

THE GROWTH AND DEVELOPMENT OF HIPPEASTRUM IN RESPONSE TO TEMPERATURE AND CO₂

Ephrath, J. E.

Jacob Blaustein Institute for Desert Research Ben-Gurion University of the Negev

Ben-Asher, J.

The Katif Research Center for development of coastal deserts | Jacob Blaustein Institute for
Desert Research Ben-Gurion University of the Negev

Alekperov, Ch.

Jacob Blaustein Institute for Desert Research Ben-Gurion University of the Negev

Silberbush, M.

Jacob Blaustein Institute for Desert Research Ben-Gurion University of the Negev

他

<https://hdl.handle.net/2324/8273>

出版情報 : BIOTRONICS. 30, pp.63-73, 2001-12. Biotron Institute, Kyushu University
バージョン :
権利関係 :

THE GROWTH AND DEVELOPMENT OF HIPPEASTRUM IN RESPONSE TO TEMPERATURE AND CO₂.

J. E. EPHRATH*¹, J. BEN-ASHER^{1,2}, CH. ALEKPEROV^{1,2},
M. SILBERBUSH¹, and E. DAYAN³

¹*Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Israel*

²*The Katif Research Center for development of coastal deserts, Neve-Dekalim, Israel*

³*Besor Experimental Station, Ministry Of Agriculture, Agriculture Research Organization, Israel.*

(Received May 30, 2001; accepted August 21, 2001)

EPHRATH, J. E., BEN-ASHER, J., ALEKPEROV, CH., SILBERBUSH, M. and DAYAN E. *The growth and development of Hippeastrum in response to temperature and CO₂*. BIOTRONICS 30, 63–73, 2001. Flowering time of Hippeastrum can be controlled by applying specific thermal regime to large sized bulbs. Due to high-energy costs, the aim of this study was to examine the possibility to reduce soil heating and keep high bulb growth rate by increasing the CO₂ concentration. Two sets of experiments were carried out in a controlled greenhouse at the North-Western Israeli Negev Desert. In both experiments, bulbs of different initial sizes were grown under two levels of CO₂ concentrations (ambient, 350 ppm and elevated, 1000 ppm) combined with different minimum soil temperature regimes. In the first experiment three temperature regimes (16°C, 22°C and 24°C) were tested, while in the second experiment only one minimum soil temperature regime (22°C) was investigated. In both experiments, raising CO₂ concentration from the ambient level to elevated one, or increasing soil temperature resulted in a higher bulb growth rate. Temperatures, CO₂ concentration and initial bulb size significantly influenced the final diameter of the bulbs. A significant difference in final bulb diameter was obtained only between the 16°C treatment and the 22°C and 24°C treatments, but not between the two high temperatures tested. The area of the largest leaf was significantly affected only by the soil temperature treatments. No effect of CO₂ concentration on leaf area development was detected. The number of leaves, however, was affected by the CO₂ but not by the temperatures. Bulbs grown under elevated CO₂ had a higher flowering rate compared to ambient CO₂. This was effective both in shortening the period of time from re-planting until flowering and by the significant high number of flowers compared to the ambient CO₂ conditions.

Key words: Leaf area; bulb size; number of leaves; flowering

*Corresponding author: J.E. Ephrath: Ben-Gurion University of the Negev, Inst. for Desert Res., Wyler Dept of Dryland Agriculture, Sede Boker Campus, Sede Boker 84990, Israel.

INTRODUCTION

The highest demand for *Hippeastrum* bulbs is during the Christmas holiday at the end of December. Previous studies (10, 12) have shown that during the winter, when soil temperature is reduced below 15°C, bulb growth would cease. *Hippeastrum* naturally flowers in the spring, from the middle of March until the beginning of May. The main factor that affects the flowering time is the size of the bulb (3, 17) with no effects of day-length or other external factors. Spring flower development would cause a reduction in the bulb size due to the use of stored carbohydrates, which results in a delay in flowering. In order to meet the market demand and to shorten the growing season, farmers in Israel and the Netherlands grow *Hippeastrum* bulbs in greenhouses and usually heat the soil in order to keep soil temperature above a threshold (15°C) and to have a continuous growth throughout the year. Several heating practices are used: Pipes buried in the soil or on the surface with hot water running through them whenever soil temperatures reduced or heating of the entire greenhouse which increases the production costs tremendously.

