low burn potential, when applied as concentrated solutions, would indicate potential for use in equipment designed to apply low volume of liquid materials to turfgrass areas.

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Increasing Returns from Roses with Root-zone Warming

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Abstract. **Three rose cultivars, Ilona, Mercedes, Sonia, on *Rosa multiflora* rootstock were grown in a nutrient film technique (NFT) system for 2 years, with root-zone warming (RZW) to 25°C compared with ambient temperature roots. In the 1st season the night air temperatures were 18°, 12°, and no heating (9°); in the 2nd season, 18°, 14°, and 10°. Harvested flowers were graded according to stem length. In the 1st winter seasons RZW increased the proportion of long stemmed roses and increased the total yield, especially in 'Ilona'. In the 2nd winter season, RZW again increased the proportion of long stemmed roses in 'Ilona' but increased the total number of blooms more in the other cultivars. The effects of RZW persisted into the summer period. Prevailing wholesale prices were used to calculate probable gross returns based on yields. Since RZW tended to give longer stemmed roses and more blooms than did ambient conditions, this treatment enhanced returns more than that of the increased air temperature treatments. RZW increased probable returns over the ambient for 'Ilona', 'Mercedes', and 'Sonia' by 49%, 69%, and 78%, respectively.**

Recent developments in soilless cultivation techniques, such as NFT (2), or rockwool systems (4) enable control of the root environment, including nutrition, water, temperature, and aeration, more easily than in soil. Yet, few have attempted to assess the value of manipulating the root environment of roses in such systems. Roses (in soil) were considered unresponsive to RZW, having root temperature optimum cited as 18°C (9). Recently, however, the number of blooms was increased by root-zone warming to 25°(1).

The aims of this study were to determine if roses in soilless culture with RZW increased yield or value of the crop, and if RZW would reduce the energy requirement of greenhouse cut roses.

Received for publication 15 Oct. 1983. The authors thank R. Forrester, CSIRO Divison of Mathematical Statistics, for his statistical advice. The use of the growing system NFT in this work does not imply that it is a fully developed method for commercial use with roses. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Materials and Methods

This study was conducted at Griffith, latitude 34°S, an area with good winter light (total horizontal solar radiation around 7 MJ m^{-2} day^{-1}), and warm to hot summers. The experiments were conducted in a 9 m span modern glasshouse divided into 3 sections. Each section was a separate night temperature treatment (see below). In each section were 4 benches running north to south, each carrying 2 NFT channels with a 45 liter plastic tank of nutrient to each bench. A thermostatically controlled heater maintained nutrient solutions at 25°C in the RZW treatment channels while the ambient root-zone treatment solutions were unheated.

Each root temperature treatment was replicated twice (i.e., 2 blocks each containing 2 treatments), but since it was not possible to duplicate night temperature treatments, statistical comparisons of night temperature effects are not strictly valid. The design was a split plot, and the chief interest was in the interaction between root temperature and air temperature. The analysis gave an error estimate for testing night temperature effects, but this value was really an estimate of within plot variance and may underestimate the between plot error appropriate for testing these effects. Analyses were carried out separately on each cultivar in each year.

The nutrient solution described by Cooper was used in the 1st season. The conductivity and pH of the solution were mea-

