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THE EFFECT OF TEMPERATURE ON THE DEVELOPMENT OF HIPPEASTRUM: A PHYTOTRON STUDY

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EPHRATH J. E., BEN–ASHER, J., ALEKPAROV, C., SILBERBUSH, M., WOLF, S. and DAYAN, E. *The effect of temperature on the development of Hippeastrum: A phytotron study.* BIOTRONICS: **30**, 51–62, 2001. Hippeastrum flowers in the spring, but the exact flowering time can be controlled by applying specific thermal regime to large sized bulbs. To control the flowering time, and improve quality and size of Hippeastrum (*Hippeastrum hybridum*, cv. Red Lion) bulbs, the effect of temperature regime was investigated. The objectives of this research were to study the effect of ambient temperature on the growth rate of bulbs, the effect of soil temperature on the growth rate of bulbs and the susceptibility of several bulbs' sizes to various thermal regimes. Two sets of experiments were conducted: A phytotron experiment with six day/night temperature combinations and a controlled greenhouse experiment in which five levels of minimum soil temperature treatments were imposed. Temperature had a strong effect on bulb and leaf development. Temperatures of 27℃ were optimal for leaf area development while temperatures of 22℃ were optimal for bulb development. Different patterns of bulb growth rate were found when bulbs of different initial sizes had grown under the same minimum growing temperature (22℃): The small bulbs (initial diameter of 5.4 cm) had grown about two cm throughout the season (180 growing days) while the large bulbs (initial diameter of 7.9 cm) had grown less the one cm. The growth rate of the other three initial bulb size categories (6.1, 6.7 and 7.3 cm) varied between these two rates. A high linear temperature dependent correlation was found between leaf area and bulb size. The distribution of the fresh matter among the roots, leaves and bulbs was also found to be temperature dependent.

Key words: Leaf area; Bulb size; partitioning

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INTRODUCTION

The main world market demand for Hippeastrum flowers is at the end of December, during the Christmas Holidays. Naturally, Hippeastrum flowers in the spring, from the middle of March until the end of April. However, the exact flowering time can be manipulated by applying an appropriate thermal regime to large sized bulbs. Bose et al., (*1*) has shown that there is no effect of day length on the flowering of the Hippeastrum. Previous studies have shown that the induction for flowering of the Hippeastrum is autonomous and primarily connected with the size of the bulb (*2, 10*).

During the winter period, when soil temperature is reduced to levels below 15℃, the growth of the bulb ceases, and bulb growth resumes as soil temperature increases above 15℃.

Ijiro and Ogata (*5*) reported that high (30℃/24℃ day/night temperatures), hastened the development of bulbs while under low temperatures, (24℃/17℃ day night temperatures), the bulbs developed slowly. Spring flower development will cause a reduction in the bulb size due to the use of stored carbohydrates, and consequently a delay in flowering in the winter (when the demand is at its peak). Several studies have shown that soil temperature between 20℃–23℃ throughout the growing season prevented the undesired spring flowering (*4, 5*). Heating the soil, therefore, will prevent the delay in bulb's development and will shorten the growing season, since the bulbs have to be ready for picking at the end of August.

The main goal of this work was to study the effects of soil temperatures on the development of Hippeastrum bulbs grown in controlled conditions. Specific objectives were (1) To quantify the effect of ambient temperature on the growth rate of bulbs, (2) to study the effect of soil temperature on the growth rate of bulbs and (3) to investigate the susceptibility of several bulbs size to various thermal regimes.

MATERIALS AND METHODS

Two sets of experiments were conducted to analyze the effects of soil and air temperatures on several physiological aspects of Hippeastrum (*Hippeastrum hybridum*, cv. Red Lion) bulbs.

