DOE/R4/10290--T1

10290

FL-80-015

Developing and Demonstrating Low-Energy Climate Control and Production Techniques for Greenhouse-Grown Citrus and Ornamental Crops

A Department of Energy - Appropiate Energy Technology

Small Grant Awarded to the

Lake Co. Board of County Commissioners

Grant Number DEFG 4480R410290

FL-414

William H. Bodnaruk, Jr.

Lake Co. Extension Horticulturist

Project Director

April 1983

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Summary of Report

The aim of this study was to develop and demonstrate low energy climate control and production techniques for greenhouse grown citrus and ornamental crops. Emphasis was placed on design, fuel efficiency and plant response to warm water soil heating systems using solar energy and LP gas. An energy requirement of 28 BTUs output per hour per square foot of bed space will provide soil temperatures of 70°F minimum when air temperatures are maintained at 60°F. Soil heating to 70° increased rooting and growth of 8 foliage plant varieties by 25% to 45% compared to plants grown under 60°F air temperature conditions.

Providing soil heating, however, increased fuel consumption in the central Florida test facilities by 30% in the winters of 1980-81 and 1981-82. Solar tie-in to soil heating systems has the potential of reducing fuel usage. Solar heated water provided 4 hours of soil heating following a good collection day. Decreased in-bed pipe spacing and increased storage capacity should increase the solar percentage to 6 hours.

Project Objective

The objective of this project was to develop and demonstrate low energy climate control and production techniques for greenhouse grown crops. Experimentation centered around the use of warm water soil heating as a means of delivering heat to the immediate plant zone without using excess energy to heat the entire growing area.

Specific objectives included:

1. The soil heating system design.
2. Plant response to soil heating.
3. Fuel use comparisons; conventional vs. soil heating.
4. Mating solar and soil heating systems.

Approach Used to Address Objectives

Central Florida tropical foliage plant nurserymen heat their greenhouses in winter to maintain production for the lucrative mid-winter and spring market. Before the fuel crises of the early and late 1970's, a 70°F minimum night temperature was the standard practice in the Apopka-Lake County, Florida area. Space heating equipment, fired by then cheap liquid propane (LP) or number 2 fuel oil, was widely used to provide supplemental heating because of its low cost and adaptability. By 1978 LP and number 2 fuel prices were surging upward and growers responded by reducing thermostat settings. The current University of Florida minimum temperature recommendation for tropical foliage plant production is 65° but a 1980 survey indicated 72% of central Florida growers responding maintained 60°or less. A 60° air temperature from space heating results in soil temperatures in the mid to upper 50's. At temperatures less than 65°F production schedules of many tropical foliage varieties lengthen. Growers report that 3 inch Philodendron can normally be produced in 8 to 9 weeks at 65° to 70°F but 12 to 13 weeks are required at 60°F minimum. Aglaonema 'Silver Queen' tips root within 40 days at 70°F but take twice as long at 60°F. Yet it is no longer economically feasible to heat greenhouses to 70°F. It was under these circumstances that warm water soil heating and solar adaptation were evaluated.

The first field trials were conducted in commerical greenhouses (Greentop Growers and Live Oaks Ranch and Nursery) in January, 1980 to determine response of certain foliage plant cuttings to soil heating. Specifics are outlined in article A in the appendix. Encouraging results led to the development of a test facility in the teaching greenhouse of the Lake Co. Vo-Tech Center. Plant response and initial fuel use trials were conducted there in the winters of 1980-81 and 1981-82. Experimental design, system layout and results are outlined in article B in the appendix. Also in the winter 1981-82 a commerical nurseryman (Thompson's Foliage World) and his engineering consultant, Jim Landrum, permitted the study of their soil heating system. This led to the fine tuning of soil heating energy requirements. DOE grant money and $4000 in grower contributions funded the construction of the Lake County Agricultural Center greenhouses and solar system and provided for the purchase of a Campbell Scientific computerized data logger in 1981-82. Trials conducted in this facility were fuel use comparisons and solar work. All work on this project was coordinated with the Departments of Agricultural Engineering and Ornamental Horticulture, Institute of Food and Agricultural Science (IFAS), University of Florida. Design and results of these trials were incorporated into the overall extension educational program for Lake Co. nurserymen. Demonstrations, tours, seminars, and newsletter articles were used to disseminate information.