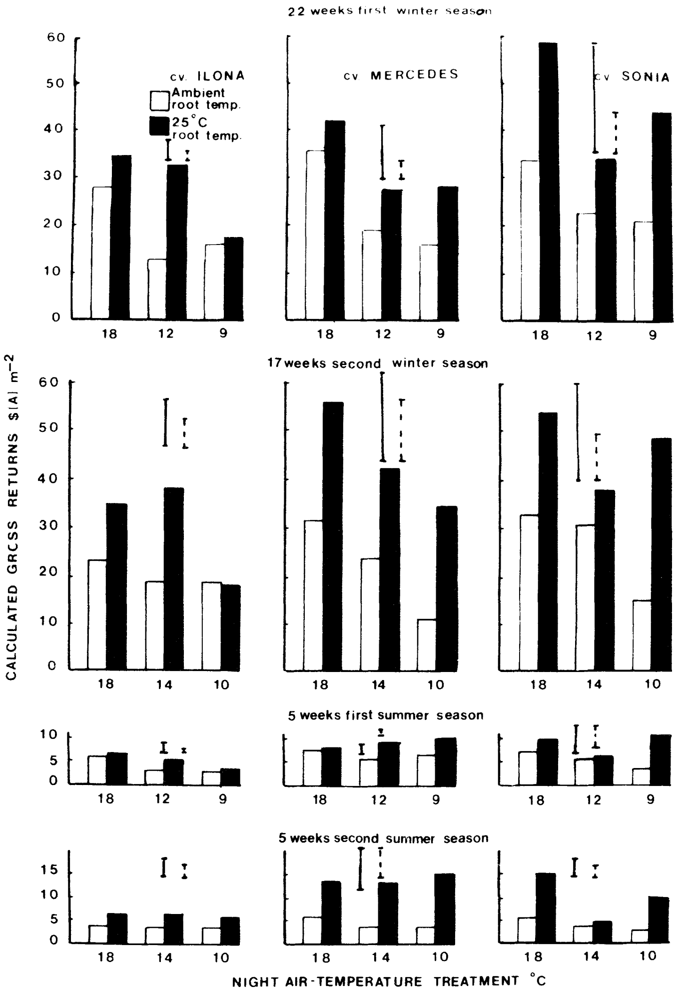

Fig. 1. Bar-graph showing the effects of night air-temperature treatments and root-zone warming on the calculated gross returns from 3 rose cultivars over 2 seasons for winter and summer periods. Vertical solid bars indicate the least significant difference between night and root temperature ($P = 0.05$), broken bars root temperature only. The error term used to calculate the LSD between air temperatures may have been an underestimate of its true value.

sured every 2nd day and the conductivity adjusted with stock solutions to between 2.0 and 2.5 dS m^{-1}; pH was adjusted to 6 with 2 N nitric acid, and iron was supplied as the EDDHA chelate. About every 3rd week, solutions were discarded.

In the 2nd season, the rose nutrient solution of Sonneveld and Bik (10) was used, and replaced every month.

First season. 'Ilona', 'Mercedes', and 'Sonia' were chosen because of their supposed temperature preferences: 'Ilona' for warm, 'Sonia' for intermediate, and 'Mercedes' for cool. They were budded onto *Rosa multiflora* rootstock, and propagated by the method of Moss and Dalgleish (8). The plants were removed carefully from pots, and the roots were washed and placed in NFT channels on 23 Apr. 1981. There were 8 plants of each cultivar in each system in an area of 1.2 m^2 (including access ways).

Thermostat settings for nighttime air temperatures were 18°C and 12°, and only enough heat was provided to prevent frost damage on very cold nights (minimum range 5° to 15°). The average minimum temperature for the entire winter period (20 Apr. - 25 Oct.) was 18.2, 12.5, and 10.0 for each of the night temperature treatments, and for the mid-winter period (25 May - 13 Sept.) 18.3, 11.7, and 9.0. The daytime thermostat setting was 21° in all cases operating from 0700HR to 1630HR, with venting at 25° and evaporative cooling at 27° from October to April.

Flowers were cut daily leaving 2 leaves on each stem or, in the case of vigorous shoots, cut back to about 300 mm above the base of the plant. Stem length of the daily cut was determined by grade for 22 weeks starting 25 May. Determinations ceased when the 1st flowers opened on outdoor rose plants denoting the end of the winter period. The plants then were given a light pruning, and the return summer crop was determined for 5 weeks (a single flush). During the summer crop period, there were limited differences in temperature among treatments because of warm external conditions.

Second season. After 13 Apr. 1982, the rose plants were removed from the channels, pruned to remove weak growth and to reduce their height, cleaned, and then replanted in the same channels. Plot size was reduced to 6 plants with an area of 0.9 m^2.

The pruning caused a delay in the return to flowering which was determined for 17 weeks for the winter period (from 22 June until 19 Oct.), and continuing for another 5 weeks until 23 Nov. The latter is refered to as the 'summer' period.

Thermostat settings for nighttime air temperatures were 18°, 14°, and 10°C. Root-zone temperature treatments were the same as for the 1st season. The average minimum temperature for the winter period (21 May - 12 Oct.) was 18.4, 13.8, and 10.6 for each of the night temperature treatments. Daytime thermostat setting and root temperature treatments were the same as for the 1st season.

The size grades for stem length are listed in Table 1 together with prevailing wholesale prices.

Result

First season, winter yield. Root-zone warming increased the number of 'Ilona' blooms only at 12°C night temperature (Table 2). The percentage of Grade 1 and 2 blooms tended to be increased (although the Grade 1 difference was not significant at

Table 1. Bloom stem-length grades and average winter and summer wholesale prices used in this study.

