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Long Term Production of Rose Flowers in the Greenhouse under Different Cooling Methods: I. Energy Balance, Flower Yield and Quality

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Summary

During the summer, flowers produced in Mediterranean greenhouses suffer reduced quality, with short, thin stems and small buds. As crop ages, quality declines in winter as well. Farmers try to solve these problems with cooling methods such as shading or wet pads. Such treatments have harmful side effects and they are often ineffective. The present study tested long term effects of cooling methods on yield and quantity. It was found that during the first half of the summer common cooling methods had no beneficial effects. During the second half of the summer, especially with aged crops, these methods increased crop yields but not their quality. It has been suggested that the quality of flowers declines, especially in mid-summer, as result of deficient carbohydrate supply for each stem. The deficiency is produced by the big population of young flower shoots, which emerge at this time of the year, especially on aged crop. The effect of cooling treatments is weak when the young crop has a fresh transpiring canopy. When crops become older, the cooling treatments help the plants to produce longer stems. In summer, and especially in a system of old crops, a high percentage of the flower stems fail to reach marketable length, and then cooling methods increase the number of marketable flowers.

Zusammenfassung

Langzeitkultur von Gewächshausrosen bei unterschiedlichen Kühlmethoden: I. Energiebilanz, Ertragsmenge und Qualität. Während des Sommers weisen in mediterranen Gewächshäusern produzierte Schnittblumen eine schlechtere Qualität mit kurzen, dünnen Stängeln und kleinen Knospen auf. Mit zunehmendem Pflanzenalter verschlechtert sich die Qualität auch im Winter. Die Anbauer versuchen das Problem mit Maßnahmen wie Schattieren oder nassen Kissen zu lösen. Dies führt häufig zu schädlichen Nebeneffekten und ist häufig nutzlos. Die vorliegende Untersuchung prüft die Langzeitwirkungen von Kühlmethoden auf Ertrag und Quantität. Dabei zeigte sich, dass übliche Kühlmethoden in der ersten Sommerhälfte keine positive Wirkung haben. In der zweiten Sommerhälfte und besonders bei alternden Kulturen steigern diese Methoden die Erntemenge aber nicht die Qualität. Es wurde vermutet, dass die Qualität der Blüten vor allem in der Sommermitte durch die Mangelversorgung der Einzeltriebe mit Kohlenhydraten hervorgerufen wird. Der Mangel wird durch die große Anzahl junger Triebe, die besonders von alternden Kulturen zu dieser Jahreszeit gebildet werden, verursacht. Die Wirkung der Kühlmethoden ist gering, wenn die jungen Pflanzen frisches transpirationsfähiges Laub haben. Wenn die Pflanzen älter werden, hilft ihnen die Kühlbehandlung längere Stiele zu bilden. Im Sommer, und vor allem in einem alten Pflanzenbestand, erreicht ein hoher Prozentsatz Blütenstiele nicht die vermarktungsfähige Länge, in diesen Fällen erhöhen die Kühlmethoden die Anzahl vermarktungsfähiger Blüten.

Key words. crop age – climate control – cooling – cutting regimes – greenhouse – flower quality – flower quantity – high temperature – *Rosa*

Introduction

Greenhouse (GH) roses are perennial shrubs that continuously form new shoots, and may be harvested for a period of 4 to 7 years (KOOL 1996). Under hot, humid conditions, e.g. during the Mediterranean summer, rose flowers have a poor economic value because of their short and thin stems which carry small buds and have a short shelf life. As crop age increases, these features reduce flower quality in wintertime too (PINES 1999). The summer and aging effects cause short cutting seasons, frequent crop replanting, and a conjunctive use of different cutting regimes with cooling systems. Common cooling methods, such as shading screens, mist, or evaporative cooling, are expensive, and each has harmful side effects. The cutting regimes – decapitation, bending, "upward" or "downward" cutting – produce short- and long-term physiological and

morphological changes (PINES 1999). The obtained results of these treatments vary with the climatic conditions, GH type, crop varieties, and age, and are not always conclusive (KATSOULAS et al. 2001).

Scientific studies under controlled conditions show that for most commercial varieties the best quality of flower shoots, in terms of stem length, diameter leaf area and flower bud size, was obtained at 18ºC (MOE and KRISTOFFERSEN 1969). As temperatures increased, the periods from cut back to flowering became shorter, stems became shorter, diameter and leaf area smaller, flower weight decreased (KI SHIN et al. 2001) and adjoined with fewer and smaller petals (MOE and KRISTOFFERSEN 1969). It was also found that at early stage of shoot development the leaves had a strong sink and became a source only after the visible bud stage (MOR and HALEVY 1979); and that low temperatures promoted the translocation of carbon towards the basal plant parts (KHAYAT and ZIESLIN 1986), while the carbohydrate export rate of expanded leaves was reduced by high temperatures (JIAO and GRODZINSKI 1998). These observations logically fit together into the explanation that high temperature reduces flower quality by restraining the availability and translocation of carbohydrate, due to the reduced number of days to flower (KI SHIN et al. 2001); increased carbohydrate consumption by dark respiration (KHAYAT et al. 1988); decreased area of source leaves and decreased sink of the buds due to the reduced number of petals (JIAO and GRODZINSKI 1998). Another explanation is that high transpiration, a result of low air humidity and low water availability, reduces turgid cell elongation and reduces shoot and bud fresh weight and other quality parameters (STANHILL and ALBERS 1974).

