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# DEMONSTRATION OF AN ADVANCED SOLAR GARDEN WITH A WATER CEILING

Six-Month Technical Progress Report, July 1—December 31, 1979

By
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February 1980

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Ann Arbor, Michigan

MASTER

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Solar Energy

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Six-Month Technical Progress Report

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under

Department of Energy Midwest Appropriate Technology
Grant Number DE-FG02-79R510122-A000

Six-Month Technical Progress Report
1 July 1979 through 31 December 1979

## SUMMARY

This report presents a history of the solar garden with the addition of the transparent water ceiling and gives a statement of the overall goals of the program. It then details the objectives of the water ceiling grant. The rationale of the transparent water ceiling is developed and its implementation in the solar garden is described. The experimental procedures for evaluating the water ceiling as an integral part of an ongoing garden agricultural experiment are discussed. The results of the first six months of the program and the future activities for the next period are presented.

## INTRODUCTION

An existing 6000-ft$^2$ Northern Climate Solar Garden is now in its third year of operation. The solar garden is a commercial demonstration of a relatively new technology where food production growing experiments have been conducted in a low energy environment. It should be stressed that an energy efficient greenhouse design is a most important ingredient in developing this agricultural system. In a free enterprise system where ever increasing energy costs are a dominant factor in overall costs, it is difficult to justify a locally based solar garden that is more energy intensive than competing or existing food delivery systems. If it takes less energy to grow, process, package and transport food from remote locations, then existing systems should prevail. The principal objective of the solar garden program is to demonstrate the technical and economic feasibility of providing locally grown fresh produce in northern climate snow belt states on a year round basis.

The basic advantage of the solar garden is its ability to reduce heating fuel requirements. The present solar garden uses approximately one-sixth the supplemental heat required by a conventional glass or single poly greenhouse. This advantage can not only make a major contribution to commercial viability of greenhouse utilization in northern climates, but can also result in some reduction of national energy demand. At the present time, fuel costs for the vegetable producing greenhouse industry, such as the one existing in Leamington, Ontario, represent about one-third the gross operation costs.

The principles of the Northern Climate Solar Garden and its technical and operational results achieved since its inception are presented in Appendices I & II.

## TRANSPARENT WATER CEILING TECHNICAL DISCUSSION

During this contract period major modifications have been made in the thermal storage system of the low energy greenhouse. A transparent water ceiling has been incorporated into the design that has many desirable features. The water ceiling absorbs infrared energy but allows photosynthetic energy to pass through to the growing environment. It is an inexpensive storage medium that does not take up useful growing space. It has an extensive absorbing and radiating surface that can help to keep the greenhouse cool in the daytime and warm at night. It has also provided a source of warmed water for irrigation of the garden. The water ceiling has the effect of smoothing the temperature variations in the garden which in turn affects the growing rate in the garden.

To implement the transition to commercial use it is necessary to conduct extensive tests to determine the expected growing parameters during actual winter conditions. Items of importance would include measurements of temperature, illumination level, humidity, and ventilation in conjunction with a diverse agricultural growing program.

This project will concentrate on evaluating a water ceiling in the solar garden. The technical improvements brought about by the water ceiling are intended to increase the overall efficiency of the system by providing additional means of storing solar energy in the form of heat. Substantial increases to total thermal storage capacity are provided by an inexpensive system of transparent roof ponds installed just below the reflector-insulator curtains.

The roof ponds have been installed at the inner ceiling of the A-frame structure. This is the level surface that normally supports the pivoted-reflector-insulator in the closed position and is shown in Figure 1. The container system consists of a transparent plastic polyethylene sheet which is physically supported by a net of fencing material. This net is secured to the horizontal roof members of the solar garden. In operation, this transparent plastic container is filled with water to an average depth of two inches. This implementation is shown in Figures 2 and 3.

The thickness or depth of water was chosen as a compromise to fit the requirements and limitations of the greenhouse. These are basically, roof loading capabilities, illumination degradation, and thermal capacity requirements. The objective is to maximize thermal storage capacity without exceeding roof loading limits or reducing input illumination to an amount lower than required for good plant

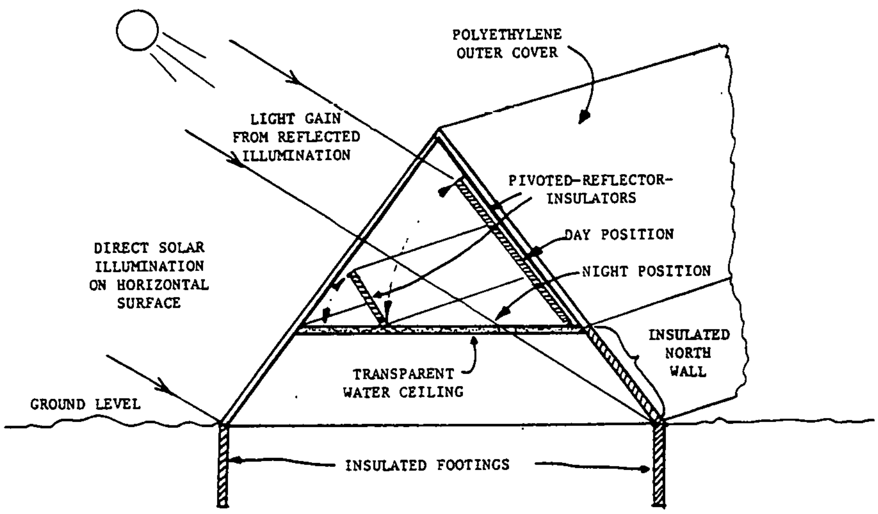


FIGURE 1. Solar Garden Functional Schematic.

