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CCEA Newsletter

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CCEA is a research organization dedicated to the improvement and vitality of the Controlled Environment Agriculture Industry. CCEA is funded by Industrial and Grower Partners who contribute a yearly partnership fee. Satellite partnership is also available to growers. Information about **CCEA** is available from:

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Vision Statement

CCEA, The Center for Controlled Environment Agriculture of NJAES at Rutgers University, a partnership among growers, industry, and researchers, will devote itself to research and transferring information required for an economically viable and environmentally aware controlled environment agriculture industry. We will particularly strive to identify future trends, critical issues, appropriate emerging technologies and provide leadership for opportunities which challenge world-wide controlled environment agriculture in the 21st century.

The boiler installation at the open-roof greenhouse is nearing completion. The floor loop is already operational. The overhead loop is waiting for an appropriate flow meter.

Insect Screening

It's the time of year again to start worrying about insect infestations in the greenhouse. Insects generally enter the greenhouse in three different ways: on infested plant material, on clothing, and through the ventilation inlet openings. Therefore, it is very important to inspect any plant material entering the greenhouse operation, even if the material comes from a reliable source. By rejecting any infested plant material, you can make sure the insects stay out of your greenhouse. If insects are entering the greenhouse on clothing, employees can be required to change clothing before they start work. As an additional precaution, the locker rooms should be continuously vented (mechanically) to prevent flying insects from entering the greenhouse.

In order to prevent insects from entering the greenhouse through ventilation openings, we can do the following. First make sure that there are no other openings except for the ventilation opening (usually the vent window). This means that all cracks in walls and glazing materials need to be sealed carefully. Next, now that we are sure the ventilation air enters only through the vent opening, we can install an insect screen in the opening. Different insect screen materials are available and generally, the smaller the opening size, the smaller insects that are excluded. Table 1 shows some recommended screen sizes for several insects to be excluded.

However, the smaller the screen opening size (i.e., mesh size), the more difficult it is for air to pass through the screen, because more of the total screen area is taken up by the threads making up the screen. Thus, as the total opening area decreases, less air is able to pass through the screen. This can have a significant effect on the cooling capacity of the ventilation system. Therefore, when using the smaller screen mesh sizes, the total screen area is usually enlarged to make sure enough air is able to pass through the screen. A good example of an insect screen installation with an increased screen area is shown in Photos 1 and 2.

The smaller the screen mesh size, the easier it is for dust particles to collect on the screen surface. The dust particles can further reduce the airflow through the insect screen, and therefore it is usually recommended to regularly clean the screen material.

Table 1. Recommended mesh sizes

Insect to be excluded:	**Recommended mesh size:**
Leafminer	**40**
Whitefly	**52**
Aphid	**78**
Thrip	**132**

Mesh size = threads per linear inch

Photo 1. NCSU, the new teaching and research greenhouses with insect screening. An enclosure was constructed along the sidewall with the ventilation inlet opening.

Photo 2. NSCU, inside the screening enclosure with the insect screen on the right and the ventilation inlet opening on the left (with evaporative cooling pad).

SOLAR RADIATION AVAILABILITY FOR PLANT GROWTH IN ARIZONA CONTROLLED ENVIRONMENT AGRICULTURE SYSTEMS

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Abstract
The availability of solar radiation and its daily and yearly distribution has a tremendous influence on the productivity and quality of plant growth. In controlled environment agriculture [CEA], where all other environmental factors such as air temperature, soil moisture, etc., are controlled or even enhanced, the solar radiation or 'light' is the most limiting factor for plant growth. Over thirteen years of solar radiation data from AZMET [Arizona Meteorological Network], which provides meteorological data for southern and central Arizona, was downloaded and analyzed to determine the total solar radiation received in Tucson, Arizona. It has been demonstrated that plant photosynthesis and subsequent growth are directly proportional to the moles of quantum units received by the plant. All data were converted into quantum units, so that the total moles m^{-2} per day, or other desired time period could be calculated. The maximum moles m^{-2} per day for the thirteen-year dataset (4,950 days) was 70.3 on June 24, 1997. Total moles per year were also calculated as well as average daily moles. Such information can be useful for predicting crop production.

Introduction

This paper provides solar radiation availability information for the Tucson, Southern Arizona region, and emphasizes how much light, when it occurs, and how it can be useful to growers in planning greenhouse construction and crop production. It utilizes available solar data from AZMET, and condenses and presents this data in more useful forms for the commercial greenhouse industry. Some background information will be reviewed first to help with the understanding of the various types of radiation units.