The shoot growth is not effected only by environmental conditions during its growth. The growth potential of the subsequent shoots that sprout from the axillary rose buds is influenced by growth conditions during bud development and by the age and position of the bud and its mother shoot. The axillary buds are correlatively inhibited by the apical dominance of the shoot apical portions. While subject to apical dominance, their meristem remains vegetative, slowly forms new bud leaves and leaf primordials, and gains dry mass. The diameter of the pith and subsequent shoots is affected by the mother stem at the axillary bud stage. Such characteristics influence accumulation and distribution of water and storage of substances such as starches and sugars (KOOL 1996). Delaying the harvesting of the mature mother shoots or releasing premature axillary buds from apical dominance by decapitation or bending may affect the time until axillary buds break, decrease the subsequent shoot length, or change the number of scales and transitional leaves (MARCELIS-VAN ACKER 1994). Many other parameters of bud position affect the number and quality of the subsequent shoots and may account for 30 % of the differences observed in rose flower yield. These include: cycloophysis (the ontogenetically age of the plant part from which the cutting originates), periphysis (environment of the parent shoot), topophysis (the position on the parent shoot) (BREDMOSE and HANSEN 1996).

This information is summarizing mostly short-term experiments in highly controlled environments. Growers must consider the long-term results of each treatment on their perennial crop, with the possibly different responses of the crop due to age, and cutting regime, which affect the crop's morphological and physiological status (KI SHIN et al. 2001). Our hypothesis is that by a long-term study on the cooling effects and by analysing the results of this study in comparison to the results obtained in the short-term experiments, we will be able to help growers adjust and modify cooling techniques and cutting regimes in order to achieve a better crop by more economical treatments.

Materials and Methods

The experiments were conducted from 1996 through 1999 in a multi-span GH in the Besor Experiment Station in Israel (31 °16 'N, 34 °24 'E). Each span was 7.5 m wide by 23 m long, with ridges at 5.6 m and gutters at 4 m. The ridge was oriented north to south. The cladding material was 150 μm polyethylene film (produced by Ganeigar, Israel). Each span was equipped with polyethylene walls, which could roll up, and a continuous 1.0 m wide roof vent along the eastern gutter.

Ungrafted rose seedlings, cv. 'Long Mercedes' (Sweet Heart type), were planted on 16 September 1996, in 0.56 (wide) x 1.04 (long) x 0.23(deep) m containers, filled with 0.8 mesh, volcanic scoria, enriched with 15 % compost of processed fruits. The containers were placed in four rows, 1.82 m centre to centre apart, and parallel to the gutters. Fifteen seedlings were planted in paired rows in each container, resulting in 7.5 plants m^{-2}. Blind and weak shoots were bent over the paths, providing a full ground cover. Irrigation, fertilization, winter heating as well as pesticide applications followed local commercial instructions (DAYAN et al. 2000).

Air temperature above 24 °C, at mid-canopy, opened the southern walls, and at 25 °C the north walls opened. From April through November, whenever the mid-canopy temperature exceeded 28 °C, separating walls between spans were automatically rolled down, separating the GH into chambers. Four main cooling regimes were examined in these chambers for 3 years: Natural ventilation (as the control), movable shading, evaporative cooling, and night cooling. The natural ventilation was applied by opening the sidewalls together with the continuous roof vent along the eastern gutter. Shading was applied by moveable nets made of aluminum-coated polyethylene ("Polysack" Nir Yitzhak, Israel, Type: "Aluminate") extended at 4 m height above the crop, removing 40 % of the global radiation. Evaporative cooling was applied by a corrugated cardboard wet pad, 1.2 m high and 7.5 m wide, in the southern air inlet of the GH, and two exhaust window fans (0.75 m diameter with a rated outflow of 16000 m^3 h^{-1} at 0 static pressure), that were mounted on the north gable, and pulled air through the wet pad. Night cooling was applied by a 5 HP air conditioner. Set points for activation of the main actuators of the daytime cooling systems are presented in Table 1.

Climatic measurements within each chamber included the estimation of incoming and reflected global radiation and net radiation above the canopy, heat fluxes into the path soil and into the substrate in the containers, air temperature and humidity 1.5 m above-soil surface, leaf temperature in two bent-shoot leaves and in

Table 1. Set points of actuators within the main cooling treatments.