The rise in global atmospheric CO₂ has been well documented. Carbon dioxide enrichment has been shown to increase growth of rice (2) and other crops (4, 7, 13). Several studies examined the combined effects of elevated CO₂ concentration and temperature on the growth and development of the above and below the soil surface parts of crops. Idso *et al.* (11) reported that the proportional yield increases due to elevated CO₂ concentration are often much larger under warmer temperatures. Similar results also were reported by Long (14). On the other hand, no such interaction was obtained in carrot (18), cauliflower (19) or wheat (15, 20).

Yield increases of root crops grown at elevated CO₂ are often larger than the average, probably because the harvestable portion of the plant is a larger sink for photosynthetic assimilates (6). It is not known if CO₂ concentration affects bulb formation in onion (5). However, the time for bulbing was found to be more rapid at high temperatures (5).

There is no doubt that a possible interaction between high temperatures and elevated CO₂ on the development of *Hippeastrum* bulbs is a complex response. Improved understanding of crop responses to these two factors is of great importance. The overall objective of the study presented here was to examine the combination of several temperature regimes and elevated CO₂ concentration on the bulb development of *Hippeastrum*. More specifically this study examines the possibility of compensating the reduction in soil heating due to high-energy costs by increasing the CO₂ concentration, and maintain high bulb growth rate

MATERIALS AND METHODS

The results presented here are from a study conducted from 1994–1999 in the Northern Negev Desert of Israel. *Hippeastrum* bulbs (*Hippeastrum hybridum*, Var. Red Lion) were planted in a controlled greenhouse. Thermometers were

installed in the soil at the depth of bulbs placement (5 cm) and minimum soil temperature was thermostatically controlled by circulating hot water in a set of pipes placed on the soil surface.

The greenhouse was divided into two sections in which two levels of CO₂ concentrations were tested: 1000 ppm (enriched) in one section and 350–360 ppm (ambient) in the other. CO₂ enrichment was achieved by a Priva CO₂ heater and controlled by an analyzer (*PRIVA 0292 model 07, Serial No. DK 2290* Priva, the Netherlands). The CO₂ enrichment system started daily at one hour after sunrise and turned off one hour before sunset.

As air temperature inside the greenhouse exceeded 32°C, the sidewalls of the greenhouse would open allowing the exchange of air to ventilate and reduce the temperature inside the greenhouse. At this point, the CO₂ enrichment system was turned off automatically. When air temperature decreased below 28°C, the sidewalls were closed again and the CO₂ enrichment system resumed operation.

Two studies, which examined the effects of CO₂ enrichment and an increase in soil temperature, were carried out. The first experiment was planted in November 15, 1994. Two hundreds bulbs of four initial sizes (50 of each of the following diameters: 3.5 cm, 4.14 cm, 4.78 cm and 5.4 cm) were grown for 255 days at three levels (treatments) of minimum soil temperature: 16°C, 22°C and 24°C and two levels of CO₂ concentrations. In the second experiment 200 bulbs were planted in January 12, 1998 and harvested 220 days later. In this experiment only one minimal soil temperature (22°C) was tested with two CO₂ concentrations and four initial size categories (50 bulbs with the following initial diameters: 3.5 cm, 4.14 cm, 4.78 cm and 6.1 cm). In the two experiments, all measurements were replicated five times and averaged. At the end of the second experiment, 18 bulbs at the size (diameter) of eight cm grown in the two CO₂ concentrations were stored in 8°C for six weeks and then were re-planted in November 4, 1998 in 41 pots and grown in a greenhouse in order to follow the flowering rate.

Bulb growth rate was expressed as a change of diameter with time. The diameter was measured every two weeks by carefully removing soil surrounding the bulbs to allow measurement of the diameter. The bulbs were re-covered after measurements.