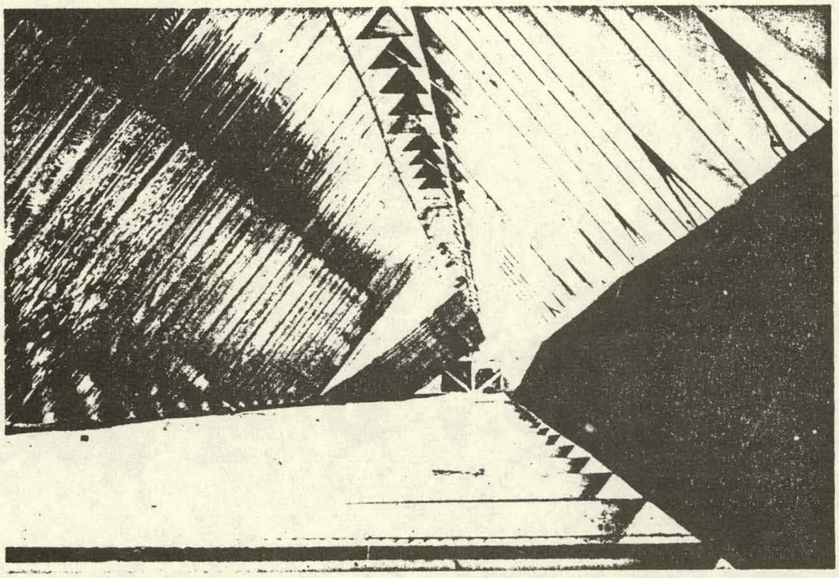

FIGURE 2. Pivoted-Reflector-Insulator and Water Ceiling.

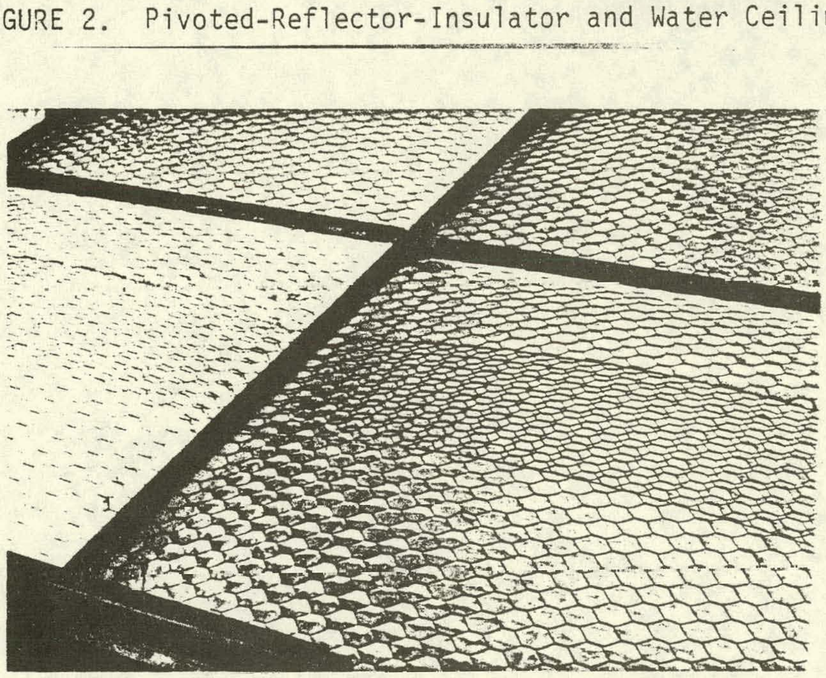

FIGURE 3. Underneath View of Water Ceiling.

growth. In our case, we used roof loading of approximately 10 lbs/ft$^2$ and a 24-hour storage capacity as our design goals. In the graph of Figure 4 the absorption spectrum of two inches of water is superimposed on the solar input. As can be seen, most of the long wavelength IR is absorbed, whereas most of the shorter wavelengths associated with photosynthesis are transmitted through the layer.

The layer of water constitutes the thermal storage medium. Water is highly transparent to visible light passing through it, but absorbs almost all of the infrared portion of the solar spectrum, constituting approximately one-fourth of the total solar energy reaching the earth. The water acts as a filter to transmit that part of solar energy most effective for photosynthesis, but absorbing the radiant energy which is not useful for this purpose. The roof ponds produce minimum interference with the photosynthesis process, but at the same time store excess heat to be released during periods when the solar energy is not available.

It is also possible that additional filter material located in the roof pond would further improve the discrimination of the roof pond between solar radiation in the spectral regions needed for photosynthesis, and solar radiation useful only for heating purposes. One pays the penalty of increased attenuation when filters are added.