	Treatments					
	Natural ventilation		Movable shading		Wet pad	
Actuators	On	Off	On	Off	On	Off
Roof vent	27(°C)	25(°C)	27(°C)	25(°C)		
Shade			600(W m^{-2})	400(W m^{-2})		
Fans					27(°C)	25(°C)
Pad					28(°C)	26(°C)

Table 2. Daily average of outside global radiation fluxes and global radiation, net radiation, latent heat, and sensible heat fluxes (all in: mJ m^{-2} d^{-1}) within the greenhouse, measured in the Besor Exp. Station during 1997–1999.

		Outside	Natural ventilation				Movable shade				Wet pad			
Date		Global Rad.	Global Rad.	Net Rad.	Latent Heat	Sensible Heat	Global Rad.	Net Rad.	Latent Heat	Sensible Heat	Global Rad.	Net Rad.	Latent Heat	Sensible Heat
97	Jun	28.2	17.7	15.4	18.3	–2.9	10.3	11.0	14.8	–3.8	17.7	14.2	11.6	2.6
	Aug	24.7	13.5	11.7	15.8	–4.1	7.8		13.6		14.4		10.3	
98	Jun	28.0	18.0	16.0	17.8	–1.8	11.9	13.5	14.3	–0.8	18.4	15.0	11.2	3.7
	Aug	24.4	15.7	15.9	15.8	0.1	9.0	11.3	13.4	–2.0	16.4	15.2	10.8	4.4
99	Jun	28.0	17.1	15.2	9.9	5.4	10.6	12.8	10.3	2.5	17.3	15.5	8.1	7.4
	Aug	26.2	15.8	14.2	9.5	4.7	9.5	11.5	9.0	2.5	16.4	14.3	7.4	6.9

the two uppermost leaves of flower shoots, and flower temperatures in two young buds. Latent heat was estimated according the evapo-transpiration rates measured by accurate lysimeters (DAYAN et al. 2000). The differences between net radiation and the sum of latent heat and heat flux to the soil were defined as sensible heat. Global radiation, air temperature, and humidity at 4 m above the GH were also measured. The signals from all the sensors were sampled at 60 s intervals, averaged every 30 min., and stored in a network of data loggers (CR10, Campbell Scientific, Logan, USA).

Quantity and quality of the flowers were determined on harvested flowers of 250 plants grown in the centre of each chamber. The flowers were harvested once in two days, sorted into groups according to stem length (40–50, 50–60, 60–70 and 70–80 cm), and counted. Short flowers were discarded. Yield was determined by the total flower number, weight and length per m^2 per day. Flower quality parameters were determined according to flower average length and weight.

Yield and quality were determined every year from 16 October to 15 October of the following year. Winter averages were calculated between 16 October and 15 April. Summer averages were calculated between 16 April and 15 October. The winter and the summer were sub-divided into early and late parts of the season, each 3 months long. Statistical smoothing methods were used to define periodical changes within yield and quality parameters: "Cubic Smooth" was used for defining "picking flushes", while B-spl Fix Order 8, Knots 13 were used for defining seasonal effects (SPSS TABLE CURVE 2D, 7-10, 1997).

The number of new initiations and the length of known stem flowers were measured every two days on 10 representative plants in each chamber. The length of each stem was plotted vs. days after planting (DAP). Asymmetrical S-shaped curves were fitted to the observed growth in length of each stem. Stem maximal growth rates were determined by the maximal derivative of these growth curves. The duration of flower development was defined as the time between shoot initiation and its final length (PRESNOV et al. 2003).

Results

Environmental variables

During the summer, outside conditions, namely average daily global radiation fluxes above the GH and ambient temperatures, were identified by similar values and changes during the 3 years of the experiment: In early summer (ES) average global radiation fluxes above the GH were higher than in late summer (LS), i.e. 28±0.2 mJ m^{-2} day^{-1} in June, (representing ES), and 25±1 in August (representing LS) (Table 2). Average ambient air temperatures were higher in LS than in ES: 27.4±0.7 °C in the ES and 29±0.5 °C in the LS (Table 3).

The GH cladding material transmitted 65 % of the intercepted global radiation into the GH: 17.7±0.6 and 14.6±1.0 mJ m^{-2} day^{-1} in June (ES) and August (LS) 1997 respectively. 8–12 % of the incoming radiation was reflected back, i.e. 2.2 and 1.6 mJ m^{-2} day^{-1} in June

Table 3. Daily (24 h) average air temperatures outside, temperatures of air, leaf and flower in the greenhouse, and differences between leaves and out side air temperatures (Tl–To) (all in: °C), measured in the Besor Exp. Station 1997–1999.