The phytotron experiment

Hippeastrum bulbs with an initial diameter ranging from 5.1 to 5.7 cm were planted on February 8, 1994 in 4 l pots with volcanic ash in a phytotron (Wolf et al., 1990). Plants in all treatments were grown under short day conditions with 8 hours of natural sunlight (day conditions), and 16 hours in a dark room (night conditions). Daytime started at 08:00 am and lasted until 16:00 hr when the plants were transferred to the dark room. The temperature and growing conditions regimes are summarized in Table 1

Plants were watered twice a day: in the morning with half strength Hogland

Table 1. Temperature regime in the Phytotron experiment 1994–5

Day length (h)	8	8	8	8	8	8
Night length (h)	16	16	16	16	16	16
Day Temperature (℃)	32	32	27	27	22	22
Night Temperature (℃)	17	22	27	17	22	12

solution and in the afternoon with tap water.

Plant monitoring

Bulb growth rate was expressed as a change of diameter with time. The diameter was measured every two weeks by careful removing of the soil surrounding the bulbs to allow measurement of the diameter. After measuring, the bulbs were covered again. Leaf area was estimated from the product of its length and width. A correction factor due to the shape of the leaf (*3*) was introduced to obtain the actual leaf area. Actual leaf area was measured with a LI–3000 leaf area meter (Li–Cor Inc. Logan Utah, USA) and the correlation between leaf length and maximum width and leaf area is described in Eqn. [1].

$$LA = (W * L) * 0.66 + 15.45 \qquad R^2 = 0.985 \quad [1]$$

Where LA is the leaf area (cm^2), W and L are leaf blade width and length (cm) respectively and 0.66 is a shape correction factor. At $LA = 15.45\ cm^2$ the first term on the right hand side of the equal sign is negligible.

Three times during the season, three plants from each treatment were removed from their pot, dissected and separated into leaves, bulb and roots to measure leaf area and flower appearance. Bulbs were cut and the number of undeveloped flower buds (inside the bulbs) was counted.

At the end of the season, all bulbs were removed from the substrate, and were dissected. Bulbs were dissected and the number of flower buds in the bulbs, leaf area, bulb size, root weight and bulb weight were determined.

Greenhouse experiment

Hippeastrum bulbs of the same variety as in the phytotron experiment were planted in a climate controlled research greenhouse (Fig. 1). Soil temperature was controlled by circulating hot water in a set of pipes buried at a depth of 40 cm. Thermometers were installed in the soil at a depth identical to that of the bulbs (5 cm). When soil temperature decreased to a threshold level, a pump circulated hot water in the pipe until soil temperature reached a pre–set minimum level. Unlike the phytotron experiment, in the greenhouse only the minimum temperature was kept above a certain threshold while the maximum temperature changed according to the meteorological conditions outside the greenhouse.

During the winter, when soil temperature was low, five levels (treatments) of minimum soil temperature were kept in this experiment: 15℃, 17℃, 19℃, 21℃