Results

Soil Heating System Design

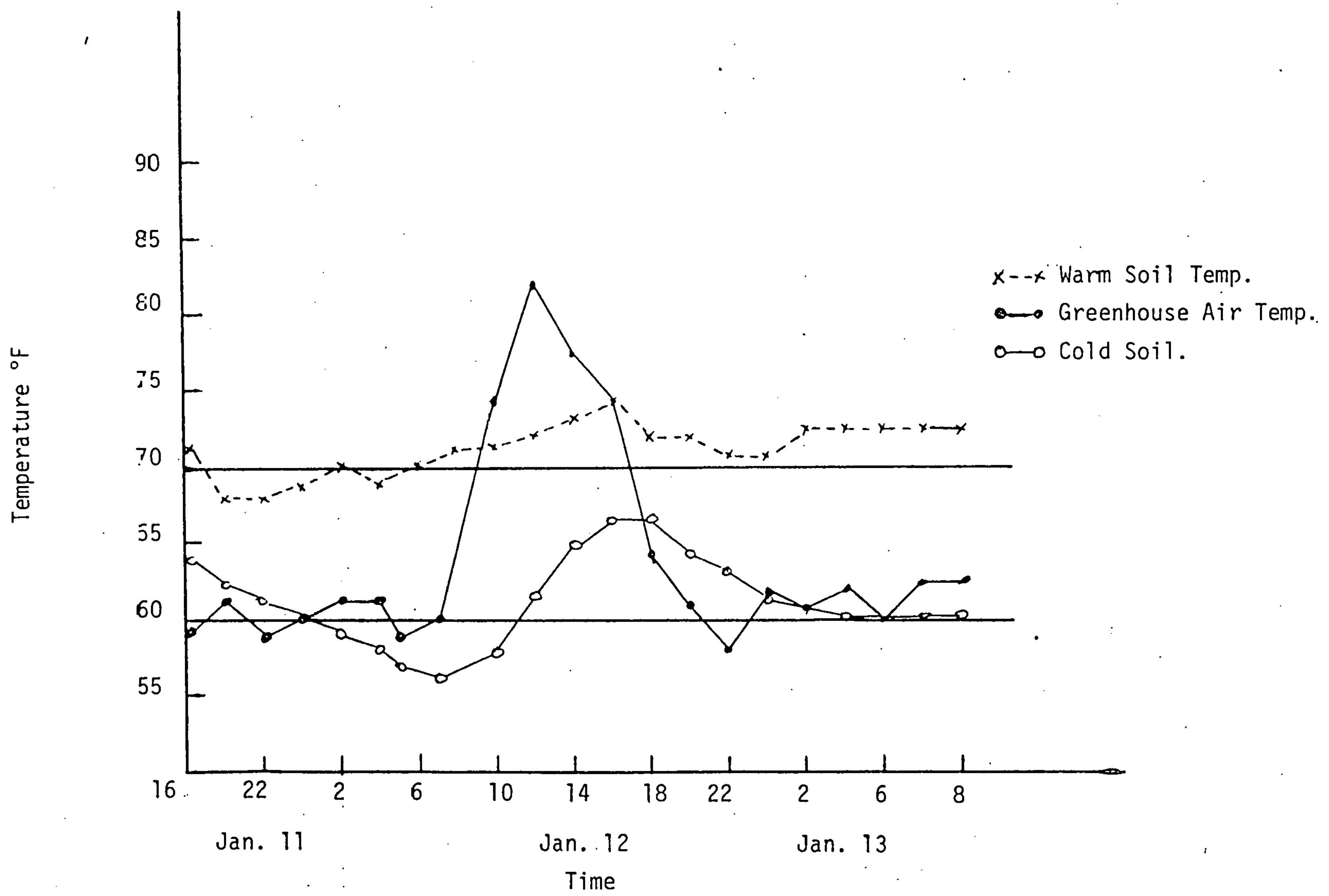
Design options for soil heating systems are reviewed in article C presented in the appendix. A follow-up study was conducted in the winter of 1981-82 at Thompson's Foliage World, Sorrento, Florida, to refine the energy input suggestions which ranged from 22 BTUs/hr to 60 BTUs/hr output. The experimental design was as follows:

1. Desired soil temperature is 70°F minimum. Air temperature is maintained at 60°F.
2. 9000 square feet (ft^2) of bed area was soil heated using a 6.6 hp boiler rated at 315,000 BTUs/hr input netting 252,000 BTUs/hr output.
3. Temperature observations included 4 warm soil temperatures, 4 canopy air temperatures, 2 unheated soil temperatures and 1 outside air temperature. Data was recorded once/hour using an Esterline-Angus multipoint data aquisition system with welded copper-constantan thermocouples.
4. The trial ran from December 23,1981 to January 15, 1982. January 11-13 were freeze nights in central Florida with temperatures reaching 18°F at the nursury location.

The results were; the heating system maintained a soil minimum of 70°F ± 2° with 60°± 5° minimum air temperatures on 2 of the colder nights central Floridans experience (see Energy Requirement for Soil Heating graph). Based on these results the output BTU requirement at these temperature ranges is 28 BTU/hr output per ft^2 of heated bed area. This observation has subsequently been demonstrated in other nursery locations.

Optimum flow rate has not yet been determined in these systems. Data collected in the 1982-83 winter may provide a figure.

