The Cultivation of Ornamental Plants in a Hydrosolaric System[1]

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The cultivation of a wide range of ornamental plants in a closed hydrosolaric greenhouse was studied. The hydrosolaric greenhouse was composed of a solar energy harvesting system and a hydroponic system. Energy collected by the greenhouse air from the sun during the day was conserved in the growth solution, which released it during the night. This system was able to maintain the air temperature 6°C above the outdoor temperature during the night. Relative humidity ranged between 85 and 100%, thus providing a favorable environment for tropical foliage plants. *Philodendron bipinnatifidum* Schott, *Gardenia jasminoides* Ellis, *Ficus benjamina* L., *F. lyrata* Warb., *Anthurium andreanum* Lind and *Brassaia actinophylla* Endl. produced under this system were of excellent quality.


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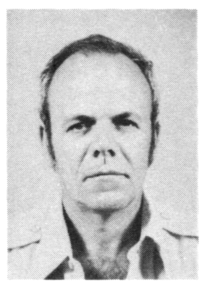
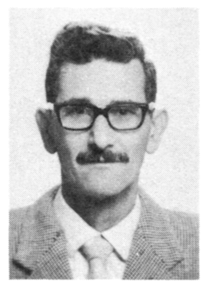

A. Hagiladi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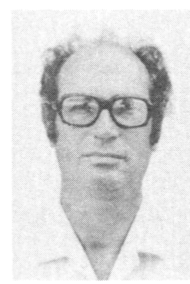
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Cultivation of foliage plants in heated greenhouses is becoming increasingly expensive, even in the warm Israeli climate. Thus, cultivation of foliage and other ornamental plants in a hydrosolaric greenhouse was investigated as a possible solution to escalating energy costs.

As the name hydrosolaric ("*hydro*" from hydroponics, and "*solaric*" from solar energy) implies, 2 principles were involved in the operation of this closed greenhouse system: first, using solar energy harvested during the day to heat the greenhouse during the night; and second, growing plants hydroponically.

The system

The hyrosolaric system was developed 1) as an environmental control system that uses the sun's energy as a heat source. The system is based on energy exchange between air in the greenhouse and the growth solution stored in a reservoir. The air is forced through a water spray to obtain efficient heat exchange between air and water. During the day, excess greenhouse heat is transferred from the air to the growth solution, while at night greenhouse air is heated by the warm solution.

In this work, the suitability of the hydrosolaric environment for a wide range of ornamental plants was tested, while the cultivation of those plants in a conventional greenhouse was used as a control.

The hydrosolaric system was built as a closed quonset-form greenhouse, covered with a double layer of polyethylene, 3 m wide, 4 m high and 20 m long (Fig 1, 2, 3). In order to adjust the environment for cultivation of houseplants, the entire greenhouse structure was shaded to reduce light intensity by 50% (meaning, maximum 50,000 Lux at 12 AM on a sunny January day). The greenhouse floor was dug out to a depth of 80 cm and walls were supported by cement blocks. The entire area (floor and walls) was lined with black polyethylene (0.2 mm thick). The pond created was filled with 38 m^3 of growth solution. The water surface was covered with Styrofoam boards (10 cm thick)


Fig. 1. General view of a hydrosolaric greenhouse.

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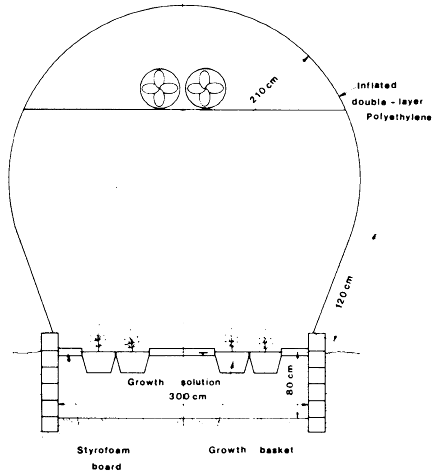

Fig. 2. Cross-section of a hydrosolaric greenhouse.