Date	Outside	Natural ventilation				Movable shade				Wet pad			
	Air	Air	Leaf	Flower	Ti–To*	Air	Leaf	Flower	Ti–To*	Air	Leaf	Flower	Ti-To*
97 Jun	22.7	26.9	27.8	29.0	0.0	26.5	27.2	28.2	–0.5	25.4	26.7	25.4	–1.1
Aug	28.5	27.6	28.0	29.3	–0.5	27.3	27.7	28.8	–0.8	26.0	26.7	26.0	–1.8
98 Jun	26.8	26.8	28.8	28.6	2.0	26.0	27.0	27.9	0.2	26.2	27.9	26.2	1.1
Aug	30.1	30.2	29.9	31.5	–0.2	29.2	29.3	30.5	–0.8	27.9	28.7	27.9	–1.4
99 Jun	27.8	26.9	27.1	28.4	–0.7	26.0	26.2	27.5	–1.6	25.7	26.5	25.7	–1.3
Aug	29.6	29.5	29.4	30.9	–0.2	28.9	28.6	29.8	–0.9	27.5	28.5	27.5	–1.1

Table 4. Daily averages of flower stem initiation and abortion rates in the greenhouse, measured in the Besor Exp. Station 1999.

	Number of young flower stems [m^{-2} d^{-1}]							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Average
Survived	0.57	0.66	0.43	0.85	1.88	1.59	2.29	1.15
StD	0.29	0.45	0.25	0.32	0.80	1.05	0.97	0.29
Aborted	0.32	0.18	0.12	0.06	0.43	0.22	2.13	0.46
StD	0.34	0.18	0.14	0.10	0.37	0.29	1.44	0.23
Total	0.89	0.85	0.56	0.92	2.31	1.81	4.43	1.60
StD	0.44	0.56	0.31	0.30	0.88	1.03	1.88	0.42

and August, respectively. Less than 4 % was absorbed by soil surface (Table 2).

Latent heat fluxes decreased each year and were lower in LS than in ES. As they decreased, the negative sensible heat differences became positive and larger; e.g. in the naturally ventilated GH the sensible heat increased by 8 mJ m^{-2} day^{-1} from –3.5±0.6 in summer 1997 to 5.1±0.3 in summer 99. In comparison to the naturally ventilated GH, the wet pad reduced latent heat rates by 40 and 30 % in June (ES) and August (LS) 97, respectively, and by 20 % in 1999. As a result, the calculated sensible heat differences in the wet pad chambers were positive in 1997, and age increased these differences by 4 mJ m^{-2} day^{-1} (Table 2).

The shading nets reduced nearly 40 % of the transmitted global radiation as compared with the radiation in the control chambers, but less than 25 % of the net radiation. The nets also decreased latent heat by 20 %, but this effect diminished with crop age, and as a result the sensible heat increased from 1997 to 1999 by 6.3 mJ m^{-2} day^{-1} (Table 2).

Daytime air temperatures in the naturally ventilated chambers (control) were usually 1–3 °C higher than outside air temperatures. On most nights, air and canopy temperatures were approximately 2 °C lower than the ambient air temperature. Shade reduced average leaf and flower temperatures, and also air temperature around the plants, by 1 °C or less. The wet pad decreased incoming air temperature by more than 2 °C, yet canopy temperatures usually decreased only by about 1 °C (Table 3).

Flower yield and growth.

Stem initiation rates were almost twice as high in summer as in winter, i.e. 1.5 stems day^{-1} m^{-2} in summer and 0.8 in winter (Table 4). Flower developmental period increased from 25 days during mid-summer to 50 days in winter. Average flower maximal length increased from 45 to 75 cm (Fig. 1). Flower quantities decreased along these periods from 1.5 flower m^{-2} day^{-1}, 80 cm m^{-2} day^{-1} to less than 0.5 flower m^{-2} day^{-1}, and less than 45 cm m^{-2} day^{-1} for the total number and length respectively (Fig. 1, 2).

Flowers accumulated by picking flushes (Fig. 2) and seasonal waves (Fig. 3). Each picking flush lasted about 70 days during winters and 40 days during summers. There were 4 picking flushes each winter and 5 each summer (Fig. 2). When the number of flowers decreased, during picking flush, their length and weight increased. For example during the picking wave from 11th Jan 1997 to 2nd Mar 1997, 1.5 flowers m^{-2} day^{-1}, with an average length of 58±10 cm, were harvested during the flush peak period (5–15th February), while on the edges of this flush only 0.2 flowers m^{-2} day^{-1} were harvested and the average length of these flowers was 80 and 68 cm $flower^{-1}$ for the flush start and end, respectively (Fig. 2).

In most cases, flower quantities were larger in early winter (EW) than in late winter (LW) of the same year (Fig. 3, 4A–C). Flower quality was lower in EW than in LW (Fig. 3, 4D–F) (The winter of the first year was exceptional). In summer, ES quantities were equal or slightly lower than in LS of the same year, e.g., in ES