Energy Requirement for Soil Heating - January 1982



Plant Response to Soil Heating

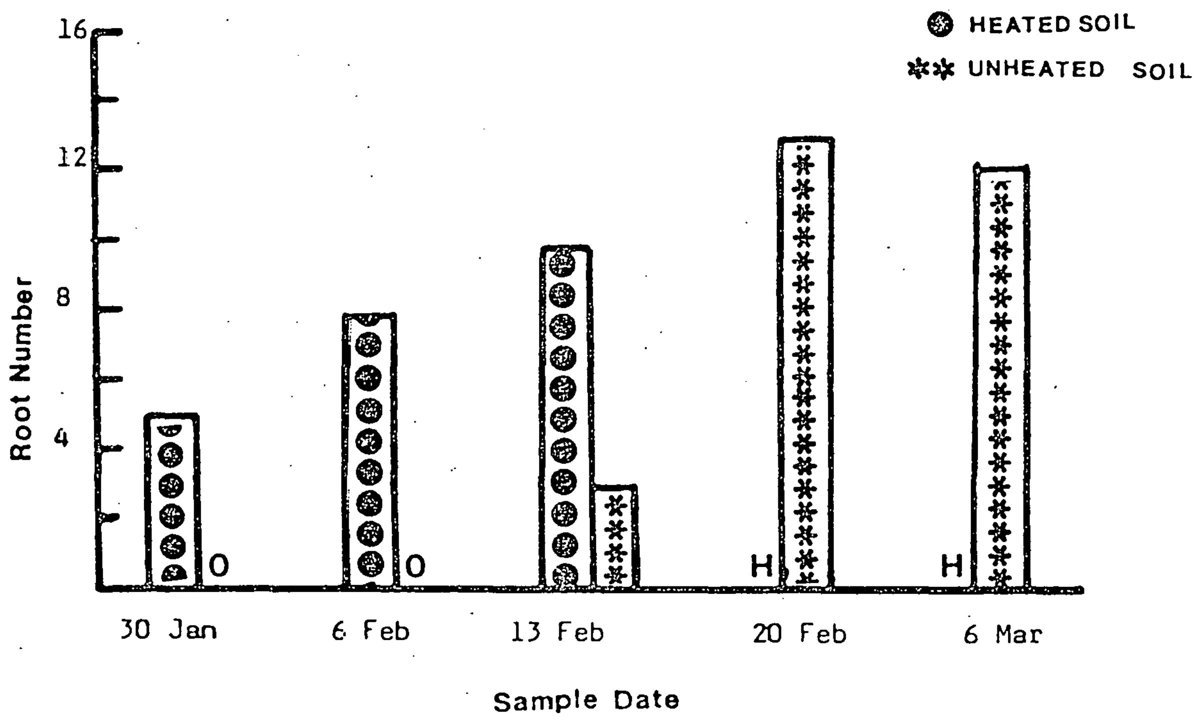
Plant response studies were conducted in 1980-81 and 1981-82. The 1980-81 testing of rooting and growth response of 4 foliage plants, *Dieffenbachia*, *Aglaonema*, pothos and *Philodendron* yielded results suitable for publication in the proceedings of the Florida State Horticultural Society. A reprint of the article is attached (article B). The article describes materials and methods, results and conclusions. The accompanying bar graphs illustrate growth differences. A similar experiment was initiated and carried out in the winter of 1981-82. Unfortunately the experiment could not be completed as planned because of the generally warm winter weather. Minimum air temperatures of 45° and 50°F were rarely obtained inside the greenhouse. However the rooting response of 4 additional foliage plants, *Dracaena sanderana*, *Maranta leuconeura*, *Aglaonema commutatum* and *Cordyline terminalis* 'Baby Doll' was determined. Minimum air temperature was 55° or 60°F and minimum soil temperature, 70°F or variable. The materials and methods were identical to those described in article B. The experiment began on November 25, 1981 and finished on March 5, 1982.

The results were as follows:

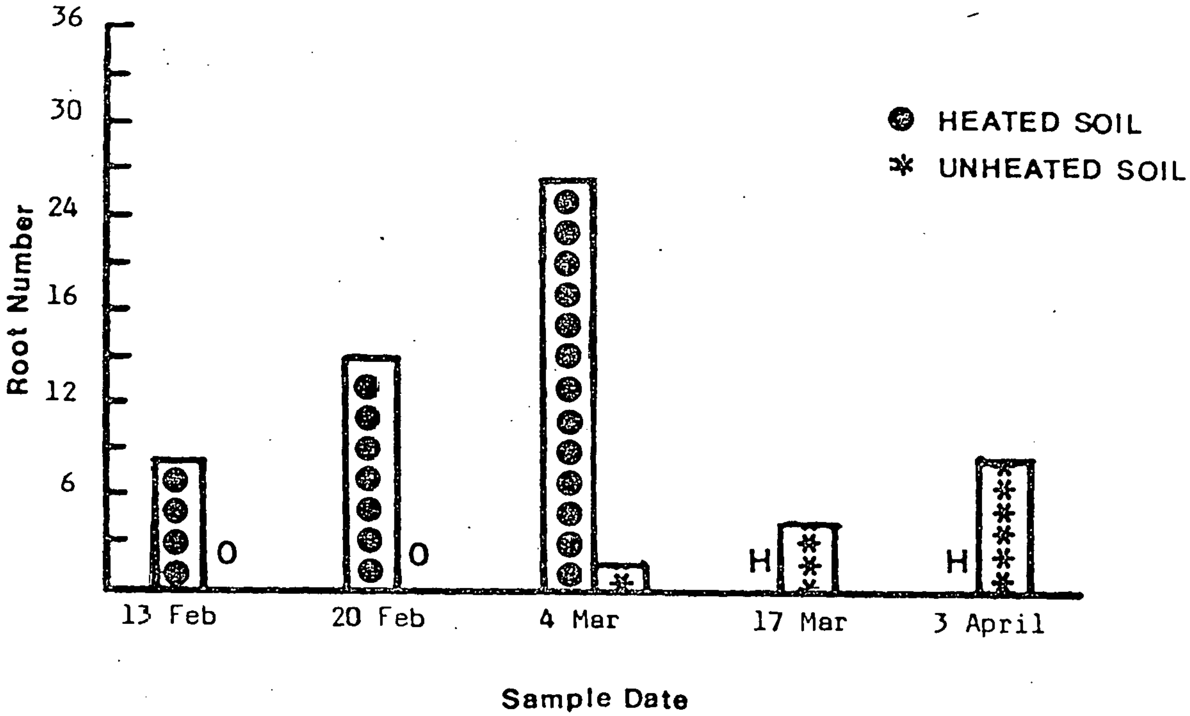
Maranta Root Number

	70°F Min. Soil Temp.		Variable Soil Temp.	
Min. Air Temp.	55°	60°	55°	60°
2 December	0	0	0	0
15 December	4	4.3	2.9	1.5
29 December	9.4	9	5.3	5.5