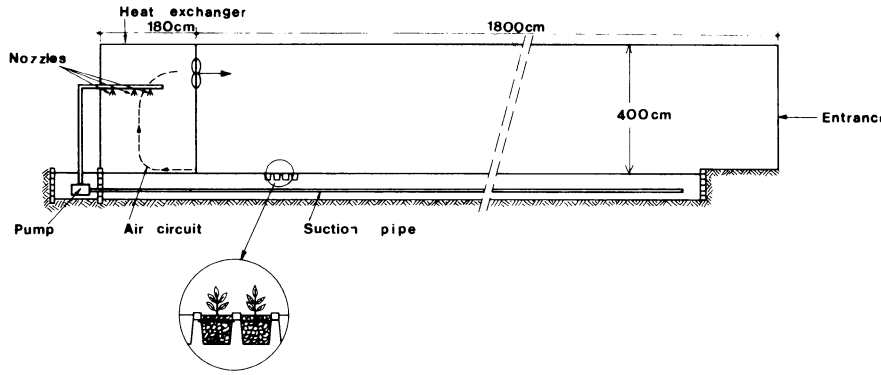

Fig. 3. Longitudinal cross-section of a hydrosolaric greenhouse and heat exchanger.

which floated on the water. Plastic baskets (48 × 28 × 17 cm deep) filled with coarse volcanic gravel (tuff) were placed in holes cut through the Styrofoam board. The floating Styrofoam board served as a path for walking between plants, as well as a floating raft which supported the baskets and kept the water level 3 cm below the upper surface of the tuff (Fig. 1, 2, 3).

The heat exchange unit was placed at the northern end of the greenhouse. In order to increase surface exposure of the solution, it was pumped and forced through nozzles, located at the upper end of the heat exchange unit. Ventilators on the wall, between the heat exchange unit and growing area, created an air circuit through the waterfall. As a result, 2 closed circuits were formed in the greenhouse: 1) the growth solution circuit with the solution being pumped from the southern end of the pond, dispersed through the heat exchange unit and back to the pond; and 2) the air circuit, with movement of greenhouse air through the heat exchange unit back to the greenhouse.

The close contact between the growth solution and the air moderated the greenhouse air temperature; cooling it during the day and heating it at night. The only source of heat in the hydrosolaric system was the natural sun energy. The daily amount of heat accumulated in the greenhouse was dependent on the amount of solar energy radiated into the greenhouse, on outdoor temperature, and on wind velocity—all natural, variable and uncontrollable factors. To obtain optimal environment in the greenhouse at each given set of these natural, outdoor conditions, it was necessary to distribute, wisely, the daily available energy accumulated in the greenhouse, between the air (by day and night) and the growth solution. The control of a proper distribution was achieved by the use of two thermostats: one determining the day temperature above which the pumps started to operate, thus transferring the excess heat from the air to the solution; and the other determining the night temperature below which the pump started to operate, thus transferring heat from the warm solution to the cold greenhouse air. When heat energy was limited (on cold nights and cool, cloudy days), the thermostats were set for maximum 22°C and minimum 12°, whereas when heat energy was not limited (on sunny warm days and warm nights), the thermostats were set for maximum 25° and minimum 18°. Setting the thermostats at too low values (22° and 12°) after hot days and nights caused overheating of the growth solution and thus reduced the oxygen level in it. On the other hand, setting the thermostats at too high values (25° and 18°), on a cloudy, cool day, and cold night exhausted the heat supply early in the night, leaving the rest of the night without any heating. On extremely hot days, a ventilating window was opened at the northern upper part of the heat exchanger, which was used as a fan and pad cooling system. Examples of the ability of the system to heat and cool the greenhouse are presented in Fig. 4 and summarized in Table 1. The hydrosolaric system maintained air temperatures of 10.5-32°, high relative humidity that dropped below 100% for only 4 hr during mid-day, and growth