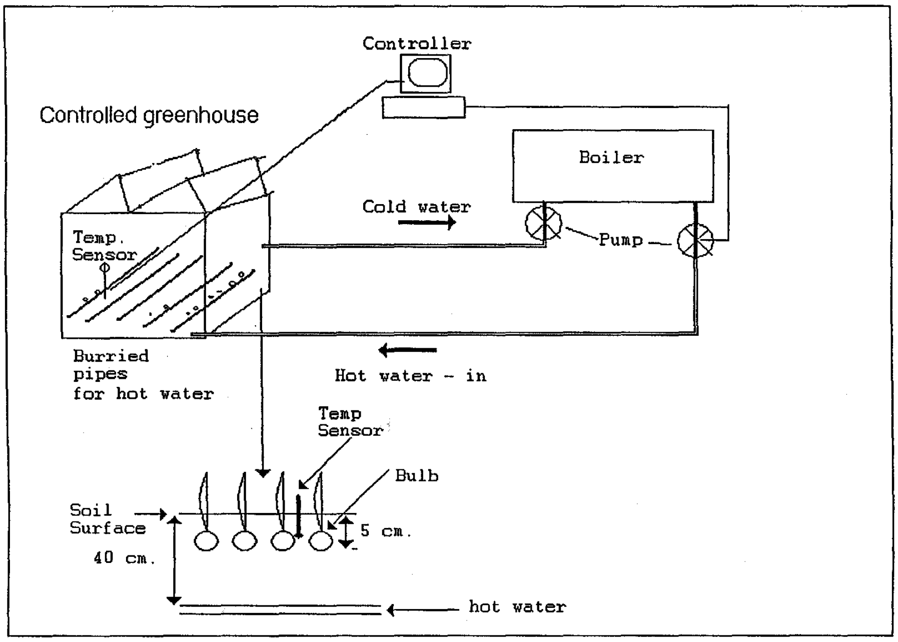

Fig. 1. Schematic description of the soil heating system of the controlled green house

and 22℃. Bulb diameter was measured and compared to the data collected in the Phytotron.

Meteorological parameters (soil and air temperatures, relative humidity and radiation) were measured continuously and data were recorded on a CR-21X data-logger (Campbell Sci. Inc. Logan, UT, USA). Temperature was measured with a Copper-Constanten thermocouple. PAR was measured with a LI-190 quantumeter and relative humidity was measured with dry-wet Copper-Constanten thermocouples, which were placed in a ventilated chamber. Data were collected every second and were averaged at 30 min intervals.

RESULTS

The development of the bulbs in the phytotron experiment is presented in Fig. 2. In the 22℃/22℃ treatment, bulbs grew from the initial diameter average value of 5.1 cm to a final size of about 7.8 cm. In the 27℃/27℃ treatment the bulbs were significantly smaller with a final diameter size of 7.3 cm at the end of the growing season. A similar bulb development pattern was obtained in the 22℃/22℃, 27℃/17℃ and 27℃/27℃ treatments. In these treatments there was a continuous growth throughout the measurement period. In the high day temperatures or low night temperatures treatments (32℃/22℃, 22℃/12℃ and 32℃/17℃) a different pattern was found: No change in bulb development until 100 days after planting (DAP) and the main growth occurred only at the last 80 days of the growing period.

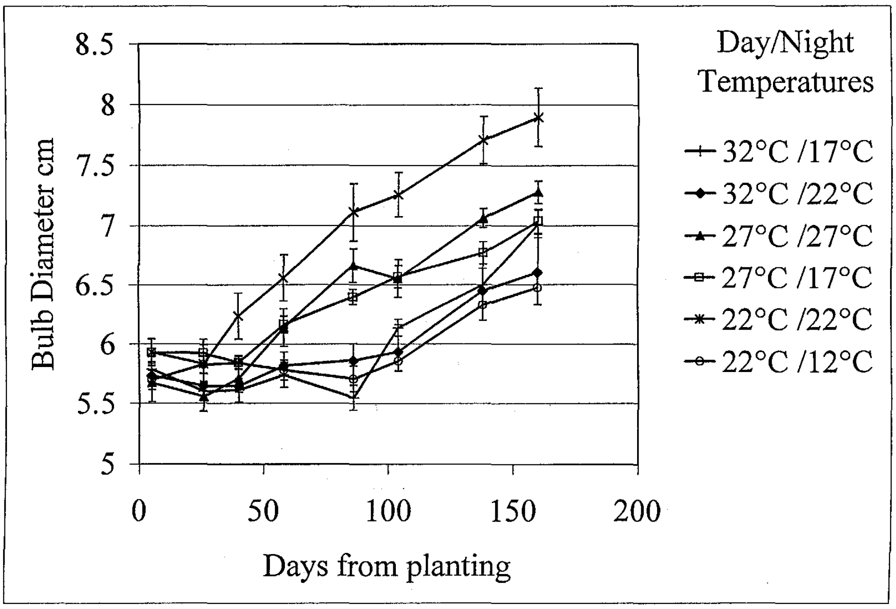

Fig. 2. Average bulb diameter development throughout the growing season in the various day and night temperature treatments (Error bars represent ± standard error of the mean, $n=10$).