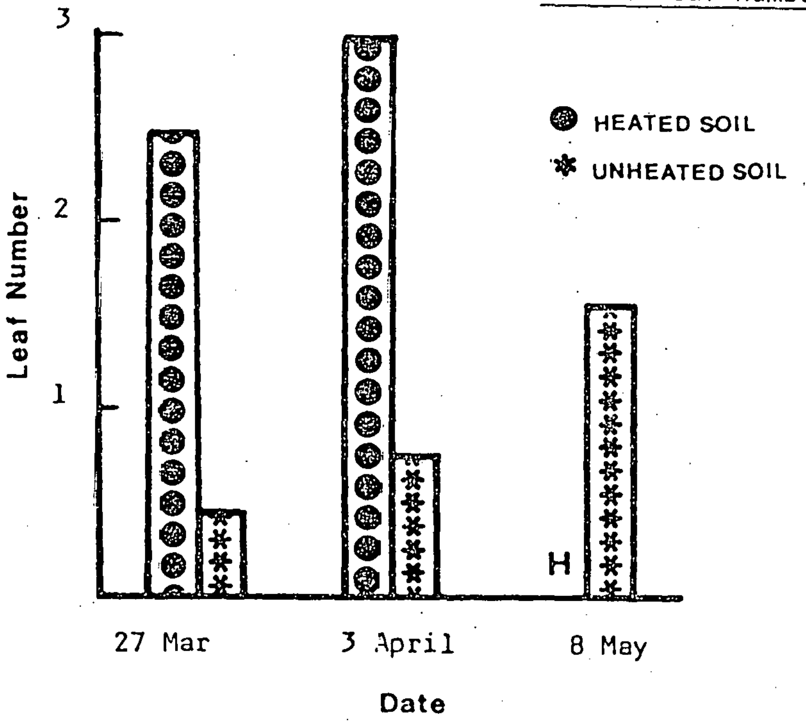
Dieffenbachia Root Number



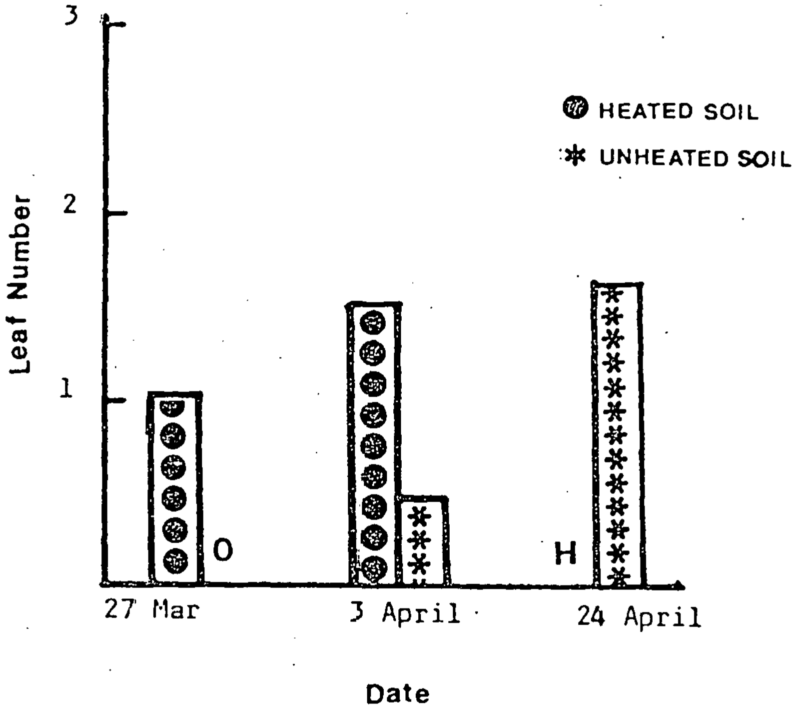
Aglaonema Root Number



Pothos Leaf Number



Philodendron Leaf Number



Maranta Tuber Formation

	70° Min. Soil Temp.	Variable Soil Temp.
% plants with tubers at harvest	5%	47.5%

Dracaena sanderana Root Number

	70°F Min. Soil Temp.		Variable Soil Temp.	
Min. Air Temp.	55°	60°	55°	60°
25 November	0	0	0	0
15 December	12.5	11.3	0	0
29 December	16.4	12.2	8.6	8.4

Aglaonema commutatum Root Number

	70°F Min. Soil Temp.		Variable Soil Temp.	
Min. Air Temp.	55°	60°	55°	60°
10 December	0	0	0	0
5 January	5.3	4	0	0
29 January	9.6	9	4.7	0

Cordyline 'Baby Doll' Root Number

	70° Min. Soil Temp.		Variable Soil Temp.	
Min. Air Temp.	55°	60°	55°	60°
7 January	0	0	0	0
26 January	13.5	15.3	3.4	16.2

Data summary from plant response studies of 1981-82 is as follows: plants growing in 70°F minimum soil broke roots faster and had more roots at the end of the experimental period. Specific root number differences at harvest were Maranta, 42% more roots, Dracaena sanderana, 41% more roots, Aglaonema commutatum, 50% more roots and Cordyline'Baby Doll', 32% more roots in 70°F minimum soil temperatures than variable soil temperatures.

Fuel Use Comparisons

Fuel use comparison trials were conducted in the Lake Co. Agricultural Center greenhouses. The DOE grant and grower contributions funded the construction of 2 identical 1620 ft^2 (36'x45') greenhouses. These quonset style houses were home built from galvanized pipe and lumber in 1981 and 1982. The roof is permanent double polyethylene (UV resistant) and is air inflated for maximum heat retention. The greenhouse sides are covered with shade fabric year-round and wrapped with 6 mil polyethylene in winter to protect against winter cold. The citrus house is hot-air heated using a thermostatically controlled 130,000 BTU/hr LP fired Modine heater. A meter measures the gas consumption of this unit. The ornamental house is space heated using 2 LP fired 105,000 BTU/hr Modine units, each with its own meter monitoring gas consumption and a thermostat. This house contains 6 4x35' beds all outfitted with warm water soil heating pipes. One-half inch PVC PR 160 pipes are spaced on 6" centers in the beds to conduct water. Four of the 6 beds contain soil with pipes buried 3 inches deep. The remaining 2 beds are presently used to test bench applications of soil heating. Warm water is provided by a 127,000 BTU RayPak boiler located outside the ornamental house. Gas consumption of the boiler is also metered. The system works as follows: a remote bulb thermostat measures soil temperature. When the temperature drops below a pre-determined level, 70°F in most cases, a 1/6 hp Bell and

Gossett circulating pump is activated. Water flow closes a flow switch, opening the solenoid in the gas valve and the boiler kicks on. Water temperature is maintained at 110°F. Water enters the bed via mains and risers and flows through the manifold pipework design described in article C. The system is closed, i.e., after leaving the bed, the water returns to the boiler. When soil temperature exceeds the predetermined level, the thermostat opens, shutting down the pump, opening the flow switch which closes the gas solenoid, shutting down the boiler.