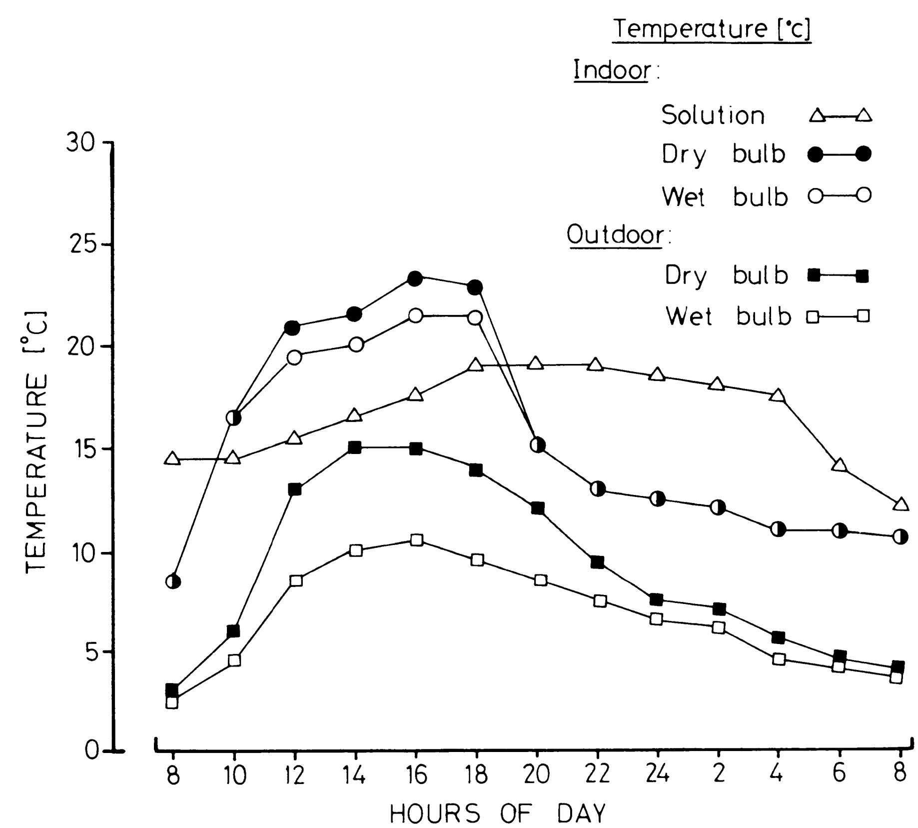

Fig. 4. Temperature fluctuations in the hydrosolaric greenhouse during a sunny, cool day and a very cold night (winter).

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solution temperatures of 13-25°.

The growth solution was prepared from 0.15% "Hydroponical-Nutricol" (courtesy of Y. Yagil, Fertilizers and Chemicals Ltd., Haifa, Israel) which was composed of 3.7% N (0.7% as NH_4 and 3% as NO_3), 1% P, 6.4% K and 6% "Koratin" (a microelements fertilizer containing 0.28% Fe, 0.42% Mn, 0.03% Cu, 0.12% Zn, 0.02% Mo and 0.21% B). The growth medium was tested periodically for pH, E.C., and NPK, and adjustments were made by the addition of nutricol, H_2SO_4 or KOH (Fig. 5). It was relatively easy to maintain the pH at about 6.3 and the conductivity at about 1.5 mmhos/cm. The large ratio of 630 liters growth solution per 1 m^2 of growth area assured the high buffer capacity of the growth solution, and the low need for its adjustment compared with nutrient film technique (NFT) and other hydroponics systems.

The hydrosolaric greenhouse was completely closed all winter, which permitted the introduction of CO_2. A level of 1000 ppm CO_2 was maintained constantly in the greenhouse.

The control plants were grown in a conventional glass-covered heated greenhours, with a minimum temperature of 12°C; the greenhouse was ventilated when the temperature reached 27°C. The relative humidity in it was 10-20% above the ambient. Light intensity was maintained at the same level as in the hydrosolaric greenhouse. The conventional greenhouse was not enriched with CO_2. The control plants were grown in a 2:1 tuff:peat medium in 5-liter plastic pots, and fertilized with the same growth solution used in the hydrosolaric system.

Plant production

A broad range of plant material was examined for its suitability for the hydrosolaric system. A list of plants is given in Table 2. Some of the plants were taken from hydroponic growth conditions and some from solid growth media (Table 2). In the latter group, root systems were washed free of any adhering solids before planting. Planting was done in January 1979 in a random fashion, with eight replications of each species. The experiment was terminated in July 1979.

Relative growth of shoots was graded on a scale of 0–5, where 0 = a dead plant, 1 = poorly growing plant, and 5 = plant with excellent growth. The root system was evaluated as to the degree of its penetration into the volcanic ash (tuff) medium and into the pond, on a scale of 0 (no roots) to 5 (excellent root system growing deep into the pond).