Leaf area was estimated from the product of its length and width. A correction factor due to the shape of the leaf (9) was introduced to obtain the actual leaf area. Actual leaf area was measured with a leaf area meter (model LI-3000 Li-Cor Inc., Logan Utah, USA) and the correlation between leaf length and maximum width and leaf area is described in Eq. [1].

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

Where *LA* is the leaf area (cm²), *W* and *L* are leaf blade width and length (cm) respectively and 0.66 is a shape correction factor. At *LA* = 15.45 cm² the first term on the right hand side of the equal sign is negligible.

RESULTS

The final size of bulb grown in three temperature regimes and two CO₂ concentrations as a function of initial bulb size is presented in Fig. 1. Raising CO₂ concentration from the ambient level to 1000 ppm or increasing soil temperature resulted in a higher bulb growth rate. The final bulb size at the end of the measuring period (255 days after planting, DAP) at all three temperature regimes was not significantly different when bulbs were grown under elevated CO₂ concentration. The analysis of variance (ANOVA), presented in Table 1, shows that temperatures, CO₂ concentration and initial bulb size significantly influenced ($P > 0.001$) the final size of the bulbs. Analysis of the data revealed that a significant difference in bulb final size was found only between the 16°C treatment and the 22°C and 24°C treatments (Table 1). No significant difference in bulb final size was found between the two high temperatures tested. There was also no significant difference in final size of bulbs developed from the two small initial diameters (3.5 and 4.2 cm, Table 1)

The effect of CO₂ concentration on bulb size for bulbs with different initial diameters grown at a constant soil temperature of 22°C is presented in Fig. 2 (A–D). In three out of the four initial size categories that were examined, higher CO₂ concentration resulted in a larger bulb diameter at the end of the growing season. In the small size category (a diameter of 3.5 cm., Fig 2–A) there was no effect of the elevated CO₂ concentration on bulb size. Only bulbs of the initial large size category (diameter of 6.1 cm), which were grown under the elevated CO₂ concentration reached marketing size (a diameter of 8 cm) at the end of the growing season. When examining the effect of initial bulb size on the difference

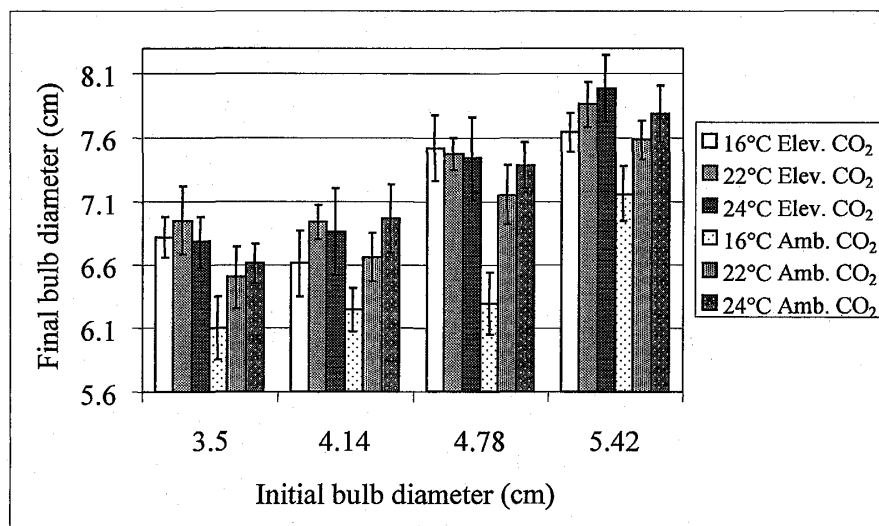


Fig. 1. Final bulb diameter as a function of three levels of minimum soil temperature, two CO₂ concentrations and initial bulb diameter (controlled greenhouse, 1994–95). Error bars represent \pm standard error of the mean, $n=5$. Temperature levels are presented in the graph. CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated).

in diameter values between the beginning and the end of the growing season at the two CO₂ concentrations (Fig. 3), we can see that as the initial bulb size increased, the differences between the initial and final diameter decreased. This slope reduction was more than two times larger under the ambient CO₂ concentration compared to the elevated CO₂ concentration.