A fuel use comparison trial was initiated in 1981 and continued through the winter of 1982. Fuel consumption by the citrus house, i.e., the conventional or control house was compared to fuel use in the ornamental house with space and soil heating. The experimental conditions were as follows:

A. Fuel Use Comparisons Winter 1981-82

The ornamental and citrus greenhouses are identical in size and covering. The heater and metering situation is described above. The ornamental space heaters maintained a minimum air temperature of 50°F. Soil temperature was 70°F minimum. The citrus house was maintained at 65°F minimum air temperature. Soil and air temperatures were monitored using a Campbell Scientific multipoint data acquistion system with copper constantan thermocouples. The trial ran from January 22 to February 23, 1982. In that period 14 nights were 50°F or above, 9 nights 49° or below.

Temperature/Fuel Breakdown

40° or below	Ornamental Usage	Citrus Usage
Jan. 24	11.5	11.5
25	11.5	8.7
26	14.4	14.4
27	11.5	11.5
28	8.7	11.5
Feb. 22	11.5	8.7
Total	69 gallons	66.3 gallons

Fuel use is within 4% when temperatures are 40° or less.

41°-50°F	Ornamental Usage	Citrus Usage
Jan. 29	11.5	5.8
Feb. 11	11.5	5.8
23	11.5	8.7
	34.5 gallons	20.6 gallons

51-60°F	Ornamental Usage	Citrus Usage
Jan. 23	2.8	0
30	5.8	0
Feb. 1	5.8	0
3	2.8	0
	17.2 gallons	0 gallons

61°+F	Ornamental Usage	Citrus Usage
Jan. 22	5.8	0
Feb. 2	2.8	0
4	2.8	2.8
8	2.8	0
15	2.8	0
	17 gallons	2.8 gallons

Total Gas Used- January 22 - February 23, 1982

Citrus House-	65° min. air temperature	112.2 gallons
Ornamental House-	50° min. air temperature 70° min. soil temperature	163.7 gallons

The ornamental house burned 31.4% more gas.

B. Fuel Use Comparisons Winter 1982-83

The experimental methods and greenhouse set-up used were identical to the 1981-82 trial except air temperatures were adjusted as follows:

Citrus house----- 60°F minimum air temperature

Ornamental house- 70° minimum soil temperature
60° minimum air temperature

Temperature/Fuel breakdown

40° or below	Ornamental Usage	Citrus Usage
Jan. 14	14.2	11.5
16	13.4	14.4
17	11.4	8.6
18	14.4	11.5
26	11.4	8.6
Feb. 3	11.4	8.6
	75.8 gallons	63.8 gallons

Fuel use is within 16%.

41-50°F	Ornamental Usage	Citrus Usage
Jan. 19	8.8	5.8
20	8.6	2.9
25	11.6	5.8
27	11.6	5.8
28	8.6	5.8
	49.2 gallons	26.1

50°F+	Ornamental Usage	Citrus Usage
Feb. 1	2.8 gallons	o gallons

Total Gas Usage January 14 - February 3, 1983

Citrus House	60° minimum air temperature	89.9 gallons
Ornamental House	70° minimum soil temperature 60° minimum air temperature	127.8 gallons