During a cold winter 24-hour period, the experimental greenhouse requires approximately $10^6$ BTU's per day to maintain inside temperatures at 62°F. A sunny winter day, the greenhouse receives 6 x $10^6$ BTU's of solar radiation or six times as much energy as needed to maintain this inside temperature. Consequently, adequate thermal storage is an important requirement for the satisfactory operation of the system. The roof pond described above will store $10^6$ BTU's for a 30°F temperature rise in the water. Thus, this section of

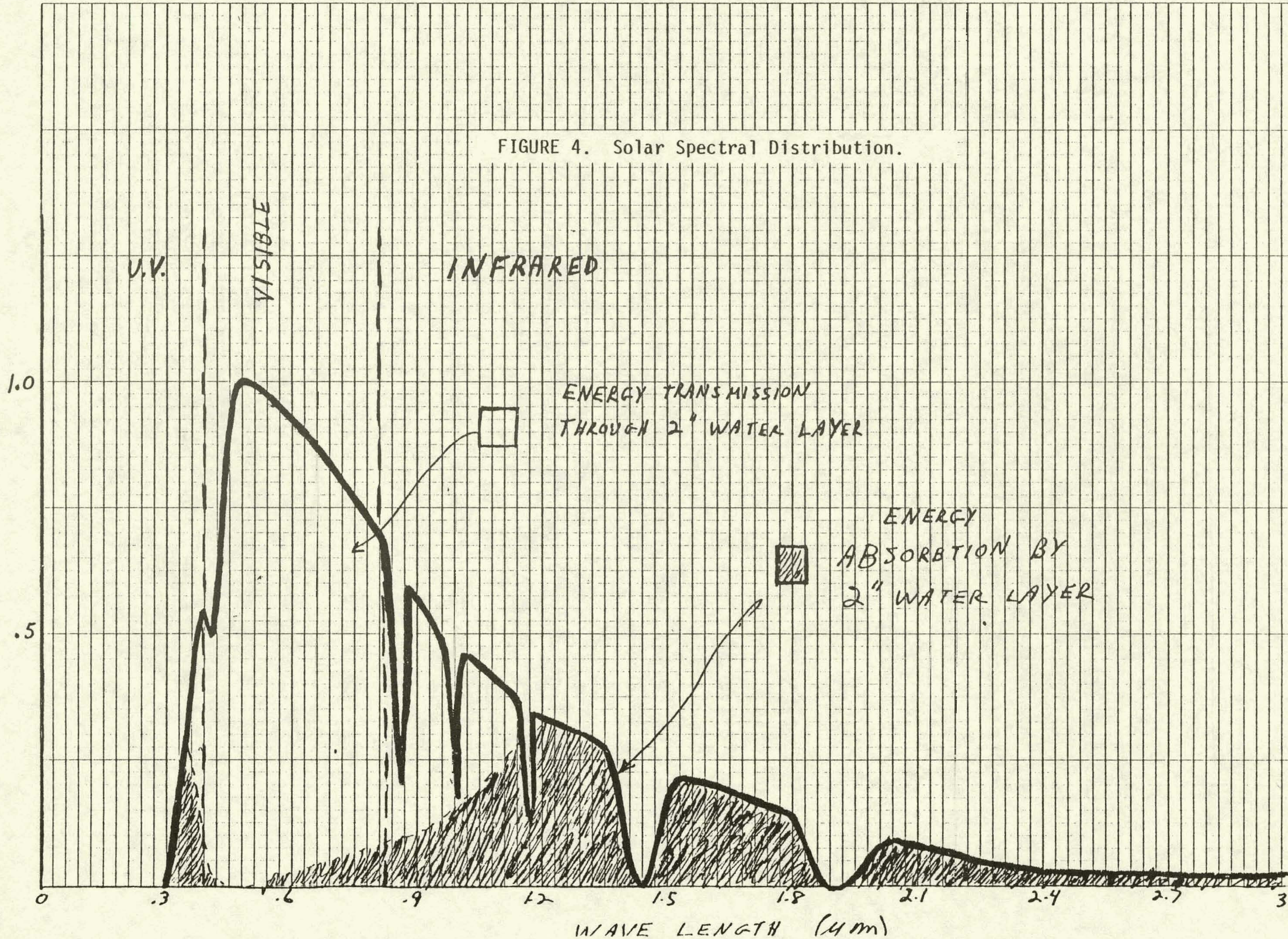


FIGURE 4. Solar Spectral Distribution.

thermal storage could potentially store enough thermal energy to maintain the inside temperature at 62°F for 24 hours.

During periods when thermal energy must be transferred from the water to the soil, this transfer would occur rapidly and effectively because of the high emissivity of water (essentially 1) in the infrared region where such radiation would occur, and because of the large exposed area of water available to radiate heat. As a thermal storage medium roof ponds have advantages over other thermal storage components in the solar garden, such as the water stored in oil drums. The total temperature excursion of the water in the roof ponds is greater than in the oil drums, yielding a greater total storage capacity per pound of water. Furthermore, as mentioned above, heat transfer rates are substantially higher for the water in the roof ponds.

Another mode of using the thermal energy stored in the water is to use the ceiling for warm water irrigation. This not only performs the irrigation function, but provides a rapid method of transferring heat to the soil at substantial depths. Under normal sunny conditions in a well foliated greenhouse, very little of the direct radiation reaches the soil. Solar energy intercepted by plant foliage is blocked from direct transfer to the soil and indirect transfer via radiation must overcome substantial resistance. By contrast, heated irrigation water will sink rapidly into the soil, and will raise the soil temperature directly. The resulting higher temperature will increase the growth rate of the vegetation, as demonstrated by various experimenters with soil warming techniques.

## EXPERIMENTAL PROCEDURE

It is desired to determine what the positive and negative aspects of a transparent water ceiling are. To accomplish this, it is necessary in the experiment design to separate the important variables and have methods available to measure these variables.

The greenhouse was modified so that one-half had water ceiling storage and the other half was open. In addition to this, each of these sections were subdivided so that each had a single glazed and a double glazed portion. There are also provisions for other minor subdivisions within these sections, such as supplemental lighting, roofheated irrigation, and buried pipe heat transfer, but their implementation has not been completed.