In the controlled greenhouse experiment, after 200 growing days, no significant difference was found among the bulbs that were grown in a minimum soil temperature of above 17℃ (Fig. 3A). Plants grown under the minimum soil-temperatures of 15℃ and 17℃ developed significantly smaller bulbs compared to the 19℃ and above. The main effect of soil temperature was on the time to reach marketing size (Figs 3A, B) : If we consider eight cm as the minimal appropriate diameter of a bulb for marketing, we can see that by keeping the minimum soil temperature on 22℃, bulbs had grown from the size of about six cm (diameter) to a size of eight cm within the period of time 90 days. A decrease of one degree in soil temperature resulted in the addition of 10 growing days until marketing bulb size.

At a minimum soil temperature of 22℃ (Fig. 4), the development of bulb of different initial diameter sizes can be divided into two phases: the first hundred days were characterized by a fast growth in all size categories. The second phase was from 100 days after planting (DAP) until the end of the measuring period. This phase was characterized by a slow growth rate or even a reduction in bulb size. The bulbs of the small size category (initial diameter of 5.4 cm) hardly developed during this period of time while in the other categories bulb size decreased. At the end of the measuring period, two groups could be statistically defined: The initial size of 7.3 and 7.9 cm bulbs (at planting), which were significantly larger than the other three categories. No significant difference in bulb size was found within each group. Daily bulb growth rates (*DGRT*) of the different size categories were examined on a seasonal scale. The

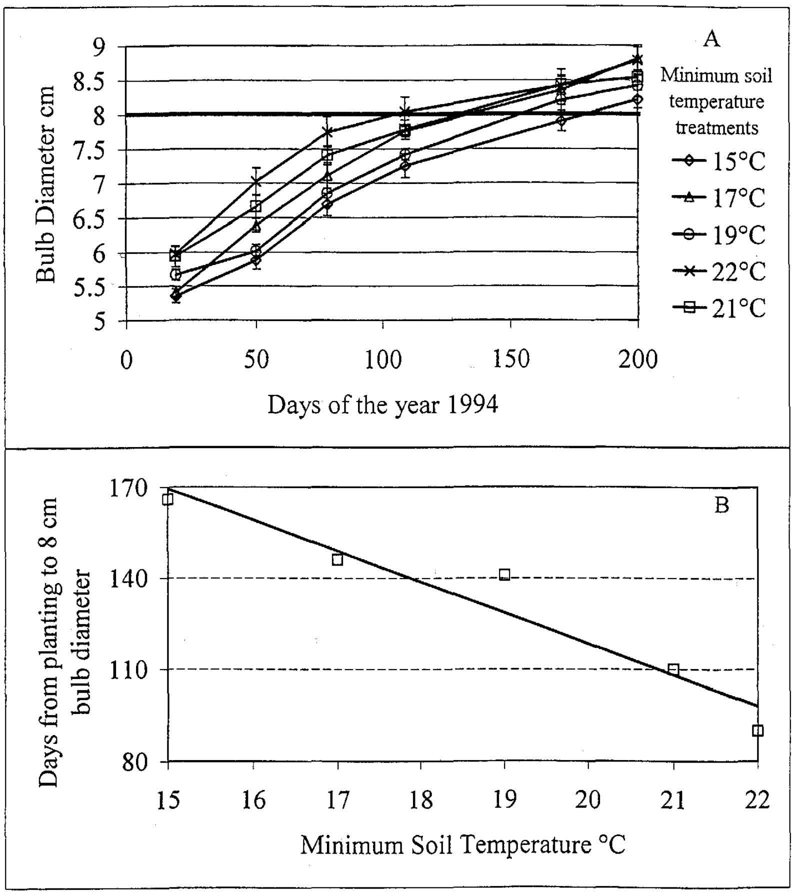

Fig. 3. (A) Average bulb diameter development throughout the growing season in the various minimal soil temperature treatments of the controlled green house experiment, Besor, 1993–95. Error bars represent ± standard error of the mean, *n*=*5*. (The solid line on the 8 cm bulb diameter indicates marketing size). (B) Days from planting to marketable bulb size (diameter of 8 cm). Equation of the line is presented in the figure (Y–days; X–minimal soil temperature [℃])