The effect of CO₂ concentration on bulb fresh biomass is presented in Fig. 4. A significant effect of the elevated CO₂ concentration on biomass was found in bulbs with initial size larger than 3.5 cm in diameter (Fig. 4 B–D compared to Fig. 4–A). Except for the bulbs of the large initial size category (Fig. 4–D, a diameter of 6.1 cm), bulb biomass increased throughout the growing period.

The area of the largest leaf was significantly affected only by the soil temperature treatments (Table 2). The effect of CO₂ concentrations on leaf area development was not significant (Table 2). The number of leaves per plant, however, was significantly affected by the CO₂ concentrations but not by temperatures (Table 3).

The effect of the CO₂ concentration on the flowering percentage of bulbs

Table 1. Analysis of variance for the final bulb diameter, 255 days after planting, in the 1994–95 experiment. Temperatures were 16°C, 22°C and 24°C. CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated). Initial diameter sizes were 3.5, 4.2, 4.7 and 5.4 cm (n=5). Means with different letters are significantly difference at $p < 0.05$.

<u>SOURCE</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	<u>P</u>
Temperature	2	0.81295	0.40647	9.93	0.0010
CO ₂	1	0.81918	0.81918	20.01	0.0003
Initial size	3	4.22431	1.40810	34.39	0.0000

LSD (T-test) comparison of means of final diameter by: Temperature	
Temperature	Mean (cm)
22°C	7.2260 a
24°C	7.1400 a
16°C	6.7997 b

LSD (T-test) comparison of means of final diameter by: CO ₂	
CO ₂ (ppm)	Mean (cm)
1000	7.2400 a
350	6.8705 b

LSD (T-test) comparison of means of final diameter by: Initial size	
Initial size (cm)	Mean (cm)
3.5	7.6713 a
4.2	7.2097 b
4.7	6.7137 c
5.4	6.6263 c

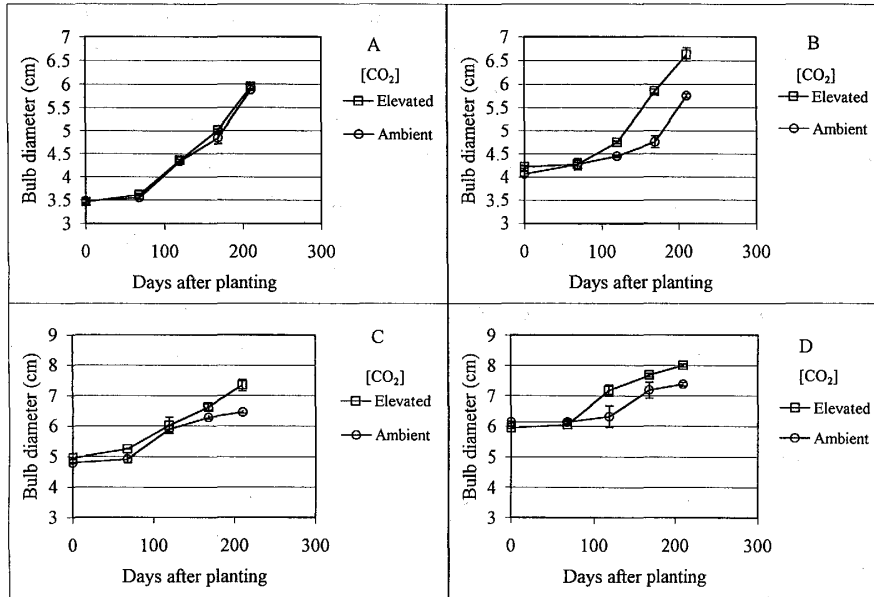


Fig. 2. The effects of two CO₂ concentrations at a minimum soil temperature of 22°C and different initial bulb size categories (A-3.5 cm.; B-4.14 cm.; C-4.78 cm.; D-6.1 cm.) on the development of bulb diameter (controlled greenhouse, 1998-99). Error bars represent ± standard error of the mean, *n*=5. CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated).