The performance of the various sections is measured by crop results and environmental monitors, such as thermometers, light meters and supplemental heat input rates. During this reporting period, a majority of the instrumentation equipment is still in the process of being completed. A 16—channel data logger driven by a microprocessor is in the process of being installed, whereas existing monitors, such as min-max thermometers, remote thermometers and a photographic light meter have been available on an ongoing basis.

The water ceiling was installed September 28 and 30 in the west half of the greenhouse. Six mil plastic supported by chicken wire form the bottom layer; two mil plastic covers the top cutting down on evaporation losses. Well water (hard) was treated with a water softener and a deionizer with expected purification of 50,000 ohms resistance. Immediately after the water was added the cover was installed to avoid contamination.

The fall crops include tomatoes, lettuce and Chinese cabbage. During the first week of August new soil (Michigan peat) was added to the greenhouse and treated with fertilizer according to recommendations and soil analysis via MSU. Seeded mid-June, the tomatoes were planted during the first week of August in double rows running the east-west length of the greenhouse. Five varieties were used: Ball Sweet 100, Small Fry, Super Fantastic, Tropic, and Heinz 1520. The use of five different varieties was not optimal for this experiment but were seeded well before the proposal was accepted in an attempt to find Verticillium resistance. In early October two double rows of Grand Rapids leaf lettuce and one double row of Micheli Chinese cabbage was transplanted to the greenhouse, both seeded July 15. The diagram in Figure 5 explains the plant distribution.

Efforts have been made to eliminate variables within the greenhouse that could affect crop growth and confuse resulting data. Air circulation is provided by three large fans and two furnace blowers. Supplemental heat is provided by two furnaces, one a combination $CO_2$ generator/furnace, placed at either end of the greenhouse and controlled thermostatically. Plants were fertilized with Peters 42-0-11 via the water system, micronutrient seaweed sprays, and initially with soil amendments for phosphorus and pH adjustments. Several variables are daily or seasonal changes day length, solar azimuth, and cloud cover which cannot be changed only expected. We experience some shading in the most northern part of the greenhouse in early fall and late spring when the sun reaches 47° north Zenith approximately between March 21 and September 24, which retards growth and production in that section. Humidity was difficult to control this fall because of (1) the nature of polyethelene covered greenhouses and (2) a burst hose and the resulting partial flooding of the western section. Pests and diseases were controlled biologically on an ongoing experimental basis (success and failures will be noted).