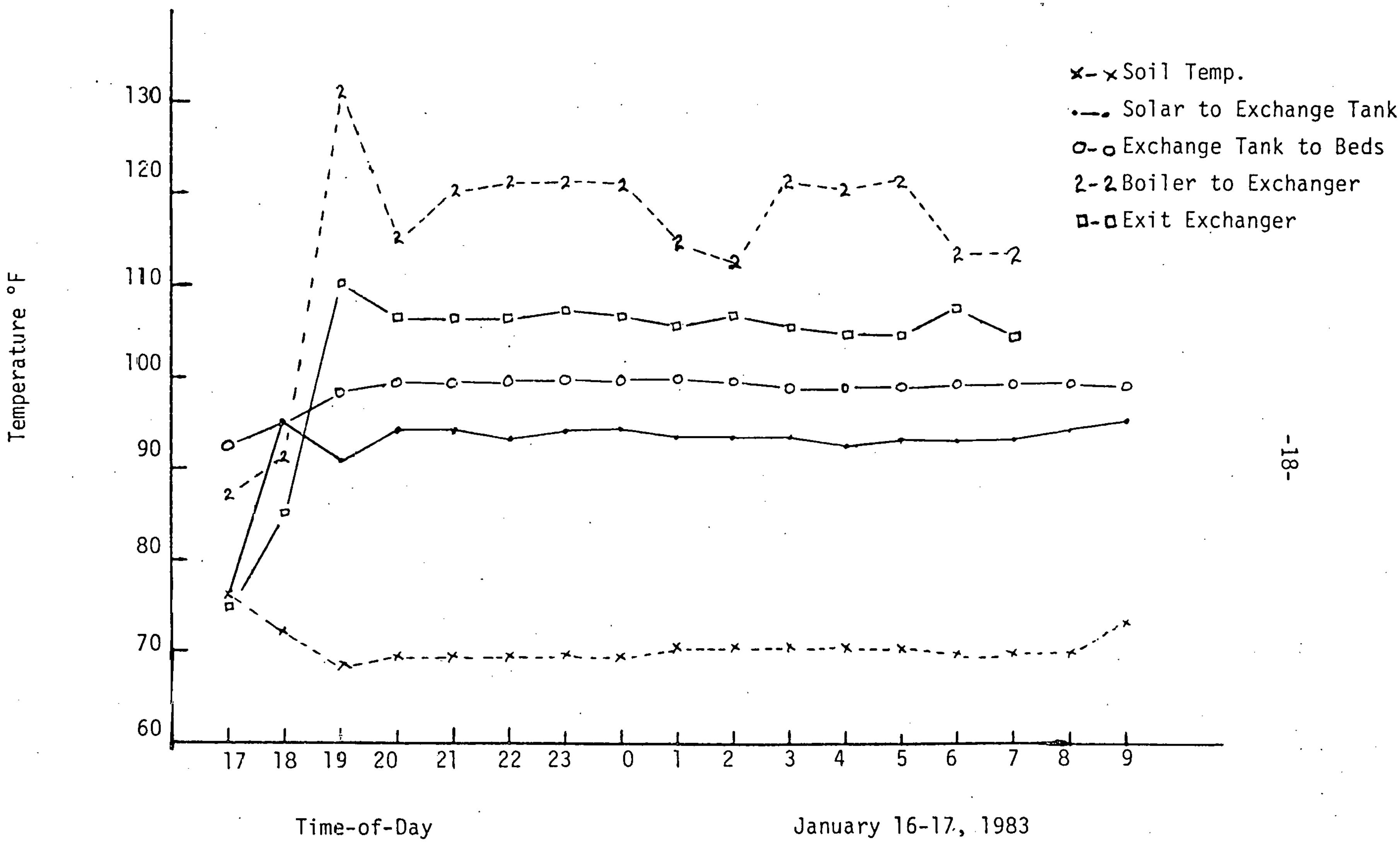
The ornamental house burned 30% more gas to provide the established temperatures

Solar Implementation

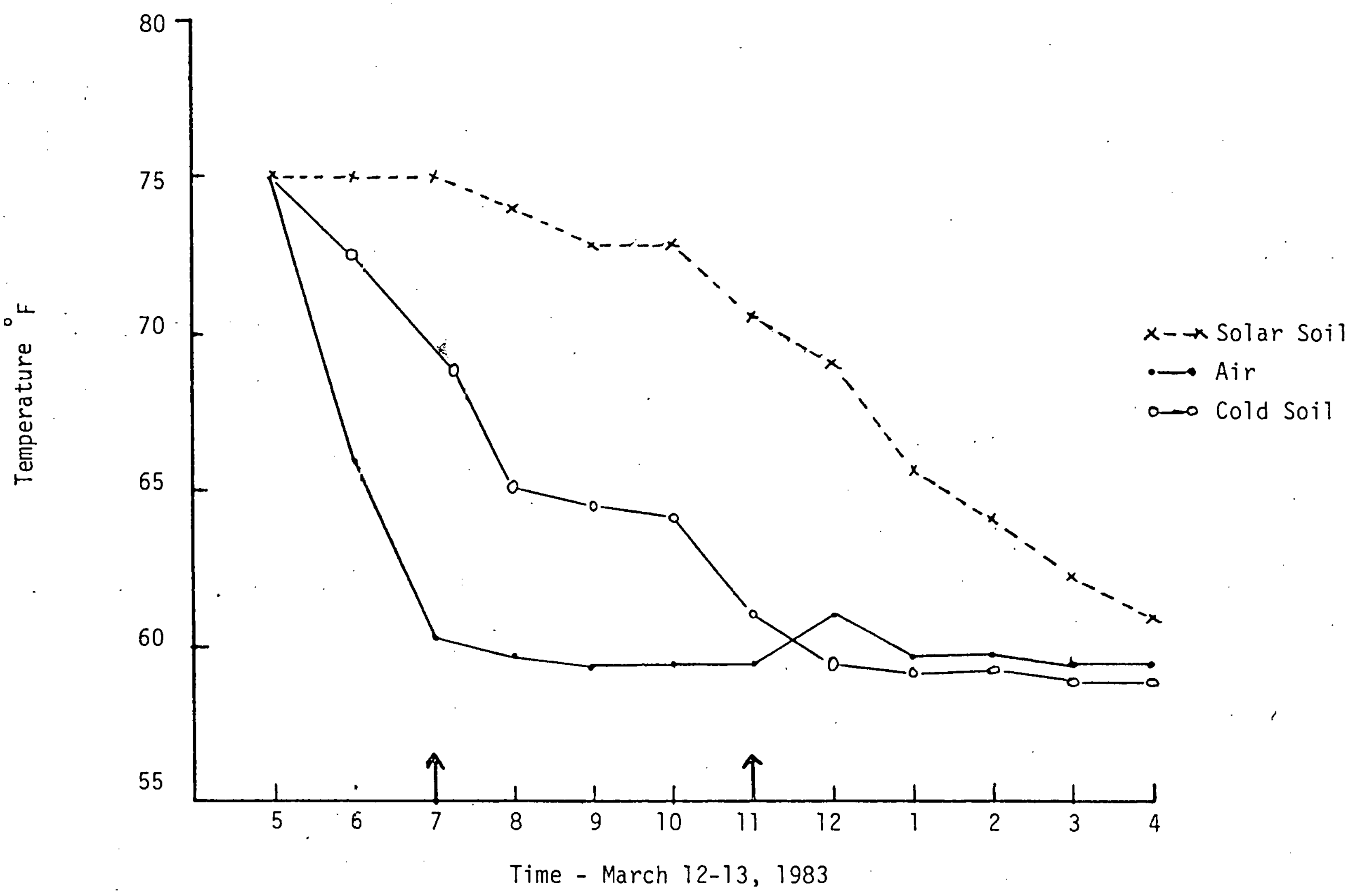
Linking solar to warm water soil heating is the long term objective. Unfortunately direct plumbing and mixing solar and boiler water is not recommended by the boiler manufacturer. Pitting and scaling problems will occur in the boiler heat exchange tubes if raw water is used continually. The focus of the experimentation to date has been to develop and test a heat exchange system that would be effective when solar heating gives out and boiler back-up is required. At this point we are at phase 2 in a 3 phase plan. The system, designed with the assistance of Dr. Direlle Baird, IFAS solar energy specialist, is layed out as follows: the basic bed plumbing and main system described in the previous section remained unchanged. Solar water is heated by the solar collector, a Rutgers Univ. polyethylene collector design (see bibliography for reference).