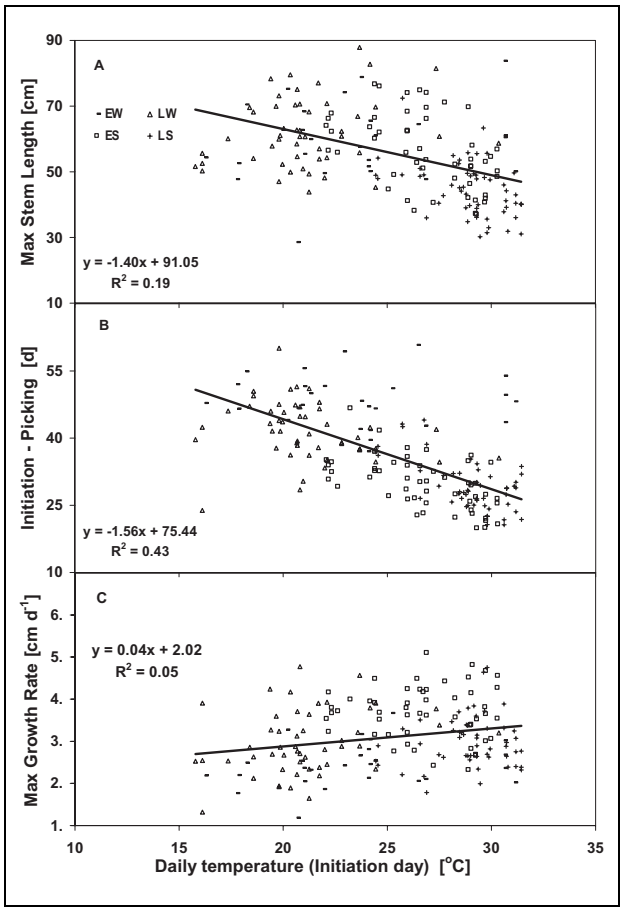


Fig. 1. Effects of daily average temperature on: A) Averages of maximum flowers stem length (cm flower^{-1}); B) Flowers life cycle (duration from initiation to picking) (days); C) Flower stem maximum elongation rate (cm flower^{-1} day^{-1}); Parameters were drawn by fitting "S" shape curves to measurements of stem elongation vs. time of known flower stems in a natural ventilated greenhouse. Measurements were done in the Besor Exp. Station during winter and summer 1999–2000.

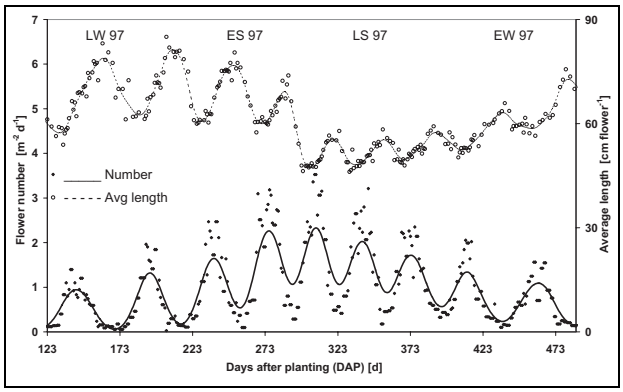


Fig. 2. Effect of picking flushes on distribution of quality and quantity parameters vs. days after planting (DAP) in the naturally ventilated greenhouse (control). Quantity is represented by daily flower production (number m^{-2} day^{-1}) and quality by average flower weight (g flower^{-1}). Symbols describe actual measurements while the lines were adopted by statistical smoothing methods. Measurements were done in the Besor Exp. Station during winter and summer 1997.

1999 average flowering rates were 1 flower m^{-2} day^{-1} and 1.25 flowers m^{-2} day^{-1} in LS. The average length of flowers in LS was much lower than in ES, e.g., in ES of 1999 average flower length was 62 cm flower^{-1}, and only 43 cm flower^{-1} in the second half of the same summer (Fig. 3, 4F).

The flowering flushes and seasonal wave patterns faded with the years and vanished towards the end of the experiment (Fig. 3). The winter quantities increased with crop age, e.g. 0.5 and 0.75 flowers m^{-2} day^{-1} for winter 1997 and 1999, respectively (Fig. 3, 4A–C). Winter flower quality was reduced with age, e.g. average flower length was 65 cm flower^{-1} and 60 cm flower^{-1} for winter 1997 and winter 1999, respectively (Fig. 3, 4D–F).

In summer, aging caused a small reduction in both quantity and quality. Flowering rates in ES 1997 were 1.1 flowers m^{-2} day^{-1} and dropped to 1.05 flowers m^{-2} day^{-1} in ES 1999. During the same periods the average flower length dropped from 65 to 62 cm stem^{-1}. During LS, the age-dependent reductions in quality and quantity were more obvious than in ES (Fig. 3, 4D–F).

As a result of the mutual age effects on summer and winter quantities and qualities, there were 54 % more flowers produced in summer 1998 compared with winter 1997/1998, and only 20 % more flowers in summer 1999 as compared with the previous winter. The average flower weight in summer 1998 was 64 % of that produced during the previous winter, while in summer 1999 it was 84 % of the previous winter. In 1999 the average weight of the flowers in summer was similar to the average weight of the winter flowers (Fig. 3).