calculation of *DGRT* was done by dividing the difference between the final and the initial bulb size (of each category) by the number of growing days (Eq. 2):

$$DGRT = \frac{(bulb_f - bulb_i)}{\text{number of days}} \qquad [2]$$

Where *DGRT* is the daily bulb growth rate in cm d^{-1}, $Bulb_f$ and $Bulb_i$ are Final and initial bulb diameter (in cm) respectively.

It was found that the daily growth rate of the bulbs decreased linearly at a rate of 0.0023 (cm d^{-1} cm^{-1} initial diameter, R^2=0.94), as the initial size of the bulb increased (Table 2).

The main source of assimilates used for the development of the various organs of the plant is the leaves. Leaf area was strongly affected by the

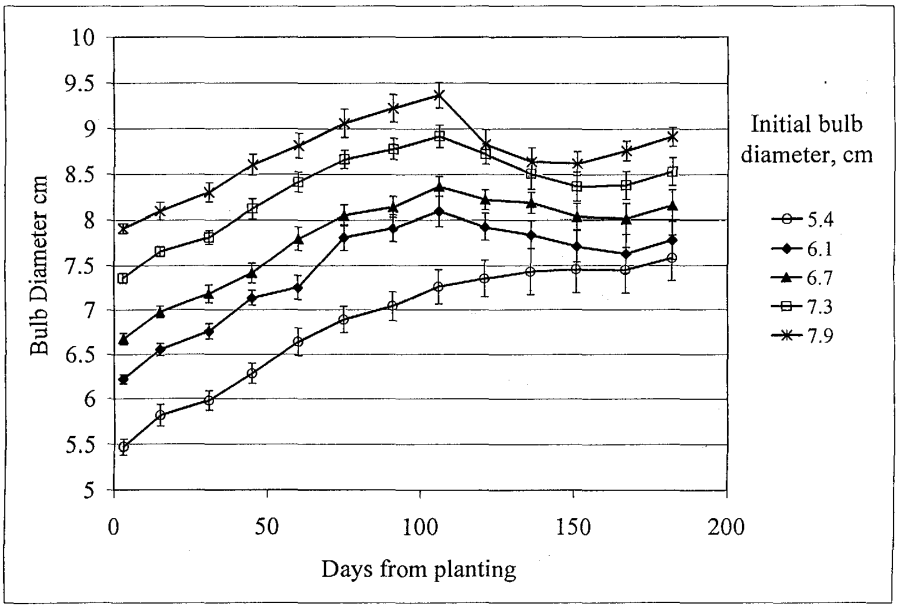

Fig. 4. Average bulb diameter development at 22℃ minimal temperatures. Bulbs were planted at five size groups at the end of December, 1991. Error bars represent ± standard error of the mean, $n=5$.

Table 2. Bulb daily diameter growth rate at minimal soil temperature of 22℃ treatment, at the controlled green house, Besor, 1992.

Average initial bulb size (diameter, cm)	Daily diameter growth rate (cm d^{-1} cm^{-1} initial diameter)
5.4	0.012
6.0	0.0087
6.7	0.0083
7.3	0.0065
7.9	0.0056

temperature regime (Fig. 5). Significant differences in leaf area were found among all treatments, with the highest area in the 27℃/27℃ treatment. Treatment 22℃/22℃ achieved a final leaf area of 1320 cm^2 per plant. Increasing day temperature by 10℃ decreased leaf area to 872 cm^2 (a reduction of 33%) and decreasing night temperature by 10℃ decreased leaf area to 565 cm^2 (a reduction of 58%). Treatment 27℃/27℃ achieved a leaf area of 1717 cm^2, an increase of 30% compared to the 22℃/22℃ treatment.