The collector measures 8'x40', 320 ft^2 of collector surface. Solar heated water is stored in a 900 gallon subterranean tank. A soil thermostat closes at a predetermined soil temperature activating a pump which pumps water to the greenhouse. The solar water enters and exits a 70 gallon heat exchange tank located in the greenhouse and proceeds to and down the beds in the manner described in the previous sections before returning to the 900 gallon storage. When solar is supplying the heating needs, the exchange tank has no function. Now the solar has given out, it can no longer provide soil heating to the desired degree. The boiler plumbing has been modified to input BTUs to the system without mixing raw and boiler water. As the system stands now, when the solar gives out the pump continues to circulate water from storage to the exchange tank, to the beds and back to storage. Inside the exchange tank is 44 feet of 3/4 inch copper tubing. A thermostat sensing soil temperature activates a hot water circulating pump, in turn, activating the boiler. Boiler output water at 130°F circulates through the 44 foot copper heat exchanger in the exchange tank. Cool "solar" water enters the bottom of the exchange tank and exits at the top about 5°F warmer (see Solar/Heat Exchanger Characteristics graph). This rewarmed solar water then circulates through the beds doing the work. The solar system is capable of delivering about 4 hours of soil heat following a good solar day (see Performance of Solar Soil Heating, March 1983 graph). At this point the boiler must come on to satify heating needs for the remainder of the night. Work will continue to increase the efficiency of the solar system. Improvements recommended by the IFAS solar energy experts include a doubling of storage capacity, reduce in-bed pipe spacing to 4 inches and isolation of solar storage when the boiler is activated.

Solar/Heat Exchanger Characteristics



Performance of Solar Soil Heating - March 1983



Conclusions and Recommendations

Warm water soil heating to 70° minimum reduced winter production time for rooted cuttings of 8 common foliage plant varieties by 25% to 45%. This increase in productivity comes at a time when demand for these items is very high, the lucrative winter and spring market. However under central Florida conditions, warm water soil heating to 70°F with air temperatures maintained between 50° and 60°F increased fuel consumption by 30%. Northern researchers report fuel savings of 50% or more using these same types of systems. Data presented in this report support northern contentions. At outdoor temperatures below 40°F, fuel consumption differences between the space heated and soil heated structures differed by only 10%. From an economic standpoint, soil heating makes sense in central Florida. Take Dieffenbachia 3 inch production for example, the cost to provide soil heating adds 8.7¢ per ft^2 to total production and operating costs or 0.1¢ to the production costs of 1 plant (assuming 8 plants per ft^2 and 8.6 turns per year). Increase in production amounts to:

soil heated production	126.1	plants/ft^2/year
conventional production	68.8	plants/ft^2/year
	57.3	plants

57 more plants/ft^2/year selling at \$.37/plant means a potential gross profit of \$21.09/ft^2 netting \$13.12/ft^2

Construction costs to provide a system in central Florida average \$1.40/ft^2. This cost is easily recovered in the first year.

Fuel costs for greenhouse heating in central Florida averaged \$.29/ft^2 of bed and bench area in 1980 (IFAS nursery production and operating costs- see Strain for more information). Providing soil heating adds an additional \$.087/ft^2 totalling \$.377/ft^2. The warm water soil heating designs are ideally suited for solar implementation. Water temperatures generated by inexpensive solar collectors fall in the proper range. With the present system, solar heating contributes about 4 hours or approximately 1/3 of the BTU requirement for an average heating night. With continued refinement, the system should provide 6 to 8 hours of solar heat.

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APPENDIX

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FLORIDA COOPERATIVE EXTENSION SERVICE
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INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES

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(904)343-4101
REPLY TO: P.O. Drawer 357
Tavares, Fla. 32778

November 19, 1980

GREENHOUSE HEATING TOUR, DINNER AND INFORMATION EXCHANGE

Tuesday, December 9, 1980

Soil heating systems make good sense! You increase winter production while cutting energy costs and consumption by putting heat where it does the most good, at the plant level.

Now is the time to consider in-bench and under-bench heating systems. Waiting will only cost you money! This program is set up so you can come or go when you need to. Feel free to attend either, any or all sessions.

Tour Segment

2:15 - Leave the Lake County Agricultural Center at 2:15 PM sharp. Carpool as necessary or find your own way.

3:00-3:45 - Arrive Greentop Growers, Lady Lake - Emory Brown, President. In-bench warm water design for soil heating 5,000 feet of direct stuck foliage.

4:00-4:45 - Arrive Tedder Nursery, Lady Lake - Bobby Tedder, President. Under-bench hot-air design heating 3,000 square feet of Dieffenbachia propagation area.

5:00-5:45 - Arrive Manly's Greenhouses, Leesburg. In-bench and ground warm water designs heating 5,500 square feet of propagating and stock area.

Dinner

6:15-7:15 - Lake County Ag Center, Tavares - $4.50/each Bar-B-Qued Chicken Dinner.