In the naturally ventilated chambers (control), flowering flush and seasonal wave patterns were similar to the patterns observed under the cooling regimes. None of the cooling treatments had a significant effect on flower quality. During the first year and during ES of the other years, the wet pad and shade had only minor effects on flower yields (Fig. 4). However, from the second year onwards these cooling methods increased flower quantities during LS (Fig. 4B–C). Night cooling increased the number of harvested flowers in summer by 34 and 23 % for 1998 and 1999, respectively, as compared with the yields under natural ventilation (control). Wet pad increased these numbers by 20 and 18 % for 1998 and 1999, respectively. Shading throughout the summer increased flower quantity by 8 %. Shading during LS increased flower quantity by 15 %. Shading during ES reduced the number of flowers. It is important to note that most of the flowers harvested in LS were of the shortest length measured (40 cm flower^{-1}) (Fig. 4E, F).

Discussion

In winter, the number of days from initiation to flowering was 2–3 times of that in summer (Fig. 1, 2). Similar results have been reported by MOE and KRISTOFFERSEN (1969) and KI SHIN et al. (2001). Plants pro-

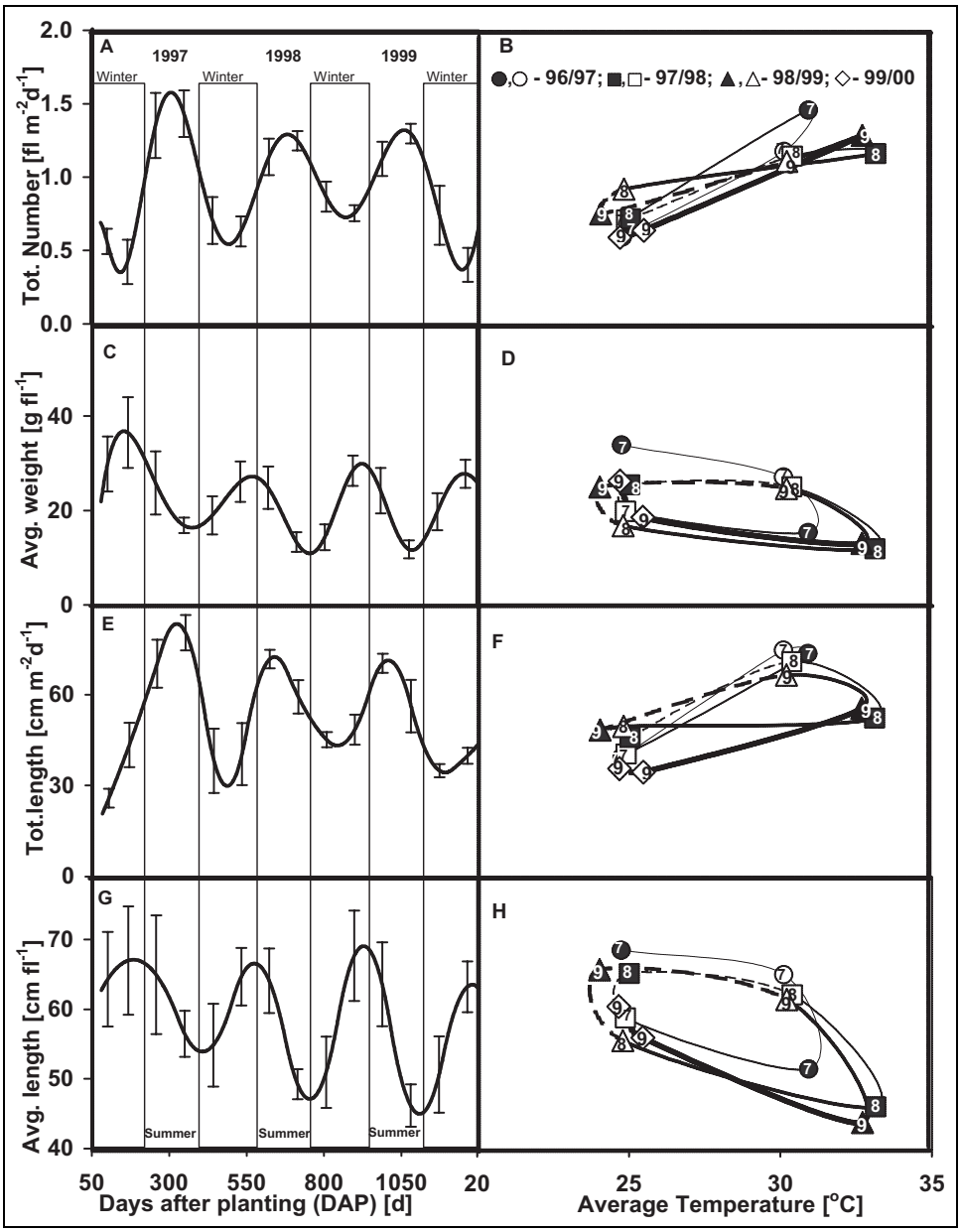


Fig. 3. Seasonal, age and temperature effects on flower quantity and quality parameters in a naturally ventilated greenhouse (control). A, B: Total number of flowers (number m^{-2} day^{-1}) vs. days after planting (DAP) (A) and vs. Temperature (B); C, D: Average flower weight (g $flower^{-1}$); E, F: Total elongation rate (cm m^{-2} day^{-1}); G, H: Average flower length (cm $flower^{-1}$). Symbols describe sub-seasonal averages, distribution bars stand for the distribution of the day by day measurements, while the lines show statistical smoothing of the detailed data aiming to show sub-seasonal and ageing effects. Measurements were done in the Besor Exp. Station. 1996–1999.