In this survey of the suitability of ornamental plants for a hydrosolaric environment (Table 2), plants can be divided into 3 categories: 1)

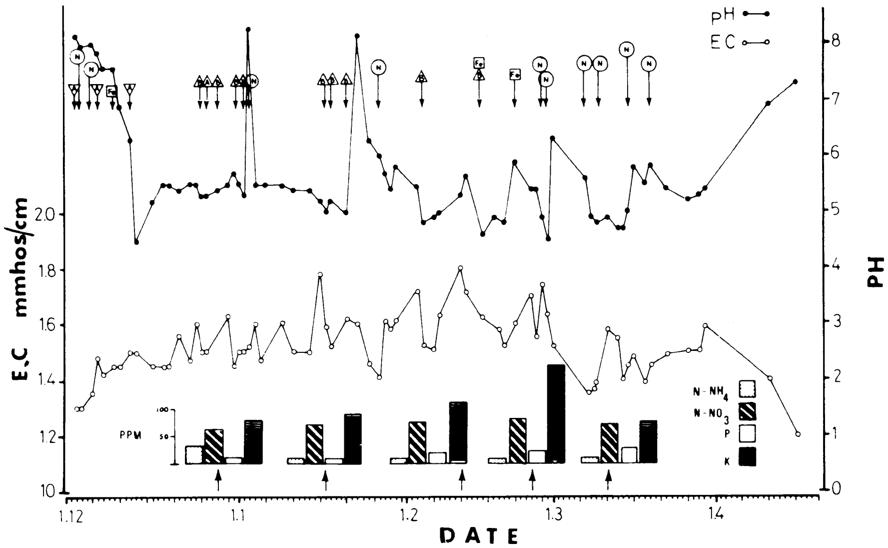

Fig. 5. Chemical composition of the growth solution. Changes in pH, E.C. and NPK as affected by time and chemicals added (N = nutricol; A = acid, H_2SO_4; B = base, KOH; Fe = iron chelate).

Table 1. Temperature and relative humidity (RH) in the hydrosolaric greenhouse during a cold-winter (upper) and hot-spring (lower) day.

Outdoor		Indoor		
Air		Solution	Air	
Temp (°C)	RH (%)	temp (°C)	temp (°C)	RH (%)
2.5–15.0	52	13–18	10.5–23.0	81–100
19.4–38.1	45	18–25	17.8–32.5	76–100

Table 2. Relative response of plants grown in a hydrosolaric (HS) system and in a conventional greenhouse (CG).

Species	Previous medium[x]	Shoot development[y] HS	Shoot development[y] CG	Root development[z] HS
Plants responding well in HS				
Philodendron bipinnatifidum Schott.	H	5.0	2.5	5.0
Gardenia jasminoides Ellis	S	4.5	2.7	4.0
Ficus benjamina L.	H	5.0	4.5	4.0
F. lyrata Warb.	S	4.5	2.0	4.0
Anthurium andraeanum **Lind.**	H	4.0	2.5	1.0
Brassaia actinophylla **Endl.**	H	4.0	2.5	5.0
Plants with no clear response in HS				
Kalanchoe blossfeldiana **Poelln.**	H	3.5	3.0	1.0
Codiaeum variegatum **L.**	S	2.5	2.5	1.0
Strelitzia augusta Thunb.	S	3.0	3.0	3.0
Dracaena draco L.	S	3.0	3.0	3.0
Xylosma salzmannii Eichl.	S	3.0	4.7	4.0
Nephrolepis cordifolia Cau.	S	2.7	4.5	2.0
Aspidistra elatior Blume	S	3.5	3.0	2.0
Chamaerops humilis L.	S	2.6	1.2	3.0
Sabal palmetto Lodd.	S	3.0	1.2	2.0
Rhododendron simsii Planch.	S	1.0	2.0	1.0
Cereus sp.	S	3.0	3.0	1.0
Euonymus japonicus L.	S	2.0	3.0	1.0
Bougainvillea spectabilis Willd.	S	2.5	3.0	5.0
Plants unsuitable for HS				
Ruscus hypoglossum L.	S	2.5	4.7	4.0
R. aculeatus L.	S	2.0	3.0	2.0
Acacia cultriformis A. Cunn.	S	1.0	1.7	1.0
Leucodendron sp.	S	0.0	0.7	0.0
Banksia sp.	S	1.0	0.0	1.0
Eucalyptus sp.	S	1.0	2.0	1.0
Fatshedera sp.	H	0.1	4.3	0.0

[x]Previous medium: S = soil, H = hydroponics.
[y]Shoot development: 0 = dead, 1 = very poor, 2 = poor, 3 = medium, 4 = good, 5 = excellent.
[z]Root development: 0 = no roots, 1 = roots above tuff, 2 = in upper tuff, 3 = whole basket, 4 = emerging out of basket, 5 = deep in pond.