The relationship between the leaf area and bulb development throughout the growing season is presented in Table 3. High and linear correlation between these two factors was found in each of the temperature treatments: The increase of leaf area resulted in an increase of bulb size. However, when examining the different combinations of day/night temperatures, we can see that there were

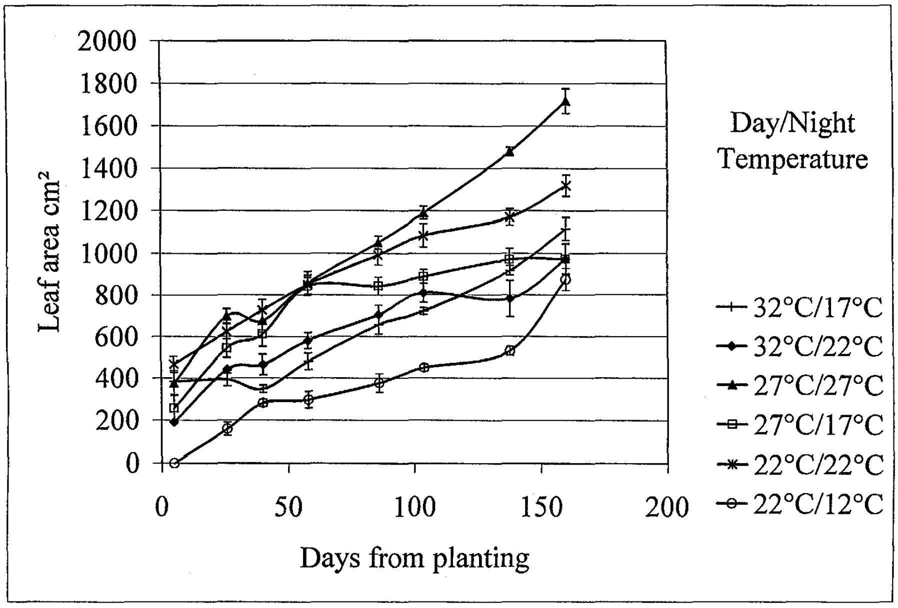

Fig. 5. Leaf area development throughout the growing season in the various day and night temperature treatments of the phytotron Experiment, Rehovot, 1994. Error bars represent ± standard error of the mean, $n=10$.

Table 3. The relations between the leaf area throughout the growing season and bulb diameter in the phytotron experiment. (Y-bulb diameter, cm ; X-leaf area cm^2)

Day/Night temperature [℃]	Regression Equation	Regression coefficient R^2
32/22	$Y=0.0012X+5.3$	0.72
32/17	$Y=0.0017X+4.9$	0.83
27/27	$Y=0.0014X+4.9$	0.91
27/17	$Y=0.0014X+5.3$	0.67
22/22	$Y=0.0027X+4.4$	0.96
22/12	$Y=0.0010X+5.6$	0.73

different slopes or different contributions of the photosynthetic area to the bulb production. The highest contribution of leaf area to bulb size was found in the 22℃/22℃ treatment and the lowest in the 22℃/12℃ and 32℃/22℃ treatments. No difference in the relationship between leaf area and bulb size was found in 27℃/27℃ and 27℃/17℃ treatments.

The total fresh weight (leaves, root and bulbs) of the 22℃/22℃ treatment was about 500 gr per plant, which was the highest, but not significantly different form the 27℃/27℃ treatment (Fig. 6).