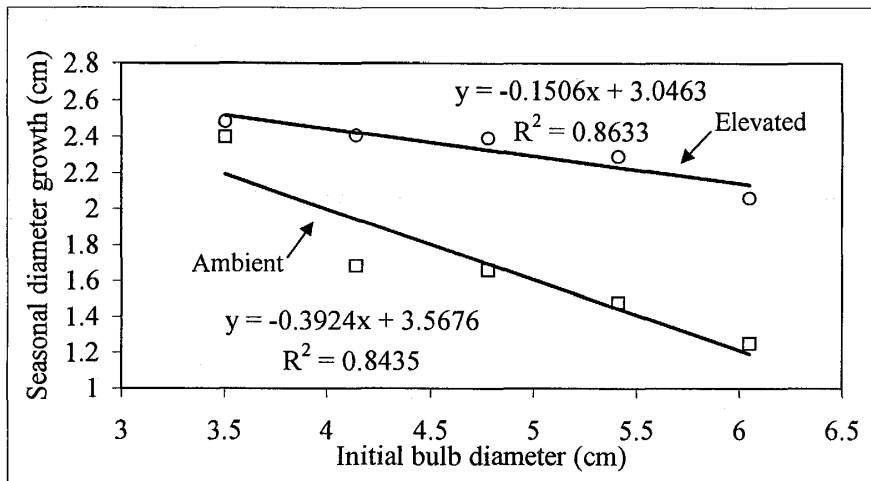


Fig. 3. The seasonal diameter growth of bulbs planted in different sizes and grown in elevated and ambient CO₂ concentrations (controlled greenhouse, 1998-99). Regression equations are presented in the graph. CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated).

replanted after storage is presented in Fig. 5. About 80% of the bulbs grown in elevated CO₂ concentration flowered compared to only 40% of the bulbs grown under ambient CO₂ concentration (Fig. 5-A). Furthermore, the elevated CO₂ grown bulbs flourished sooner: 88% of the flowered bulbs bloomed after 88 days and the rest after 95 days compared the ambient CO₂ concentration where only 30% bloomed after 88 days and the remaining 70% flowered after 102 days (Fig. 5-B).

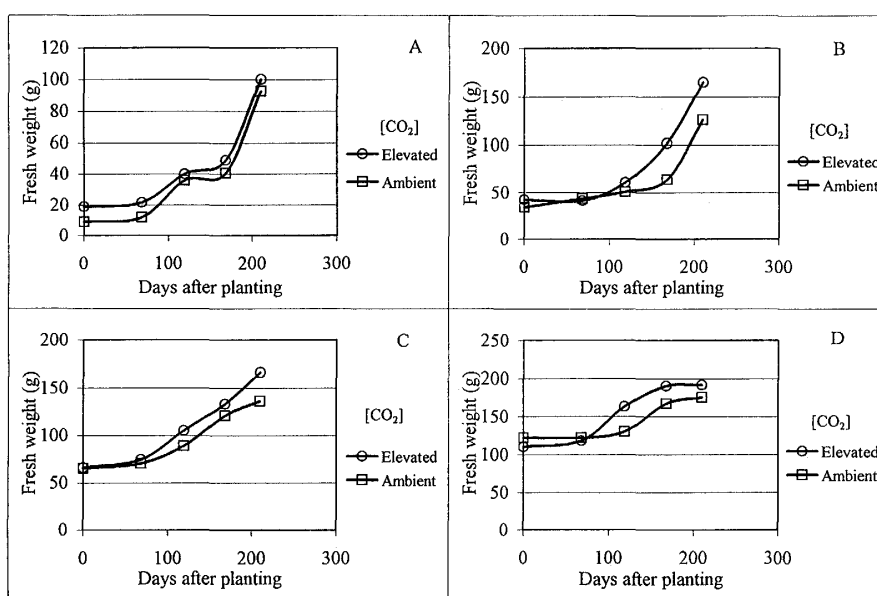


Fig. 4. The effects of two CO₂ concentrations at a minimum soil temperature of 22°C and different initial bulb size categories (A-3.5 cm.; B-4.14 cm.; C-4.78 cm.; D-6.1 cm.) on the development of bulb fresh weight (Controlled greenhouse, 1998-99). CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated).