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Those which responded well to the hydrosolaric system; *Philodendron* plants developed very rapidly, with huge dark green leaves, many off-shoots, and a long and spreading root system. *Gardenia* and *Ficus* had difficulties adjusting at first, but subsequently developed very well. *Anthurium* developed excellent growth with many large flowers as compared with the plants growing in a conventional greenhouse. The *Anthurium* root system was concentrated in the upper layer of the tuff, and did not penetrate through the basket. *Brassáia* adjusted very rapidly to the hydrosolaric environment, developed huge leaves and stems with many aerial roots. The root system penetrated through the tuff and into the growth solution. 2) The second group of plants included species which at present have not been shown to benefit from the hydrosolaric system. Especially interesting in this group was the growth habit of *Kalanchoe,* since shoots developed very well, with almost no root system. 3) The third group consisted of plants which failed to grow in the hydrosolaric system.

Plants that had been growing under hydroponics, adjusted immediately to the system and continued their normal growth (except for *Fatshedera lizei*), while plants that had been growing previously in soil took time to adjust; in many of them the old roots died and new ones formed. There was no difficulty involved in transplanting plants from the hydrosolaric system to conventional, soil media and greenhouse conditions.

Conclusion

The hydrosolaric system is a closed growth system which permits CO_2 enrichment of the greenhouse air and maintains a very high level of humidity and a reasonable growing temperature (without heating) for foliage plants during the Israeli winter.

In addition, the hydroponic growth medium permits the maintenance of an optimal root environment. The system was found to be excellent for growing tropical foliage plants; other species did not show any clear response to the system, and some species failed to grow under these conditions.

It is possible to separate between the 2 components of the hydrosolaric system—hydroponics and solar heating of the greenhouse. Thus, the system can be used just to control the greenhouse air atmosphere (heating, cooling, raising humidity, and maintaining a high CO_2 level), and the plants can be grown in conventional solid media.

The advantages of the hydrosolaric system in the cultivation of some tropical foliage plants are clear: Very rapid production of an excellent quality tropical foliage plant without the need for any heating. The practical use of the system is presently under investigation.

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Guidelines for Measuring and Reporting the Environment for Plant Studies[1]

Growth Chamber Working Group of the American Society for Horticultural Science

Guidelines for measurement and reporting of the environment in plant growth chambers have been developed by research scientists in the United States and Canada and are presented in Table 1 to encourage their use and adoption by horticulturists.

Detailed and complete measurements are needed, because of the large variation in environmental conditions in different laboratories and chambers even though attempts are made to maintain similar control. These differences occur because of variations in the reflectivity of surfaces, size of chambers, direction of air flow, degradation of lamps, carbon dioxide concentration of makeup air, humidity level of makeup air, temperature cycling of chambers and various other reasons.

These guidelines were developed initially by the North Central Regional 101 Growth Chamber Use Committee composed of Agronomists, Horticulturists, Botanists and Engineers from Experiment Stations and government laboratories across the United States and then discussed in detail at a Controlled Environment Working Conference held at Madison, Wisconsin in March, 1979 (3). This workshop was jointly sponsored by the North Central Regional 101 Growth Chamber Use Committee, SE 303 Environment and Plant Structures Committee of the American Society of Agricultural Engineers, the Growth Chamber Working group of the American Society of Horticultural Science and by the Biotron at the University of Wisconsin. The guidelines published here have been revised and edited by the NCR 101 Committee in March, 1980.

These guidelines are an expansion of the guidelines published in HortScience in 1972 (2) and 1977 (1) and encourage more complete and precise reporting of the plant growing environment. These guideline provide recommendations on types of instruments to utilize for measurement, where measurements should be taken, when measurements should be taken, and the format and units that should be utilized in reporting the environment of each study. These guidelines have incorporated SI units to a large extent, but for certain parameters, common usage has dictated recommendations for units that are not in the accepted SI units. It is anticipated that these guidelines will be continually updated as instrumentation is improved and the need for greater environmental precision is demanded by environmental researchers. Scientists are encouraged to utilize the sample paragraph that was published with the 1977 guidelines (1) for reporting the environmental conditions monitored. A listing of useful instruments for making measurements to meet these guidelines can be obtained by writing to the Growth Chamber Working Group, American Society of Horticultural Science, Mt. Vernon, VA, 22121.

The adoption of these guidelines by researchers, and adherence to these suggestions by review editors wherever possible, will significantly improve the quality of environmental research and greatly aid in making comparisons among studies conducted in different laboratories. We strongly urge and encourage our society to adopt these guidelines.

[1]Received for publication July 3, 1980.

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