duced more initiations in summer (Table 4) and more flowers (Fig. 2–4) than in winter. KOOL (1996) and PINES (1999) show a similar course in a commercially controlled system, while BERG (1987) shows that high temperature induces intensive initiation rate. Aged bushes produce more flowers than young plants (Fig. 3). Similar phenomena are known from common practice. The large number of initiations is explained by a high number of ramifications (BREDMOSE and HANSEN 1996; PINES 1999).

Substitutions between flower quantity and quality parameters were demonstrated in this work to control crop growth along picking flushes (Fig. 2), seasonal and sub-seasonal waves (Fig. 3) and because of the crop aging (Fig. 4). The curves that may be adjusted to data of flowering quality parameters vs. quantity along picking flushes, seasonal waves, or along crop age may show typical substitution circles, similar to the graphical representations of interfering species or prey-predator systems that are usually described by the model of Lotka and Volterra (KEULEN and WOLF 1986).

In winters, the substitution between quality and quantity parameters can be shown by comparing the relatively high quantities and low qualities of the first part of the season to the relatively low quantities and higher qualities along the other part of the same season in the same year (first year is exceptional because of technical reason). In summers, such sub-seasonal substitutive relationships prevailed only during the first year (1997), while during the other two years (1998 and 1999) quality and quantity parameters mutually decreased (Fig. 3–4).

Our assumption is that the substitution between flower quantity and quality, along picking flushes, season and age, as well as the exceptional mutual reduction of quality and quantity in summer, results

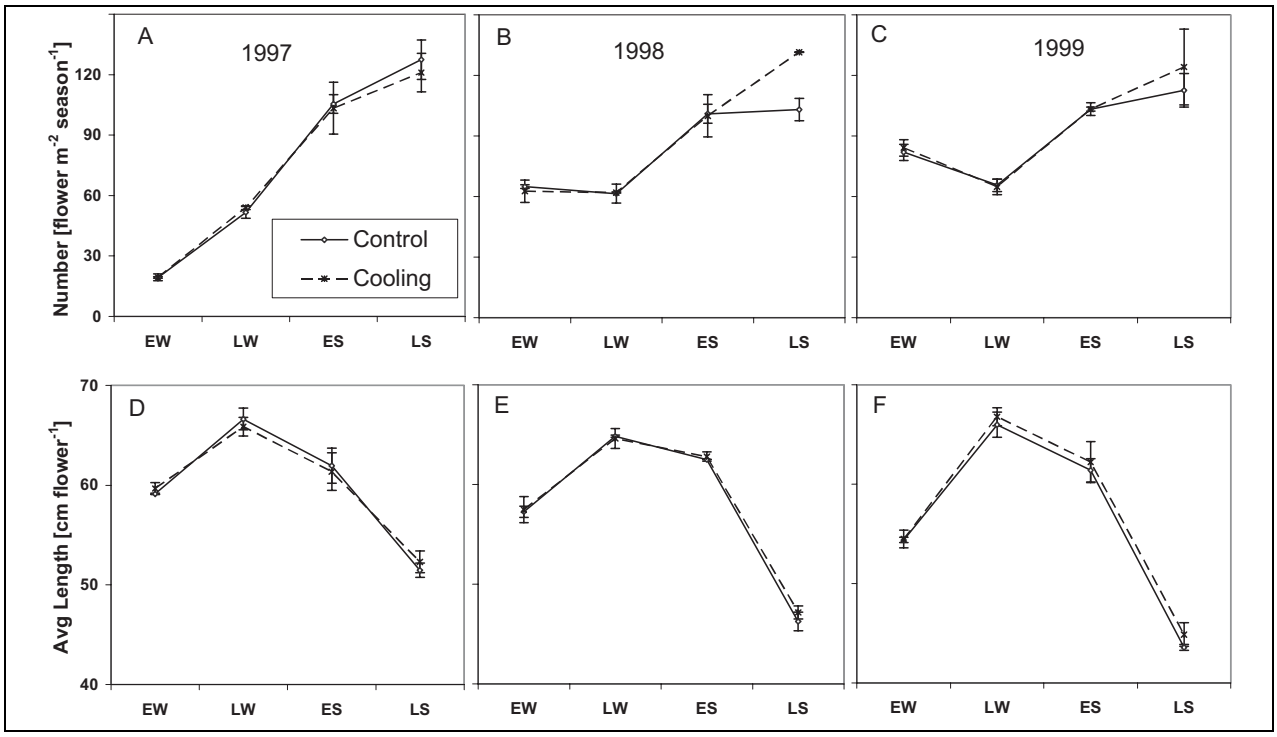


Fig. 4. The effects of sub-seasonal, ageing and cooling treatments on representative parameters of yield quantities and qualities of roses in the Besor exp. Station. A–C: show the effects on the number of flowers produced (flower number m^{-2} day^{-1}) along each sub season (early (EW) and late winter (LW); early (ES) and late summer (LS) of each year, and D–F: show the effects on average stem length (cm $flower^{-1}$) along the corresponding periods. The symbols present averages of all cooling treatments for each sub-season within each year. The bars represent the deviation because of an experimental error and cooling treatments, for each sub-season.