Table 2. Analysis of variance for the area of the largest leaf in the 1994-95 experiment. Temperatures were 16°C, 22°C and 24°C; CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated). (n=5). Means with different letters are significantly difference at p<0.05.

SOURCE	DF	SS	MS	F-value	P
Temperature	2	4640.62	2320.31	7.76	0.0032
CO ₂	1	0.02927	0.02927	0.00	0.9922

LSD (T-test) comparison of means of leaf area by: temperatures

Temperature	MEAN (cm ²)	GROUPS
24°C	179.04	a
22°C	170.78	a
16°C	146.30	b

Table 3. Analysis of variance for the number of leaves (per plant) in the controlled greenhouse experiment, 1994–95. Temperatures were 16°C, 22°C and 24°C; CO₂ concentrations were 350 ppm (ambient) and 1000 ppm (elevated). (n=5). Means with different letters are significantly difference at $p < 0.05$.

SOURCE	DF	SS	MS	F	P
Temperature	2	0.49000	0.24500	1.44	0.2602
CO ₂	1	2.53500	2.53500	14.91	0.0010

CO ₂	MEAN (number of leaves)	GROUPS
Elevated	8.6167	a
Ambient	8.0333	b

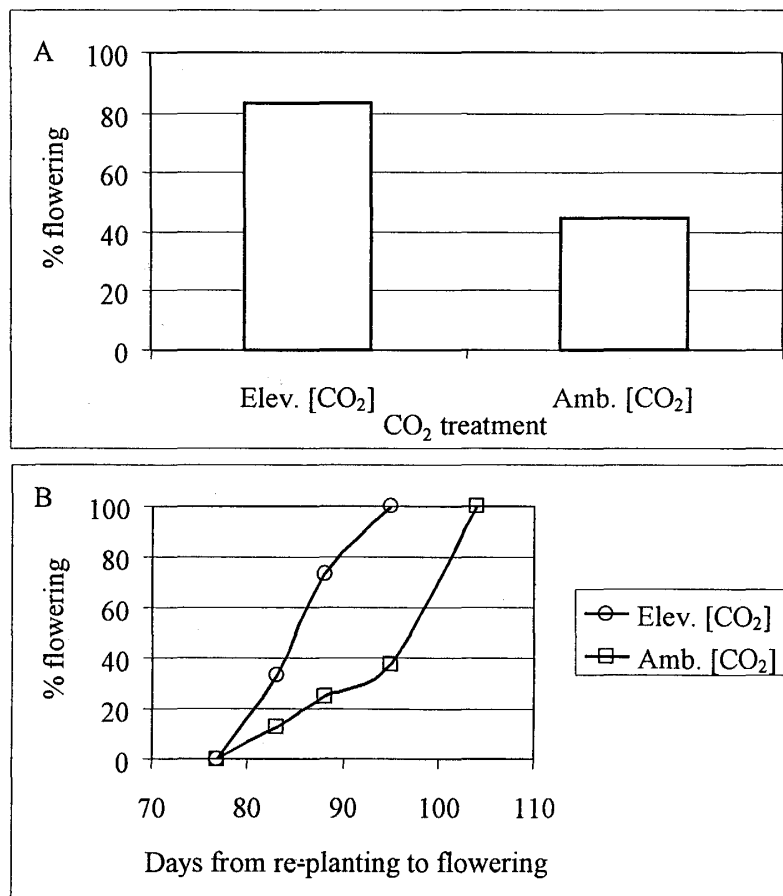


Fig. 5. Percentage (A) of flowering of bulbs and flowering rate of the flowered bulbs (B) grown under ambient (350 ppm) and elevated (1000 ppm) CO₂ concentrations flowering rate of the flowered bulbs (controlled greenhouse, 1998–99).