Length and price	Grade G1	G2	G3	G4	G5	G6	G7	G8
Stem length (mm):	<550	501–550	451–500	401–450	351–400	301–350	251–300	<251
Mean winter price: $ bloom^{-1}	0.72	0.64	0.56	0.48	0.40	0.32	0.24	0.16
Mean summer price: $ bloom^{-1}	0.36	0.32	0.28	0.24	0.20	0.16	0.12	0.08

Table 2. Effects of night air temperature and root temperature on grade and total yield for a 22-week winter period for 1st-year bushes.

Cultivar	Night temp °C	Root temp °C	Blooms in each stem length grade (mm) (%) G1	G2	G3	G4	G5	G6	G7	G8	Total yield of blooms no./m − 2[z]
Ilona	18	Ambient	13.0 a[y]	5.6 a	12.0 a	11.7	13.5	14.2	22.7 a	7.3 a	55.8
		25	15.2 a	9.0 d	15.9 c	18.5	15.2	12.4	9.0 b	4.8 a	60.4
	12	Ambient	3.0 b	2.8 b	6.8 b	16.0	24.0	14.0	9.5 b	23.9 c	30.0
		25	20.9 c	13.3 c	14.1 ca	13.7	13.2	13.7	7.1 b	4.0 a	54.2
	9	Ambient	2.5 b	12.2 c	8.7 ab	8.4	19.3	19.6	14.7 c	14.6 b	34.2
		25	14.2 a	4.7 a	3.6 d	16.3	12.0	22.0	15.2 c	12.0 b	35.4
Mercedes	18	Ambient	0.8 d	0.7 d	4.0 e	7.3	9.3	14.3	25.8 e	37.8 d	108.3
		25	1.2 de	0.3 e	2.4 e	4.9	18.9	21.8	24.7 e	25.8 e	120.0
	12	Ambient	0.8 d	0.0 e	3.5 e	12.1	17.9	26.7	26.1 e	12.9 f	48.3
		25	4.0 f	5.2 f	2.1 e	16.1	24.1	16.6	15.2 f	16.7 f	61.7
	9	Ambient	0.0 d	0.0 e	5.6 e	8.7	17.7	20.9	23.5 e	23.6 e	44.2
		25	6.0 f	3.6 f	9.3 f	12.9	15.6	20.1	17.5 f	15.0 f	63.8
Sonia	18	Ambient	2.8 g	2.3 g	4.1 g	9.4	11.1	19.5	27.7 g	23.1 g	87.9
		25	7.8 i	5.9 i	9.0 i	11.6	16.8	20.0	18.7 hi	10.2 h	125.0
	12	Ambient	0.8 h	0.7 h	2.1 gh	5.4	25.4	23.6	19.8 hi	22.2 g	60.0
		25	4.9 ig	2.4 g	4.5 g	12.5	22.3	23.5	16.2 h	11.7 hi	77.1
	9	Ambient	0.0 h	1.6 h	2.1 h	10.5	19.4	24.7	25.1 gi	16.6 gi	54.6
		25	5.4 i	7.4 i	8.9 i	15.8	18.8	18.1	13.6 h	12.0 hi	90.4

[z]LSD (P = 0.05) between combined night and root temperatures: 'Ilona' = 10.98, Mercedes' = 29.96, 'Sonia' = 52.60; between root temperatures: 5.41, 9.10, 19.70, respectively.
[y]Different letters within any one cultivar denote significant difference (P = 0.05); comparison valid only within a cultivar, analysis carried out on transformed (angular) data; letters not used where F test not significant for night and root temperature effects. The LSD between night temperature treatments tends to be an underestimate as the error term used to calculate it would exclude main plot error.

18°C night temperature), and Grade 8 decreased (significant only at 12°C night temperature).

Root-zone warming increased yield in 'Mercedes' at all night temperatures, but the effect of RZW on stem length was only significant at the lowest night temperature.

The effect of root-zone warming on 'Sonia' yield was similar to that with 'Mercedes' (although not significant at 12°C night temperature), but quality differences were marked. Root-zone warming increased the proportion of Grades 1–3, and decreased the proportion of Grades 7 and 8 (Grade 8 difference not significant at 9°C night temperature, Grade 7 not signficant at 12°C night temperature).