Information Exchange

7:15-9:00 - Lake County Ag Center, Tavares

A. Adapting Space Heaters to Under-bench - How I Did It.

Glen Maguire - Maguire's Nursery, Groveland.

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February 11, 1981

NEW FRONTIERS IN GREENHOUSE HEATING

March 5, 1981

Lake County Agricultural Center & Lake County Area Vo-Tech School

* *

Prolonged cold temperatures and rising fuel prices joined forces this winter and sent heating bills soaring through the double poly. Prospects for stable heating costs next year are virtually nil with the deregulation of fuel and unpredictable weather patterns.

Alternative heating systems, particularly in-bench heating fueled at least in part by solar, offer the potential of significant dollar savings on heating bills. Dr. Direlle Baird, Solar Researcher, University of Florida, will present the keynote program on solar greenhouse heating. This seminar is set up so you can come or go when you need to. Feel free to attend any or all sessions.

* *

OPEN HOUSE: Lake County Area Vo-Tech School, Kurt Street, Eustis

12:00 - 2:00 LAKE COUNTY EXTENSION - VO-TECH - In-Bench Heating Demonstration. Hosted by School of Nursery Operations - Lake County Vo-Tech and Lake County Extension Service.

Review results from in-bench heating experiments - Aglaonema "Silver Queen", Dieffenbachia compacta, Pothos (Golden and Marble Queen), and Philodendron cordatum were grown under 4 air temperatures (45,50,55,60°F) in warm soil (70 to 75°F). Points of interest include:

1. Plant Production
2. Plant Quality
3. System Operation
4. Fuel Usage
5. Temperatures Maintained

This project was funded in part by the Lake County Ornamental Advisory Group.

REFRESHMENTS:

2:30 - 3:00 Refreshments - Lake County Agricultural Center.

Refreshments donated by FLORIDA GROWERS SUPPLY, Apopka.

(over)

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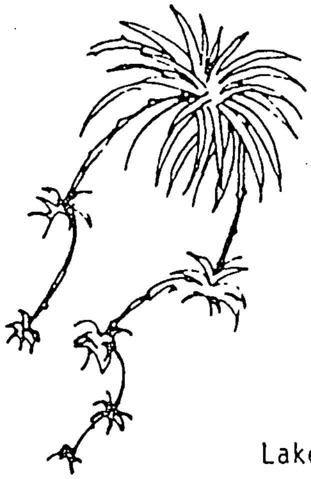
2 February 1982



NEW FRONTIERS IN GREENHOUSE HEATING II

February 25, 1982

Lake County Agricultural Center & Lake County Area Vo-Tech School

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Announcing our second annual New Frontiers in Greenhouse Heating Seminar. How far have we come in a year? Fuel prices certainly have not come down! Winter-time productivity is still the name of the game and growers and University of Florida researchers continue to look for ways to produce more plants using fewer inputs.

Look over the Agenda. The program is open to all and you're welcome to attend any or all sessions, so come at your convenience.

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OPEN HOUSE: Lake County Agricultural Center, Tavares
Lake County Area Vo-Tech School, Kurt Street, Eustis

12:30 - 2:00 LAKE COUNTY EXTENSION - VO-TECH - In-Bench Heating Demonstration.

Hosted by School of Nursery Operations - Lake County Vo-Tech and Lake County Extension Service.

Review results from warm water soil heating experiments - Aglaonema commutatum, Red maranta, Dracaena sanderiana, Cordyline "Baby Doll", and Nephthytis varieties were grown under four air temperatures (45, 50, 55 60°F) in warm soil (70°F). Points of interest include:

1. Plant production.
2. Plant quality.

[over]

9 March 1983

P.O. Drawer 357
Tavares, FL 32778

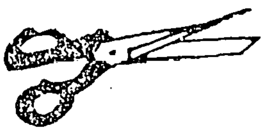
New Frontiers in Heating and Cold Protection III
Central Florida Ornamental Energy Short Course
April 5, 1983 10 AM - 3 PM

Lake Co. Agricultural Center Auditorium
Tavares, Florida

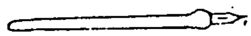
Water, the indispensable element in ornamental production. Plants absolutely require it to carry on essential chemical processes like photosynthesis and respiration. Water pressure maintains plant form. In the business we use it as a carrier for spray materials and fertilizers. Some growers cold protect and even heat with it.

Cold protection and heating ornamentals with water, a fascinating concept. Central Florida ground water averages 70°F. How can this resource be put to use to heat greenhouses and outdoor growing ranges? Where does the water come from in the first place, and how can we use water for cold protection without wasting this precious resource? Growers, industry reps. and University researchers will address these questions and more on April 5th.

This program is open to all interested and is set-up so you can come or go when you need to. Feel free to attend any or all sessions.



(Cut here, fill out form and return mail)



REGISTRATION FORM - Ornamental Energy Short Course

Registration is required. A registration fee is charged to pay for lunch.
Please return mail by Friday, April 1.

Name:______________________________

Firm: ______________________________

Mailing Address:________________________

City:________________ Phone:__________

Number of People @ $5.00 each ____________

Make check payable to Lake Co. Ornamental Advisory Acct.
and mail to: Lake Co. Ornamental Advisory Acct.
c/o Manly's Greenhouses
Rt. 1, Box 255, Leesburg, FL 32748

Greenhouse Energy Programs given at industry meetings by the Projector Director.

Southwest Florida Foliage Short Course
Tampa and Ft. Myers, FLa. April 1981.

Orange County Greenhouse Seminar
Apopka, Fla. June 1981.

Gold Coast Seminar
Ft. Lauderdale, Fla. October 1981.

Florida State Horticultural Society Annual Meeting, November 1981.

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