Increasing day temperature by 10℃ or decreasing night temperature by 5℃ caused a reduction of more than 30% in the total fresh weight. The 22℃/12℃ treatment total fresh weight was significantly lower than for all the other

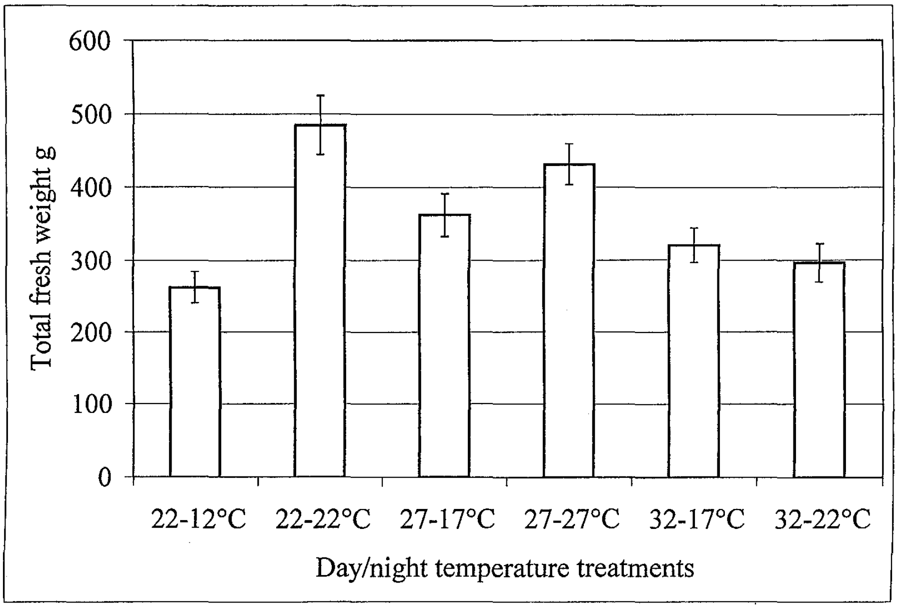

Fig. 6. Total fresh weight of the plant at the end of the phytotron experiment (Aug 22, 1994) in the various day and night temperature treatments of the phytotron Experiment, Rehovot, 1994. Error bars represent ± standard error of the mean $n=10$.

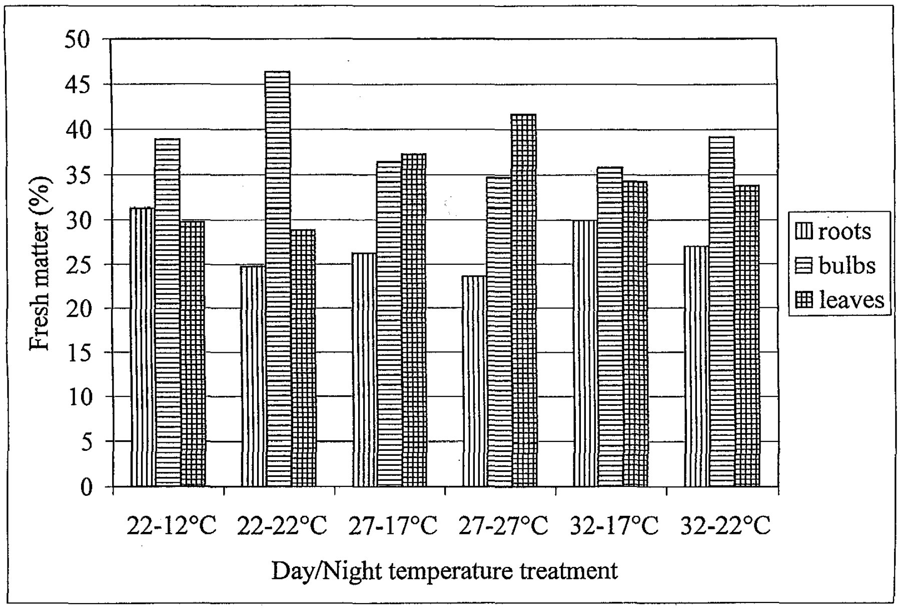

Fig. 7. Distribution of the fresh weigh among the different organs of the Amaryllis plant, in the various day and night temperature treatments of the phytotron Experiment, Rehovot, 1994.

temperature treatments.