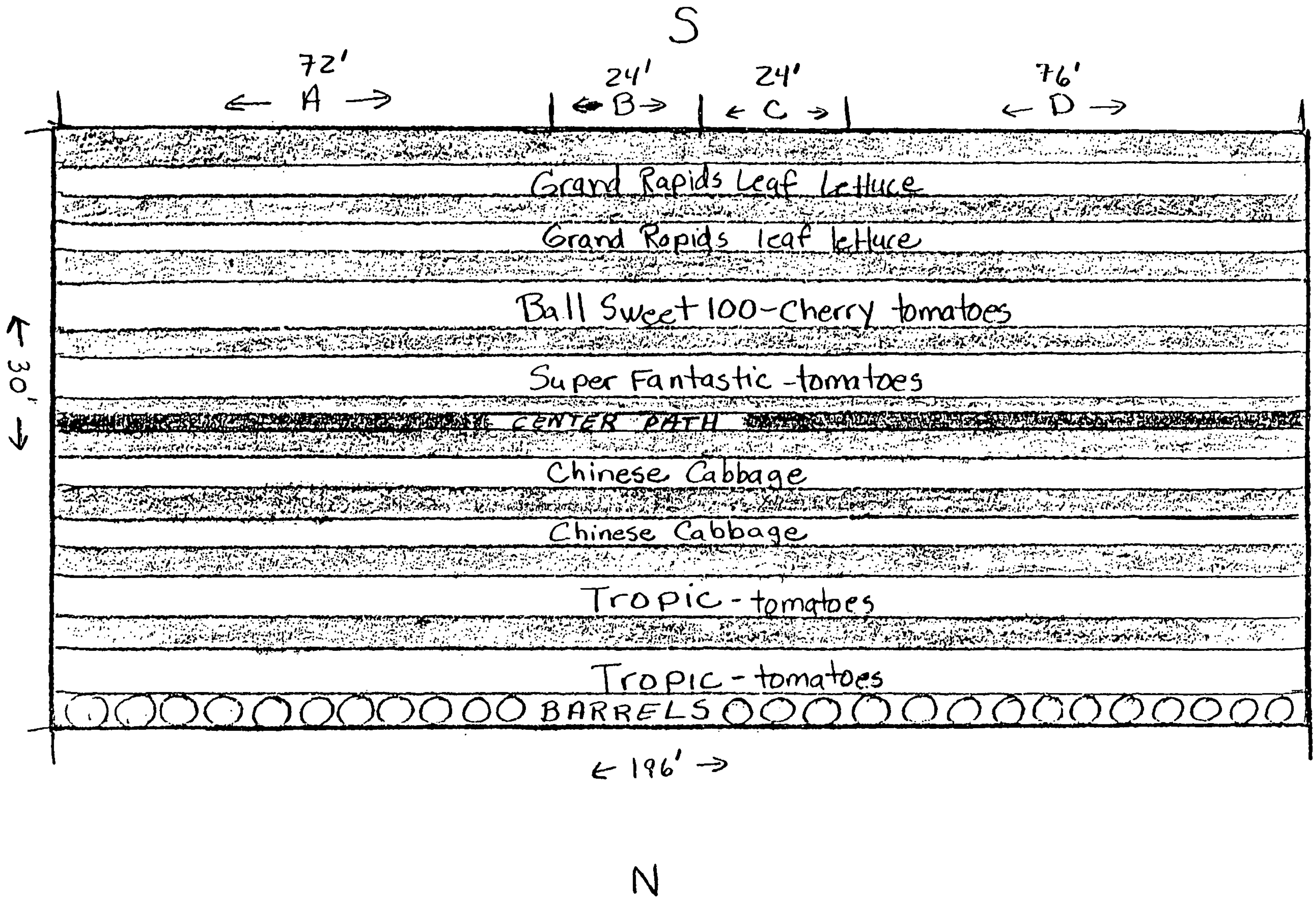


FIGURE 5. Fall Plant Distribution.

Tomato harvests began October 7 and continued through this reporting period. The fruit was weighed per variety per section (i.e., with or without double poly, with or without water ceiling) and recorded. Estimates of fruit damaged by Botrytis scenaria are included. Graphs of weekly harvests are presented in Figures 6, 7, and 8 and Tables 1, 2, and 3 show pounds per plant and pounds per sq ft, number of plants and heights. Lettuce harvest began December 5 and are not included in this report. The Chinese cabbage crop was lost to aphids. Other data collected on a bimonthly basis measured lettuce height, number of clumps of flowers and fruit, number of tomatoes per fruit clump, height of Chinese cabbage and height of a few, scattered cucumbers.

To date results are not conclusive due to several factors; primarily differing soil and moisture conditions throughout the greenhouse. Tomato harvest is still in progress but some trends are noted to date; north side production is lower than south side production, ripening under the water ceiling is delayed by approximately two weeks-one month (it is expected the harvest in section D with water ceiling to be approximately equal to that of section A without water ceiling; section B and C with double poly are nearly the same and are too small to be used for a data base).

Two problematic factors affected fall crop growth and production. Early in the fall, a hose connection burst flooding a sizeable area in the west end of the greenhouse, killing a few plants, damaging others. Those plants were excluded from the data. Plastic greenhouses usually have greater moisture problems than glass - ours proved no exception. The high humidity contributed to the establishment and spread of leaf mold Botrytis scenaria, especially among the tomatoes but also of late affecting the lettuce crop. The humidity was lowered and the disease held in check but crop yields were affected variably throughout the greenhouse.

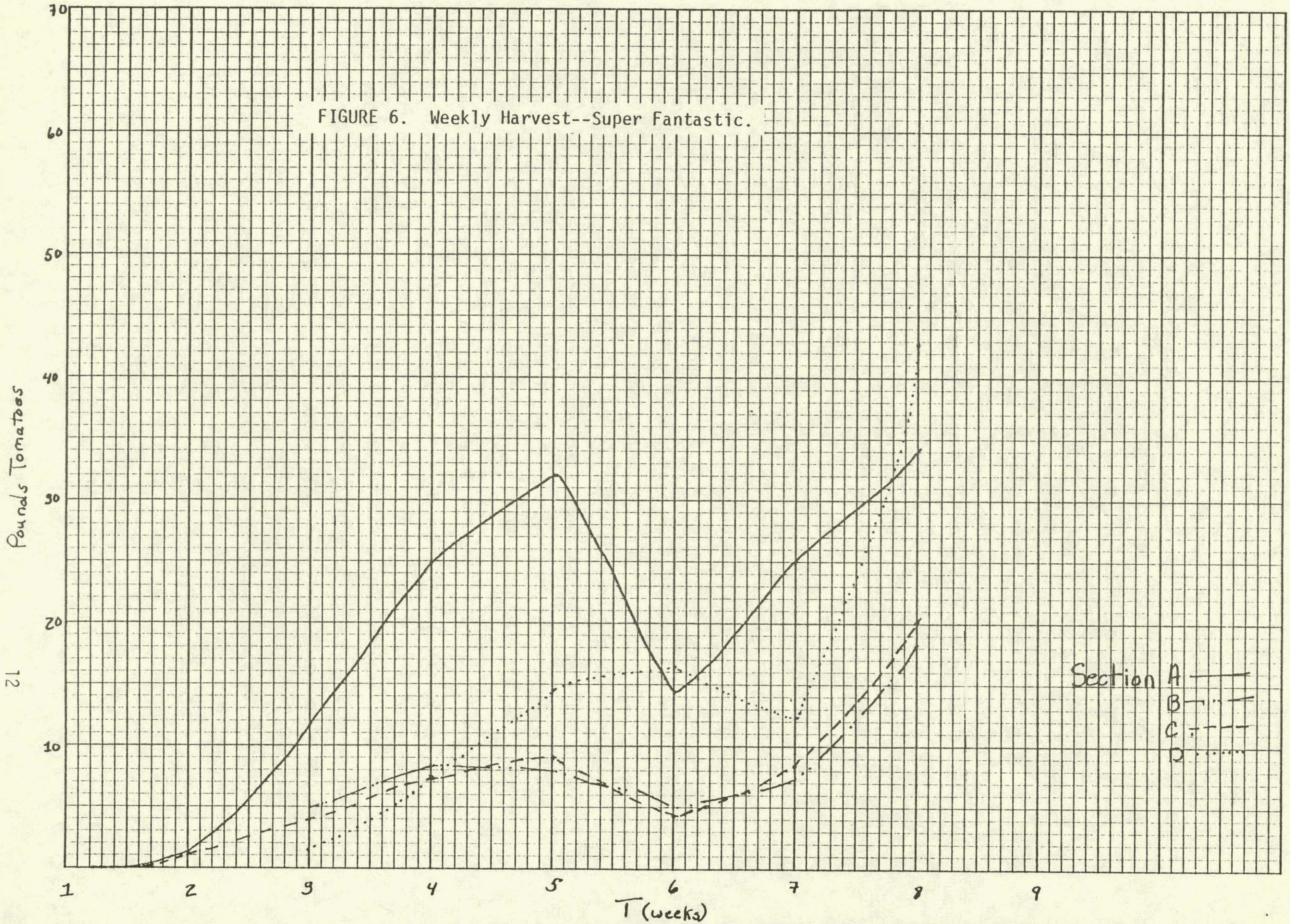
FIGURE 6. Weekly Harvest--Super Fantastic.
Pounds Tomatoes
T (weeks)
Section A
B
C
D
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9