DISCUSSION

The aim of this study was to investigate if elevated CO₂ in a greenhouse could compensate for the reduction in temperature needed for high bulb growth rate of Hippeastrum plant. To answer this question a series of experiments were carried out in a controlled greenhouse in which several soil temperatures treatments and two CO₂ concentrations were imposed on the plants.

Several indices were tested to study the effects of temperatures, CO₂ and the combine effects of the two. The indices were bulb diameter, bulb weight, number of leaves and leaf area and the potential flowering capacity of bulbs grown either in elevated or ambient CO₂ concentration after storage in 8°C for eight weeks.

Increasing the soil temperatures from 16°C to 22°C and above resulted in a larger bulb but no effect was observed when soil temperature increased from 22°C to 24°C. This response is similar to what was reported in previous studies with onion (5, 8). The results of this study confirm our hypothesis that reduced soil temperature can be compensated by increasing the CO₂ concentration: When comparing the final size of bulbs grown in the three temperature regimes (Fig. 1) we can see that, under elevated CO₂ concentration no significant differences in bulb size were observed. These results were obtained for all the initial size categories tested. We found a similar pattern in bulbs of different initial size grown at a minimal soil temperature of 22°C (Fig 3, A-D): Elevated CO₂ concentration increased bulb growth rate. Except for the small size bulbs (initial diameter of 3.5 cm, Fig 2-A) a significant difference in bulb size and biomass was observed between bulbs grown under the ambient and the elevated CO₂ concentration. The minimal marketing size of amaryllis bulb, which will ensure flowering, is 8 cm. in diameter (3, 17). In our study we found that bulbs grown at a minimum soil temperature of 22°C and under elevated CO₂ concentration reached the marketing size within 210 days. In all other initial sizes and CO₂ treatments bulbs attained smaller final diameter. This result indicates that the elevated CO₂ concentration treatment shortened the time for maturity. The effect of elevated CO₂ concentration on bulb fresh weight (Fig. 4 A-D) was similar to that of bulb size increase throughout the season. Since we found that under the elevated CO₂ concentration bulbs were larger, with no effect on the area of the largest leaf (Table 2) but with a significant effect on the number of leaves per plant (Table 3), we can assume that the enhanced bulbs development under these conditions was associated with an increase in the total photosynthesizing area, as was found in other crops (1, 16).

The commercial product of the amaryllis is a bulb, which is supposed to flower within a short and pre-determined period of time after harvest. One of the most significant effects of the elevated CO₂ concentration appeared to be the flowering rate after storage (Fig. 5). Bulbs grown under elevated CO₂ concentration had better flowering characteristics compared to those grown under ambient CO₂ concentration. The improvement was both in shortening the period of time from planting to flowering and in the significantly higher number

of flowers in bulbs grown under elevated CO₂ compared to those grown under ambient CO₂ conditions.

CONCLUSIONS

The results presented in this study show that reducing the soil temperature from 24°C to 16°C did not affect bulb growth rate when grown under elevated CO₂ concentration of 1000 ppm. Elevated CO₂ concentration significantly increased the number of leaves developed while higher temperature increased the area of the largest leaf. We also found that elevated CO₂ concentration significantly improved the flowering characteristics of *Hippeastrum* and shortened the period from re-planting to flowering after common storage conditions.

ACKNOWLEDGMENTS

The authors wish to thank the *Rashi Foundation*, The Israeli Ministry of Science, Culture and Sport and The Katif Research Center for Development of Coastal Deserts for partial support in this project.