The partitioning of the fresh weight is described in Fig. 7. In the 22℃/22℃ treatment, 47% of the total fresh weight of the plant was allocated in the bulbs and the rest was distributed between the leaves (28%) and the roots (25%). In treatment 27℃/27℃ treatment, only 35% of the total fresh weight was allocated to the bulbs and much higher proportion was allocated to the leaves (42%) and to the roots (23%). In treatment 32℃/17℃ the percentage of bulb fresh weight out of the total weight was similar to that of treatment 27℃/27℃ but more fresh matter was allocated to the roots (28%). In the other temperature treatments the bulbs portion was about 35% of the total fresh weight, with small variations in the distribution of fresh weight among the leaves and the roots.

DISCUSSION

The main goal of this work was to investigate the effects of soil temperatures on the development of Hippeastrum bulbs grown in controlled conditions. The results (Figs. 2–5) demonstrated the effect of soil temperature on bulb size and weight and on leaf area and weight. The effect of temperature on bulbs growth rate of various specious is well documented: Ijiro and Ogata (*5*) examined the effects of temperature on amaryllis, Kim et al. (*7*) tested the effect of temperature on growth and bulb production of lilies and Lancester et al., (*8*) showed that in onion.

Our results, however (Figs 2–5), show that the effect of temperatures on growth is not constant throughout the growing season and depends on the diurnal variation of temperatures, initial bulb size and day/night temperature regimes. In the phytotron experiment air temperatures in each of these treatments were kept constant for the entire day or night. These growing conditions negatively affected the development of the bulbs. This can be demonstrated by the small change in bulb size under the high day-time or low night time temperatures (Fig. 2): The fact that throughout the day bulbs were subjected to the same high temperatures resulted in increasing respiration rate and decreasing photosynthetic rate, causing low bulb growth rate. Under low temperature the bulbs developed slowly (*5*). In the controlled greenhouse experiment, however, the growing conditions were more suitable for the amaryllis bulbs: During day time soil and air temperatures changed according to the meteorological conditions outside the greenhouse and the heating system prevent soil temperature to go down below the desired threshold, resulting in continuous bulb growth in all treatment for the entire growing period.

The major effect of increasing soil temperatures was in shortening the period of time from planting to mature, market-size bulbs (Figs. 3A and 3B). By calculating the costs of energy and compare it with the growing cost (irrigation, fertilization, labor), it is easy to determine the optimum soil temperature needed to shorten the growing period and maximize the profit.

Amaryllis plants grown in a phytotron under high temperature regimes (23℃ during the night and 28℃ during daytime) developed a high leaf area.

Roberts et al., (*11*) showed that the rate of leaf and flower buds development and stem elongation rate were directly proportional to the range of temperature used in their experiment.

A competition between the leaves (source) and bulbs (sink), which was found to be temperature dependent, can be seen in the phytotron experiment (Table 3) : Under moderate day/night temperatures the contribution of the photosynthetic area, the leaves, to the bulbs was higher compared to the extreme day/night temperatures:

When daytime temperature was less than 27℃, increasing night temp resulted in a significant increase of fresh weight. This can be seen clearly when comparing pairs of treatments with the same day temperatures and different night temperatures. When day temperature was higher than 27℃, a small and not significant reduction in the total fresh weight was recorded as night temperature increased (Fig. 6). When examining the effect of increasing the night temperature on the fresh weight of root, leaves and bulbs we can see that under the low day time temperatures (22℃) bulb weight increased with increasing night temperatures but leaf and root weight decreased. In the treatment with the higher daytime temperatures (27℃) there is a different pattern: Bulb and root fresh weight decreased with increasing temp (from 17℃ to 27℃) but leaves developed vigorously. A possible explanation to this phenomenon is due to high maintenance respiration under high temperatures or the different priorities of carbohydrates allocation to different organs of the plant (Figs 6 and 7). Similar results were reported also by Iortsuun and Khan, (*6*) and Lancester et. al., (*8*)

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