FIGURE 7. Weekly Harvest--Cherry.

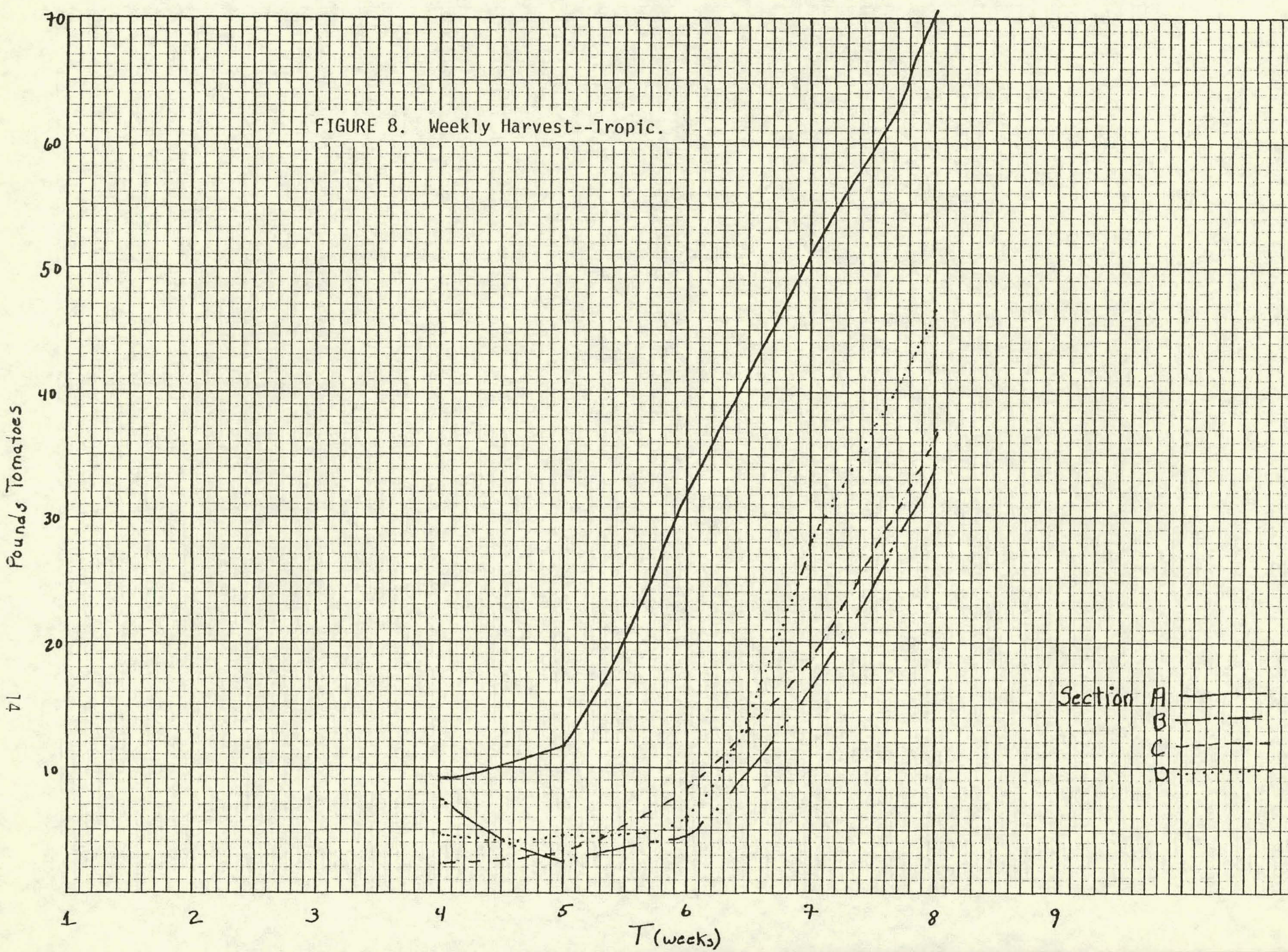
FIGURE 8. Weekly Harvest--Tropic.
Pounds Tomatoes
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
T (weeks)
Section A
B
C
D

