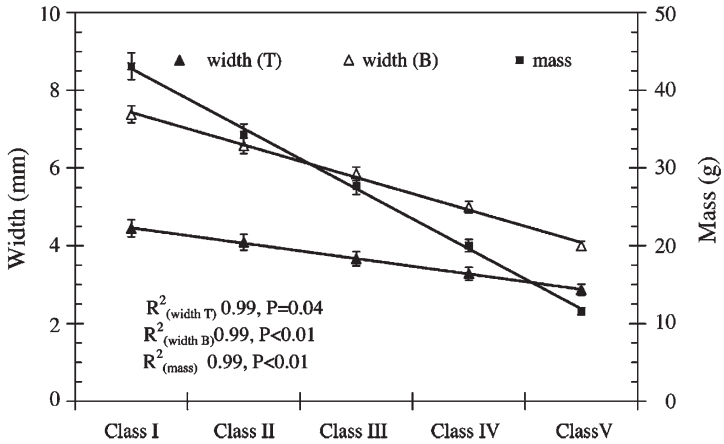

Figure 4. Overall average and respective standard error bars of stem width at the base (B) and top (T) and corresponding stem mass in five classes (I–V) of hydroponic roses.

Photosynthetic rates for rose leaves have been reported to range from 6.9 μmol m^{-2} s^{-1} for the "Forever yours" (Aikin and Hanan, 1975) to 13 μmol m^{-2} s^{-1} for "Samantha" cultivar (Bozarth et al., 1982). Aikin and Hanan (1975) and Bozarth et al. (1982), reported that photosynthesis reached the point of saturation at 450–500 μmol m^{-2} s^{-1}. Maximum rates reported in the current study (18.36 and 19.11 μmol m^{-2} s^{-1}, PAR 700–900 μmol m^{-2} s^{-1}) are consistent with those reported by other authors for outdoor-growing rose plants (e.g. Lieth and Pasian, 1990). Net photosynthesis was higher and WUE was lower in 25z:75p than in 100z:0p on several sampling dates. It is known that plants under increasing water stress respond by an increase in WUE. In the current study, the observed trend of a lower WUE in 25z:75p substrate suggests that roses in this media had more readily available water than roses in 100z:0p. Both substrates (zeolite and perlite) were coarse, however, during establishment (bag filling and transplanting,) and cultivation periods, an alteration (fragmentation) of perlite material usually occurs (Orozco and Marfa, 1995). Zeolite, though subjected to the same procedure, is usually not affected because of its hardness. Consequently, the 25z:75p substrate was altered the most, resulting in the presence of particles with sizes smaller than 3 mm in the medium. The latter is believed to decrease the percentage of pores with large diameters (60 μm), containing the gravitational water that is easily drained, and to increase the percentage of those with a diameter between 30 and 60 μm. Consequently, an increase in the total available water content of the growing media occurred, improving water status, resulting in a better water and nutrient uptake, and avoiding a pronounced midday water stress. These favorable conditions in the 25z:75p media resulted in a slight, but not significant, increase in rose productivity compared to the other treatments.

First flush in flower production was observed in May, 4 months after planting. Productivity did not significantly differ among treatments. Similar observations were reported in the literature for other rose cultures (Brun and Tramier, 1988). Production and quality results indicated that particle size of coarse zeolite (3–5 mm) and perlite (3–6 mm) ensured sufficient aeration in all four growing media (Maloupa et al., 1992; Issa

et al., 2001). The fertigation management and the cultural practices implemented (open hydroponics system) lead both substrates to react as inert materials, therefore, imposing no direct effects on nutrient availability in the rhizosphere. Results on positive effects of zeolite on productivity reported in the literature (e.g. Mumpton, 1999; Issa et al., 2001) may be explained by the powdery form of zeolite material used, which provided a higher surface available for absorption and cation exchange and/or by the fertilization management applied. We conclude that coarse zeolite in soil-less cultures simply acts as an inert material and does not exert any positive effect on productivity. The use of perlite, on the other hand, resulted in some photosynthetic improvement which, however, was not reflected by a significant increase in productivity.

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