Second season, winter yield. Root-zone warming increased 'Ilona' yield significantly except at the lowest night temperature (Table 3). The effect on quality in comparison to yield was less significant; only at 18°C night temperature did RZW result in a significant higher increase in percentage of Grade 1 blooms.

'Mercedes' yield was greatly increased by root-zone warming, but the effect on quality generally was not signficant. Root-zone warming increased 'Sonia' yield (but only statistically significant at 10°C night temperature). The percentage of the shortest blooms (Grade 8) was significantly reduced by RZW at 18° and 10° night temperatures.

First season, summer yield. Although differences between treatments were small, and there was a break in production since the winter, the effects of root-zone warming still persisted, especially where night temperature had been low (Table 4). In no case was there a reduction in yield due to RZW. While RZW has few significant effects on grade, differences persisted with a tendency for more Grade 1 and 2 blooms and less Grade 7 and 8 blooms than under ambient conditions.

Second season, summer yield. Recording of production was continued from the winter period, and RZW resulted in an increased number of blooms from all 3 cultivars at all night temperatures. This effect was statistically significant for 'Mercedes' at all night temperatures, and for 'Sonia' for all except the 14°C night temperature.

Root-zone warming and night temperature effects on gross returns. In the 1st winter season root-zone warming increased the value of the crop in most instances (excepting 'Ilona' at 9°C and 'Sonia' at 12°C night temperature where differences were not significant). The greatest values obtained from RZW were at 18°C night temperature. With 'Ilona' and 'Sonia', similar values could be obtained from RZW-12° night temperature and 18°-ambient root temperature plants. In the 2nd season the beneficial effects of RZW on value were even greater, and a higher value was obtained for 'Ilona' with RZW at 12° night temperature than for ambient root temperature at 18° night temperature. With 'Mercedes' and 'Sonia', values obtained with RZW at 10°C were not significantly different from those with ambient root temperature treatment at 18° night temperature.

RZW resulted in slightly increased crop values in the 1st summer, but its effects in the 2nd summer increased. Air temperatures had less effect on crop values during the summer period than during the winter.

Discussion

There have been many experiments on the effects of air temperature on roses in growth cabinets (5) and in greenhouses (11),

Table 3. Effects of night air temperature and root temperature on grade and total yield for a 17-week winter period for 2nd-year bushes.

Cultivar	Night temp. °C	Root temp °C	Blooms in each stem length grade (mm) (%) G1	G2	G3	G4	G5	G6	G7	G8	Total yield of blooms no./m − 2[z]
Ilona	18	Ambient	3.8 a[y]	9.1 a	8.5 a	13.6 ab	21.1	20.4	11.4	12.1 a	58.9
		25	16.1 b	9.4 a	8.1 a	16.7 bc	17.3	12.6	10.9	8.9 a	76.1
	14	Ambient	12.3 b	10.1 a	2.1 b	19.2 bc	18.7	16.1	8.6	12.9 a	43.3
		25	12.9 b	12.2 a	10.3 a	19.8 bc	16.2	13.4	9.2	6.0 a	82.2
	10	Ambient	2.6 a	1.4 b	10.7 a	8.9 a	22.1	26.3	12.9	15.1 a	52.2
		25	2.4 a	4.1 b	8.9 a	12.4 bc	18.4	17.1	21.5	15.2 a	51.7
Mercedes	18	Ambient	0.6 cd	0.0 c	1.9 c	9.9 d	15.8	25.8	18.6	27.4 b	103.3
		25	0.6 cd	1.6 dc	5.4 d	10.3 d	17.2	23.4	20.4	21.1 bc	172.8
	14	Ambient	2.2 c	0.0 c	5.7 d	5.1 e	22.8	24.5	18.6	21.1 bc	72.2
		25	1.9 c	3.9 d	4.8 d	16.4 d	25.4	20.7	12.0	14.9 c	115.6
	10	Ambient	0.0 d	0.0 c	2.4 c	3.7 e	29.1	28.0	17.5	19.3 bc	35.0
		25	2.8 c	2.8 dc	8.1 d	12.9 d	21.0	17.4	16.4	18.6 bc	96.1
Sonia	18	Ambient	0.6 e	1.0 e	6.7 e	11.7 f	13.7	21.1	17.2	28.0 d	105.0
		25	4.4 f	6.9 f	9.1 e	20.2 f	14.7	20.2	12.6	11.9 e	135.6
	14	Ambient	1.8 e	3.2 e	8.8 e	17.4 f	17.0	21.1	18.7	12.0 e	82.8
		25	2.8 e	4.5 fg	13.2 e	13.6 f	20.0	20.8	12.9	12.2 e	98.9
	10	Ambient	1.3 e	2.6 e	0.0 f	6.7 g	9.8	22.0	22.6	35.0 d	57.2
		25	1.6 e	2.0 eg	9.1 e	14.9 f	29.1	23.2	12.5	7.6 e	127.2