TABLE 1

TOTALS

| A | B | C | D |
|---|---|---|---|
| 441.25 | 161.82 | 172.32 | 267.13 |

WEEKLY TOTALS

| | SF | | | | Cherry | | | | NS-tropic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 1. 10/7 - 10/13 | | | | | 4.31 | .69 | .56 | 1.0 | | | | |
| 2. 10/14 - 10/20 | 1.31 | 1.31 | | | 9.31 | 3.44 | 3.13 | 2.0 | | | | |
| 3. 10/21 - 10/27 | 12.0 | 4.0 | 5.25 | 1.81 | 9.31 | .5 | 1.5 | 6.38 | | | | |
| 4. 10/28 - 11/3 | 25.0 | 7.06 | 8.56 | 7.88 | 20.0 | 1.63 | 1.88 | 3.69 | 9.63 | 7.75 | 2.88 | 5.0 |
| 5. 11/4 - 11/10 | 32.25 | 9.0 | 8.31 | 14.63 | 23.75 | 13.75 | 8.63 | 16.38 | 11.75 | 2.5 | 3.31 | 4.81 |
| 6. 11/11 - 11/17 | 14.19 | 4.5 | 5.19 | 16.5 | 20.19 | 9.81 | 12.81 | 16.03 | 32.19 | 4.63 | 8.38 | 5.88 |
| 7. 11/18 - 11/24 | 25.44 | 8.38 | 7.63 | 12.5 | 12.31 | 7.88 | 7.81 | 14.63 | 52.38 | 16.30 | 18.19 | 28.25 |
| 8. 11/25 - 12/1 | 34.19 | 20.13 | 18.5 | 42.81 | 22.38 | 7.25 | 13.0 | 20.69 | 71.38 | 34.25 | 37.0 | 46.88 |
| 9. 12/2 - 12/8 | 12.44 | 7.5 | 7.44 | 37.13 | 13.5 | 3.5 | 8.5 | 7.25 | 26.0 | 14.75 | 14.25 | 65.81 |

Note: A - single layer plastic w/o water ceiling
B - double layer plastic w/o water ceiling
C - double layer plastic w/ water ceiling
D - single layer plastic w/ water ceiling

TABLE 2

No. Plants/Section

| SF | Cherry | NS-tropic |
|---|---|---|
| A 75 | A 75 | A 120 |
| B 31 | B 31 | B 58 |
| C 33 | C 33 | C 58 |
| D 77 | D 50 | D 115 |

As of 12/5 the Pounds/Plant/Section

| SF | Cherry | Tropic |
|---|---|---|
| A 2.1 | A 1.73 | A 1.72 |
| B 1.9 | B 1.56 | B 1.38 |
| C 1.84 | C 1.75 | C 1.45 |
| D 1.73 | D 1.75 | D 1.36 |

TABLE 3

Lettuce Height in Inches

| | $A_2$ | $B_2$ | $C_2$ | $D_2$ |
|---|---|---|---|---|
| 10/10 | 6 | 5 | 5-1/2 | 5 |
| 10/24 | 8 | 6-1/2 | 6-1/2 | 8 |
| 11/7 | 9 | 8 | 10-1/2 | 9 |
| 11/21 | 9-1/2 | 9-1/2 | 11 | 11-1/2 |
| TOTAL Δ | 3-1/2 | 4-1/2 | 5-1/2 | 6-1/2 |

Tomato Flower and Fruit Production

No. of fruit clumps

| | A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|---|
| | SF | C | SF | C* | SF | C* | SF | C |
| 10/10 | 4 | 6 | 4 | 8 | 4 | 10 | 4 | 8 |
| 10/24 | 4 | 7 | 4.5 | 12 | 4.5 | 12 | 4 | 8 |
| 11/7 | 4 | 8 | 5 | 15 | 5 | 14 | 4 | 8 |
| 11/21 | 5 | 7 | 6 | 14 | 5 | 13 | 4 | 8 |

No. of flower clumps

| | A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|---|
| | SF | C | SF | C* | SF | C* | SF | C |
| 10/10 | 3 | 3 | 1.5 | 12 | 2 | 10 | 2 | 4 |
| 10/24 | 3 | 3 | 2 | 8 | 1 | 6 | 1 | 3 |
| 11/7 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 1 |
| 11/21 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 0 |

*Note. B and C cherry tomatoes are a different variety (than A and D) having a greater number of fruit and flower clusters.

Phase II of the experiment plans to provide a sterile growing medium for the experimental plants, separated from the inground commercial operation, which can be controlled and more easily studied. Leaf analysis of plants from both sections will be taken to determine differential nutrient uptake.

The water ceiling has performed admirably with only two 4-ft sections developing algae problems. We expect the algae to be identified and the water treated with hydrogen peroxide to kill the algae and clear the water.

## INSTRUMENTATION

The solar garden has, historically, functioned with a minimum of automatically controlled mechanical equipment (ACME). The gas-furnace used to supplement solar heating in the solar garden represents its main piece of ACME. In the future, and most certainly in a full-scale commercial solar garden, more use will be made of automated systems for such things as opening and closing thermal curtains, positioning solar reflectors, watering/fertilizing plants and modifying $CO_2$, humidity and heat levels. During the second half of the solar garden experiment we will explore the use of a microcomputer for acquiring the growing environment data required for automatically controlling solar garden mechanical equipment.