REFERENCES

1. Baker J. T., Allen L. H., Boote K. J., Jones P. and Jones J. W. (1989) Response of soybeans to air temperature and carbon dioxide concentration, *Crop Sci.* **29**, 98–105.
2. Baker J. T., Allen L. H., Boote K. J., Jones P. and Jones J. W. (1990) Rice photosynthesis and evapotranspiration in subambient, ambient and superambient carbon dioxide concentrations. *Agron. J.* **82**, 834–840.
3. Bose T. K., Jana B. K. and Mukhopadhyay T. P. (1981) A note on the effect of day length on growth and flowering in *Hippeastrum*. *Indian J. Hortic.* **38**, 110–112.
4. Bowes G. (1991) Growth at elevated CO₂: photosynthesis responses mediated through rubisco. *Plant cell environ.* **14**, 795–806.
5. Brewster J. L. (1990) Physiology of crop growth and bulbing. Pages 53–81 in Rabinowich H. D. and Brewster J. L. (eds) *Onions and allied crops. Volume 1: Botany, Physiology and Genetics*. CRC Press, Boca Raton, Florida.
6. Clough J. M., Peet M. M. and Kramer P. J. (1981) Effects of high atmospheric CO₂ and sink size on rates of photosynthesis of a soybean cultivar. *Plant Physiol.* **67**, 1007–1010.
7. Cure J. D. and Acock B. (1986) Crop responses to carbon dioxide doubling: a literature survey. *Agric For. Meteor.* **38**, 127–145.
8. Daymond A. J., Wheeler T. R., Hadley P., Ellis R. H. and Morison J. I. L. (1997) The growth, development and yield of onion (*Allium cepa* L.) in response to temperature and CO₂. *J. Hort. Sci.* **72**, 135–145.
9. Ephrath J. E. and Hesketh J. D. (1991) The effect of drought stress on leaf elongation and transpiration rates in maize (*Zea mays* L.) leaves. *Photosynthetica* **25**, 607–619.
10. Hong Y. P. (1970) The effects of temperature treatments on flowering and growth in amaryllis *Hippeastrum hybridum*. *Sci. Hort.* **13**, 57–63.
11. Idso S. B., Kimball B. A., Anderson M. G. and Mauney J. R. (1987) Effects of atmospheric CO₂ enrichment on plant growth: the interactive role of air temperature. *Agriculture, Ecosystems and Environment* **20**, 1–10.
12. Ijiro Y. and Ogata R. (1997) Effect of ambient temperature on the growth and

- development of amaryllis (*Hippeastrum hybridum* hort.) bulbs. *J. Jap. Soc. Hort. Sci.* **66**, 575–579.
13. Kimball B.A. (1983) Carbon dioxide and agricultural yield: an assemblage and analysis of 430 prior observations. *Agron. J.* **75**, 779–788.
 14. Long S.P. (1991) Modification of response of photosynthetic productivity to rising temperature by atmospheric CO₂ concentrations: has its importance been underestimated? *Plant Cell Environ.* **14**, 729–739.
 15. Mitchell R. A., Mitchell V. J., Driscoll S. P., Franklin J. and Lawlor D. W. (1993) Effects of increased CO₂ concentration and temperature on growth and yield of winter wheat at two levels of nitrogen application. *Plant Cell Environ.* **16**, 521–529.
 16. Morison J.I.L. and Gilfford R.M. (1984) Plant growth and water use with limited water supply in high CO₂ concentrations. I. Leaf area, water use and transpiration. *Australian Journal of Plant Physiology.* **11**, 361–374.
 17. Rees A.R. (1985) Hippeastrum Pages 294–286 in A.H. Halevi (ed). *Handbook of Flowering*. CRC Press, Boca Raton, Florida.
 18. Wheeler T.R., Morison J.I.L., Ellis R.H. and Hadley P. (1994) The effects of CO₂, temperature and their interaction on the growth and yield of carrot (*Daucus carota* L.). *Plant Cell Environ.* **17**, 1275–1284.
 19. Wheeler T.R., Ellis R.H., Hadley P. and Morison J.I.L. (1995) Effects of CO₂, temperature and their interaction on the growth, development and yield of cauliflower (*Brassica oleracea* L. *botrytis*). *Scientia Horticulturae.* **60**, 181–197.
 20. Wheeler T.R., Batis G.R., Ellis R. H., Morison J.I.L. and Hadley P. (1996) The growth and yield of winter wheat (*Triticum aestivum*) crops in response to CO₂ and temperature. *Journal of Agricultural Science.* **127**, 37–48.