[z]LSD (P = 0.05) between night and root temperatures: 'Ilona' = 21.01, 'Mercedes' = 47.37, 'Sonia' = 52.56; between root temperatures only: 8.60, 30.71, 32.96, respectively.

[y]Different letters within any one cultivar denote significant difference (P = 0.05), analysis carried out on transformed data; letters not used where F test not significant for night and root temperature effects. The LSD between night temperature treatments tends to be an underestimate as the error term used to calculate it would exclude main plot error.

but few have attempted to control the root temperature. The effects of night temperature are the result of increased air and, to a lesser extent, root-zone temperature. Roses respond readily to increased air temperature by having accelerated bud break, and increased growth rate and yields. Flower quality tends to decline at high air temperatures, with the best yield and quality occur around 18°C (11).

It had been taken for granted that roses did not respond to elevated root-zone temperatures. The soil optimum usually cited is 18°C (9). Until about 10 years ago, soil warming was effected by passing hot water (>60°C) through widely spaced steel pipes. This system may results in hot spots drying the soil around pipes, results in poor conduction of heat away from the pipes. It also is possible that raising soil temperatures could reduce oxygen levels by increasing the rate of breakdown of organic matter. Another possibility is that the increased soil temperature might increase the activity of nematodes (van den Berg, personal communication). It is now apparent that the optimum root temperature for roses in soilless media is considerably higher than 18°.

In a pot experiment (1) the number of cut roses was increased by a soil temperature of 25°C at an air temperature regime of 16° day and 11° night compared with ambient soil temperatures, but not at 20° day and 16° night air temperatures. In a 2nd experiment, there was no significant difference in yield due to soil temperature. As this was a growth cabinet experiment, light levels may have been limiting. In the present work, integral light levels in the glasshouse averaged (per 6 weeks) 5.4 - 9.1 MJ m^{-2} day^{-1} over the winter period in the 1st season, and from 6.0 - 13.1 MJ m^{-2} day^{-1} in the 2nd season, with summer levels around 10.6 - 11.1 MJ m^{-2} day^{-1} (the glasshouse was shaded in summer). With tomatoes, where yield is very light dependent, there was no interaction between light level and root temperature effect (6), and it is possible that RZW may only be effective in roses where light levels are fairly high, possibly above 5.0 MJ m^{-2} day^{-1}. Roses with adequate light will be sink limited, and the main effect of RZW would be to induce additional buds to develop, thus providing more sinks.

The effects of RZW seemed to be consistent. The 1st season: work was repeated in another experiment with very similar results to those presented here. Since RZW had a marked effect on stem length in the 1st season, it can be used to bring roses into early commercial production; an important consideration because of the high capital cost of hydroponic systems.

Roses have been grown in various hydroponic systems (4). A modified NFT method was used in this study, and the recycling nutrient was used to warm the root-zone. Although satisfactory on an experimental scale, commercially, a rockwool system might be an improvement because of control over root aeration. Rockwool systems with intermittent recycling flow (usually through drippers) are being used in commercial rose production where RZW would have to be effected by circulating warm (25° to 30°C) water through plastic pipes under the rockwool (7). Most cultivars grown in a rockwool system without RZW produce about the same as roses grown under good soil culture, except for the cultivar 'Mercedes' which has superior yield (3). Commercial rose production in a rockwool system has proved successful in Australia.

Root-zone warming of roses is capable of giving greatly increased returns at a high night temperature (18°C), or of main-

Table 4. The residual effects of night air temperature and root temperature on grade and yield for a 5-week mid-summer period for 1st-year bushes.