Various pieces of computer and sensor equipment, some of it ERIM supplied, will be assembled to provide most of the functions shown in Figure 9. Sensors for detecting levels of temperature and sunlight will be deployed at various locations in the solar garden. The analog output from these sensors will flow via wires to an analog-to-digital converter coupled to a microcomputer. The microcomputer will read the sensor digital signals at some predetermined rate such as once per hour and transfer the signals to a cassette

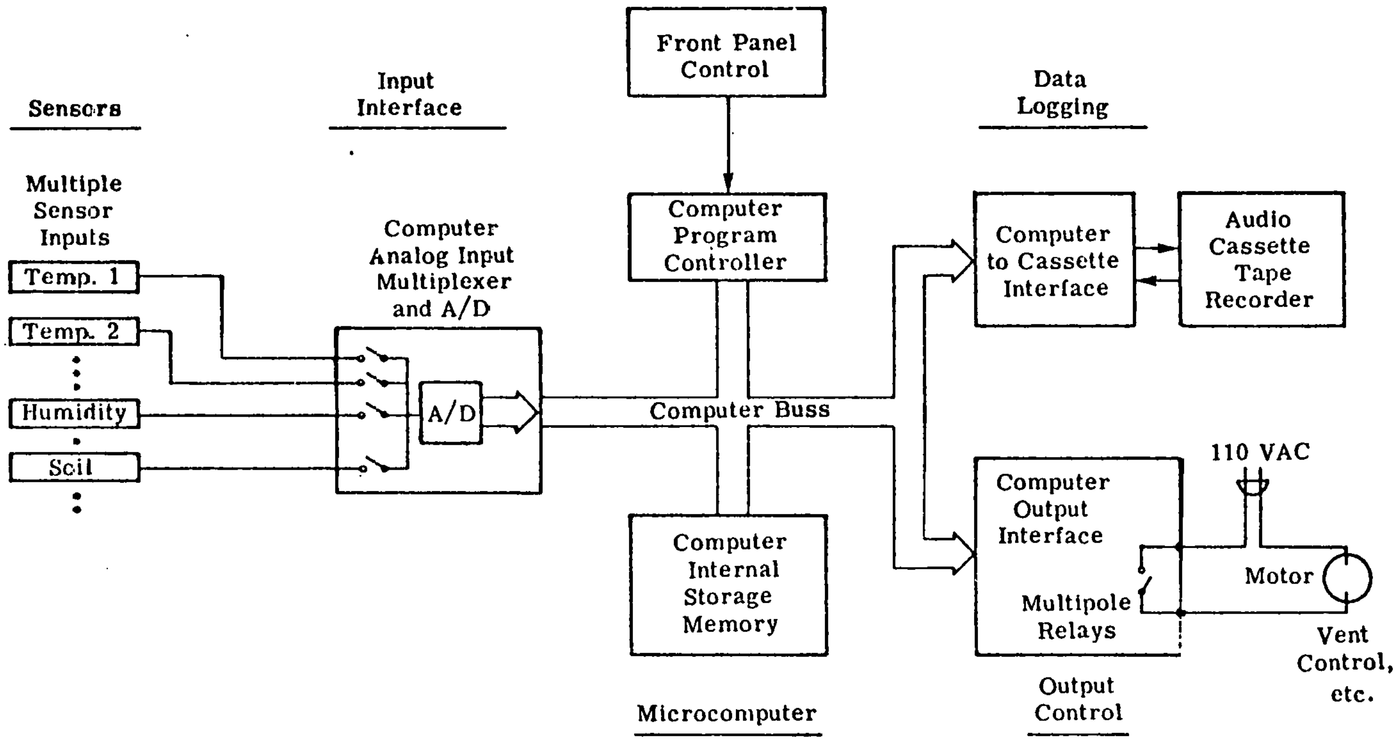


FIGURE 9. Microcomputer-Controlled Solar Garden Function Block Diagram.

tape recorder where they can be accumulated (see Table 4 for more complete description of parts). At certain times the data will be recovered from the tape recorder cassette and analyzed. The only system controlled by the microcomputer at this time will be the tape recorder which will be turned on when data is to be recorded and shut off afterward.

## PROGRAM PLANS

The second six months of the program will include a continuation of the growing and measurements experiments that have been initiated. The data will be analyzed and evaluated to determine performance of the water ceiling and other factors in the greenhouse that affect performance. The measurements of the growing program will be supplemented with light measurements and a thermal analysis of the greenhouse.

An attempt will be made to identify problem areas and limitations in this low energy environment. As an example, humidity in the conventional greenhouse is controlled by venting and then adding extra heat. In the low energy greenhouse a non-venting solution would be preferred. The resulting problem is that moisture accumulates on the glazing which in turn reduces the solar radiation entering the greenhouse and thereby degrades greenhouse performance.

TABLE 4

COMPUTER MONITORING EQUIPMENT LIST

| Function | Unit |
|---|---|
| Thermal Sensor | Glass Probe Thermistor (Newark No. 30F1768) |
| Light Sensor | Cadmium Sulfide Photoconductive Cell (Newark No. 61F1066) |
| Analog Input/Output (I/O) | Analog Manifold Module (Anaman1) |
| Coupling Analog I/O Module w/Analog to Digital (A/D) Converter | Manifold Module (Manmod1)[2] |
| Analog to Digital Converter | Analog Input Module (AIM 16)[3] |
| Couple A/D Converter w/ Microcomputer | Kim Interface (KIMMOD)[4] |
| Microcomputer | KIM[5] |
| Record Data | G.E. Cassette Tape Recorder |

1,2,3,4 Manufactured by Connecticut Microcomputer, Inc., 150 Pocono Road, Brookfield, Connecticut 06804

5 Manufactured by MOS Technology, Inc., 950 Rittenhouse Road, Norristown, Pennsylvania 19401



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