from competition on the available carbohydrates and restricted supply of carbohydrates per one single shoot. The mutual decrease in quality and quantity in summer can be attributed to the combined effect of an aging crop with the fast ripening rate of flowers that occurs with high summer temperatures. High ES temperature imposed quick ripening and harvesting of a high number of flowers, in a relatively short time. As a result, a large number of axillary buds was released from the apical dominance and burst to grow together during the LS (Table 4). The large number of young shoots generated a strong assimilate sink (MOR and HALEVY 1979), while the combination of high mass of the aged plant parts and high temperature conditions impaired the carbohydrate source by increasing dark respiration (KHAYAT et al. 1988). Each of the growing stems received a relatively small amount of carbohydrates, resulting in a large number of stems that did not reach the minimal weight or length (40 cm) requirements, and were thus aborted (Table 4), bent before harvesting or discarded. The number of harvested flowers decreased (Fig. 3–4) (DAYAN et al. 2004). Our assumption is confirmed by reports about relatively low carbohydrates transportation during summers (KHAYAT et al. 1988; JIAO and GRODZINSKI 1998). It seems in line with the explanation that the short stems and low weight flowers produced in summer are due to the short period from initiation to flowering and the quick growth rates that deplete carbohydrate reserves (KI SHIN et al. 2001).

Throughout the entire first summer (1997) and the ES of the other years, latent heat via evapo-transpiration in the naturally ventilated GH was higher than the intercepted net radiation, and the calculated sensible heat values were negative (Table 2). These are probably the reasons for the measured lower canopy and GH temperatures, which were frequently lower than the outside temperatures (Table 3). The relatively high evapo-transpiration rates that prevailed during these periods, resulted of the relatively large leaf area and high portions of fresh rose canopy (Fig. 3, 4A, D). During these periods, cooling treatments, e.g. shading and evaporative cooling, induced higher stomata resistance or lower air vapour pressure deficit, and reduced the crop's transpiration and self-cooling abilities (Table 2–3) (KATSOULAS et al. 2001). As a result, cooling effects on the physiological crop performances were negligible. During the last 2 years (1998–1999) and mainly in the LS sub- seasons, the older canopy produced a relatively smaller leaf area and included a higher portion of non-transpiring too young or to old stems (Fig. 2–4), which made less transpiration (Table 2). With the reduced self-transpiring canopy, cooling treatments had stronger reducing effects on air and plant temperature (Table 3) and had improving effects on the crop performances. Most of the stems produced during these sub-seasons were shorter than 40 cm. By applying cooling treatments, more shoots grew to length above 40 cm and less shoots were discarded. These additions were recorded as higher quantities of flowers, but have

no significant impact on the quality parameters (Fig. 4D–F).

Night cooling had the highest positive effect on flower numbers (and also the highest, although still insignificant, effect on flower quality). Its relatively high positive effect was attained by its specific night time cooling, or resulted from the negative effects on self-cooling or photosynthesis, which were invoked by the other systems (the shading and wet pad).

Conclusions

Our observations confirm the conclusions of BREDMOSE and HANSEN (1996), that the controlling possibilities of both growth and development of rose bushes in GHs are reduced by the mutual effects of the environmental and correlative factors.

Microclimate measurements show that common cooling treatments have negative side effects which reduce their effects on temperatures and plant performances, e.g. shade may reduce the canopy photosynthesis, or both shade and wet pad may reduce transpiration and self-cooling efficiency. Night cooling had fewer negative side effects and was more effective than the other treatments. Another meaning of these conclusions is that by maintaining a fresh and large leaf area the grower may increase the crop's self-cooling ability and thus reduce or eliminate dependence on expensive or hazardous cooling systems.

Similar conclusions may be drawn from the measurements of yield and quality: The morphological and physiological changes, encountered in the canopy due to the combination of age and late summer, reduced the yield quantity and quality parameters, but they increased the cooling methods improving effects on crop yield (Fig. 1–4).

In order to improve flower quality and reduce the energy investments, the grower should adjust the canopy morphology, especially in midsummer, i.e. maintain a large and fresh transpiring canopy and reduce the number and proportion of young stems in the canopy, in order to achieve an optimal balance between carbohydrate sink and source. Employing "Downward cutting" during ES, may reduce number of initiations along LS (KOOL 1996), and should be tested as a mean to achieve these goals.

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