Cultivar	Night temp. °C	Root temp. °C	Blooms in each stem length grade (mm) (%) G1	G2	G3	G4	G5	G6	G7	G8	Total yield of blooms no./m − 2[z]
Ilona	18	Ambient	28.5 a[y]	10.4 a	20.3	15.2	11.2	6.0	4.0	4.4 a	19.2
		25	32.2 a	19.1 a	9.2	11.3	11.1	7.6	5.7	3.8 a	22.1
	12	Ambient	4.8 b	0.1 c	23.5	15.6	19.5	3.8	18.7	14.0 b	14.2
		25	6.3 b	4.0 b	12.1	25.4	9.4	11.7	19.7	11.4 b	21.2
	9	Ambient	2.8 b	16.7 a	16.1	5.5	2.7	19.8	14.3	22.1 b	12.9
		25	21.5 a	13.2 a	9.6	14.2	8.3	20.1	4.7	8.4 b	14.6
Mercedes	18	Ambient	0.0 d	1.3 d	6.1	17.3	31.4	22.5	12.5	8.9 de	33.3
		25	3.5 e	4.6 d	11.6	29.8	24.1	16.1	8.0	2.3 e	36.2
	12	Ambient	0.0 d	0.0 d	18.6	22.0	13.1	25.8	7.4	13.1 d	27.9
		25	0.0 d	2.5 d	17.1	24.1	26.7	14.2	5.4	10.0 de	32.1
	9	Ambient	0.0 d	1.4 d	5.4	20.8	21.5	30.6	15.3	5.0 de	32.5
		25	4.3 e	2.2 d	16.4	27.3	17.3	17.1	7.6	7.8 de	38.3
Sonia	18	Ambient	7.4 f	5.8 eg	17.5	12.4	18.7	20.6	8.7	8.9 g	28.7
		25	16.6 f	12.7 g	20.0	14.1	16.2	10.1	6.4	3.9 g	32.9
	12	Ambient	0.0 g	3.0 ef	8.1	9.5	16.6	19.0	19.4	24.4 g	28.7
		25	2.3 g	1.2 ef	25.3	13.3	14.4	18.8	17.7	7.0 g	24.6
	9	Ambient	2.1 g	0.0 f	9.2	9.1	13.3	14.1	24.2	28.0 h	18.3
		25	13.5 f	11.2 g	11.4	12.6	27.8	14.6	4.9	4.0 g	37.5

[z]LSD (P = 0.05) between night and root temperatures: 'Ilona' = 6.78; 'Mercedes' = 10.52; 'Sonia' = 18.81; between root temperatures only: 3.74, 3.19, 13.47, respectively.

[y]Different letters within any one cultivar denote significant difference (P = 0.05); analysis carried out on transformed (angular) data; letters not used where F test not significant for night and root temperature effects. The LSD between night temperature treatments tends to be an underestimate as the error term used to calculate it would exclude main plot error.

Table 5. Effects of night air temperature and root temperature on grade and yield for a 5-week early summer period for 2nd-year bushes.

Cultivar	Night temp. °C	Root temp. °C	Blooms in each length grade (mm) (%) G1	G2	G3	G4	G5	G6	G7	G8	Total yield of blooms no./m − 2[z]
Ilona	18	Ambient	7.2 a[y]	18.3 a	13.0 ab	17.1 ac	17.1	14.2 ad	7.1 a	6.0 a	16.1
		25	34.0 c	19.3 a	15.1 ab	7.2 b	9.5	5.0 c	7.6 a	2.3 a	22.8
	14	Ambient	4.8 a	7.2 b	19.0 a	4.7 b	15.1	17.4 a	8.0 a	23.8 b	16.7
		25	29.6 cd	6.9 b	13.4 ab	13.3 c	20.9	5.3 c	1.9 ac	8.7 c	25.0
	10	Ambient	0.1 b	1.8 b	10.1 b	3.7 b	11.1	33.8 b	29.3 b	10.1 c	21.1
		25	16.6 d	2.2 b	8.3 b	22.9 c	22.9	10.4 d	4.2 ac	12.5 c	26.7
Mercedes	18	Ambient	2.0 ef	7.0 c	8.4 c	14.0 de	23.4	23.6 e	10.1 d	14.5 de	32.2
		25	3.7 f	4.4 c	9.6 c	18.7 de	21.3	18.0 ef	10.8 d	13.5 de	69.4
	14	Ambient	0.1 e	6.0 c	6.1 d	7.4 d	24.3	24.3 e	19.0 e	12.8 de	21.7
		25	6.7 f	5.8 c	16.6 f	15.0 de	22.3	16.6 ef	8.4 d	8.6 dc	62.8
	10	Ambient	1.8 ef	5.4 c	0.1 e	20.0 de	11.0	24.2 e	20.5 e	17.0 d	22.8
		25	10.1 g	4.9 c	12.0 c	21.4 e	22.8	13.8 f	10.8 d	4.2 e	68.9
Sonia	18	Ambient	4.3 h	2.9 df	6.7 gh	16.5 f	21.0	14.7 g	11.2 h	22.7 f	30.0
		25	18.0 j	18.0 e	11.0 h	11.5 f	14.2	13.8 g	9.9 h	3.6 g	61.7
	14	Ambient	0.0 i	3.0 df	4.6 g	13.6 f	10.0	14.9 g	21.9 i	32.0 f	21.1
		25	5.2 h	1.9 d	22.6 i	22.3 f	13.2	20.0 gh	7.4 h	7.4 g	23.3
	10	Ambient	0.1 i	0.1 d	4.2 g	2.0 g	6.4	26.0 h	31.0 i	30.2 f	20.6
		25	4.7 h	7.0 f	8.2 h	24.4 f	27.7	10.5 g	9.3 h	8.2 g	47.8

[z]LSD (P = 0.05) between night and root temperatures: 'Ilona' = 18.70, 'Mercedes' = 34.61, 'Sonia' = 16.41; between root temperatures only: 10.52, 25.67, 10.58, respectively.

[y]Different letters within any one cultivar denote significant difference (P = 0.05); analysis carried out on transformed data; letters not used where F test not significant for night and root temperature effects. The LSD between night temperature treatments tends to be an underestimate as the error term used to calculate it would exclude main plot error.

taining returns at a low night air temperature (down to 10°). Because of the high capital costs involved in cut rose production, the former strategy might be prefered, in which case energy used per bloom is still reduced due to the increased yield.

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The Maturation and Ripening of the 'Wonderful' Pomegranate

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Additional index words. *Punica granatum* L., composition, respiration, ethylene

Abstract. **Pomegranate (*Punica granatum* L. 'Wonderful') fruit reached horticultural maturity for commercial harvest when the soluble solids content (SSC) attained a fairly constant level of 15%. The level of titratable acidity (TA) varied from one location to another and from one year to the next but also generally remained stable at the same time that the SSC reached 15%. After harvest, there was no further change in either SSC or TA at 20°C, but redness of the juice continued to increase in intensity up to and after harvest. The respiration pattern of the mature fruit was of the nonclimacteric type, with only traces of ethylene evolved on occasion. Ethylene treatment of the fruit caused a rapid transient rise in CO_2 evolution but no changes in SSC, TA, and fruit or juice color. A pseudo-climacteric pattern of respiration was found in very young immature fruit. The respiration rate of dehisced arils paralleled that of the intact fruit, but there was no response to exogenous ethylene treatment. Ethylene evidently stimulated the CO_2 output only of the fruit rind.**

Although the history of the pomegranate dates to biblical times (4) and the fruit is a well-known orchard crop in Mediterranean countries, it has not been the object of much scientific investigation (8). This is especially true with regard to the physiology of the fruit. The few reviews and studies that deal with pomegranates (3, 5, 8) address mainly such questions as botanical characteristics, cultural techniques, diseases, and cultivars.

Hodgson (5) stated in 1917 that the pomegranate is harvested before it is fully ripe and that it continues to ripen in cold storage, even improving in quality and flavor. Yet he did not present data in support of this statement. Lee et al. (6, 7) described changes in polyphenols, anthocyanins, sugars, and acids and a decline in the respiration rate during fruit development but not thereafter.

The objective of the work presented here was to study the maturation and ripening processes of the 'Wonderful' pomegranate and to determine whether its respiratory pattern is climacteric or nonclimacteric.

Materials and Methods

Pomegranate fruits, 'Wonderful', were harvested during 2 seasons from 2 orchards cultivated under different climatic conditions. Location A was an 8-year-old orchard in the Mediterranean coastal plain of Israel, with a temperate to subtropical climate. Location B was a 15-year-old orchard in the Jordan Valley, with a hot and dry, subtropical to tropical climate. In location A fruit were sampled monthly from the time of fruit set until the beginning of the harvest season in September. From then, sampling was weekly until the commercial harvest was terminated in late October. Since fruit set occurs in about 3 distinct waves, fruitlets (17–22 mm in diameter) were tagged on 3 dates (3, 13, and 23 May) for later samplings. This sampling occurred about 2 weeks after the peak of each wave of fruit set, when the chances for fruit drop had decreased notice-

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