The two types of preferred units are the radiometric and quantum units[1]. Both types of units are expressed in terms of "light" per unit area per unit time. Seconds and square meters are the units of time and area. In radiometric units, the concern is to express light in terms of energy so the unit is the Joule, the same unit that can be converted to calories or Btu's. The Watt, commonly used to rate lamp fixtures, is actually a measure of "work" (energy per unit time), but it uses the same energy unit also. One Watt is 1 Joule per second. Therefore, radiometric measurements of light have the units of Watts per square meter (W/m^2).

Energy is also of concern when using quantum units, except here the energy is expressed in photons. A photon is a quantum packet of light. A single photon is an extremely small amount of energy. So it's more common to speak about micromoles of light, where a mole of photons is Avogadro's number (6.02×10^{23}) of photons. When totaling light over the course of the day, 'moles' is the integrated unit (per unit area).

PAR, Photosynthetically Active Radiation, is light in the waveband between 400 and 700 nanometer (nm), which are the limits of wavelengths that are of primary importance for plant photosynthesis. This waveband is also *roughly* the same as *visible* light that the human eye can detect. A major pitfall in comparing visible light to PAR is that the sensitivity of our eyes to wavelengths within this waveband is very different than the response of plants. Consequently it is difficult to judge the amount of PAR present just by how bright an environment seems to our eyes.

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Materials and Methods

The light data that was analyzed was obtained from the AZMET station in Tucson, Arizona. The data was originally obtained at the station using a LI-COR Pyranometer, which measures electromagnetic radiation in the 400 - 1,100 nm waveband. The data was presented and downloaded in the form of hourly averages with units of MegaJoules/m^2 (MJ/m^2). This was converted and integrated into Moles/m^2 using the scaling factor developed by Ting and Giacomelli[2]. Consequently, all the following table mole values are based on light *per square meter*, unless otherwise noted.

Thirteen years of data (1988 to 2000 inclusive) plus the first 210 days of 2001 are in the data set. With so few years in the set, only *general* trends are shown, and must be applied with caution.

In most of the tables and all graphs, the *Julian* calendar is used. This is a numerical representation of each day of the year, which facilitates the use of xy-graphs. January 1st is day 1 of the Julian year. December 31st is Julian day 365 except on leap years when it is day 366. To get the Julian equivalent of any day of the year, the total days per month for all the months before the desired day are summed, plus the number of days into the month that the day occurs. For example, May 10th is day 31 + 28 + 31 + 30 + 10 = 130 Julian.

Results and Discussion

When planning on siting a greenhouse and growing a crop, available light is one of the most important parameters to consider. Utilities of various sorts can be made available to the planned greenhouse at some cost. Lack of natural light however, cannot be corrected. Artificial lighting is expensive even as a supplement to natural light and would be prohibitively expensive as a *replacement* for sunlight.

Potential growers need to consider total light, intensity, as well where the sun is in the sky-in position and elevation. At the local latitude the sun is never directly overhead, and always shines from the south. This southerly angling is particularly acute in the winter.

Greenhouses of different types and glazings transmit varying amounts of light. The object is to construct a greenhouse that meets all the other criteria (such as the capital construction budget and local codes) but that also transmits enough PAR for adequate crop production.

Table 1 presents the average daily moles and standard deviation for each month of the year. These were generated from all the years in the dataset. Julian days for each month are shown with the month labels. The standard deviation for the variation in average daily moles for each month is a measure of how much haze, dust, and cloud cover occurs over the year, all of which is somewhat influenced by local human activity.

June was the month in the dataset that had the highest average daily mole total, at 60.0 moles per day. While seasons with differing amounts of cloud cover are noted for Tucson, astronomic facts about the declination of the planet also impact the total light received. Since Tucson is in the Northern Hemisphere (latitude ~32^o North), the *summer* solstice occurs around June 22$^{nd.}$ It is no coincidence that the day in the set with the highest total moles occurred near this event (in 1997). The unpredictable variable quantity that can influence the total light received around that time is the degree of cloud cover.

Figure 1 shows the maximum intensities, which occurred on any day of the year. The highest values occur around the summer solstice and reach about 1,110 W/m^2. The lowest values occur in winter and are about 700 W/m^2. Translated into PAR, these values are about 2,300 and 1,450 µmol/m^2s, respectively.

Total moles per year received for the Tucson area, as well as a calculation of average daily moles on a whole-year basis were also made. Aside from the total energy that's received over the course of the year (averaged at 15,400 moles), of note was the consistency of yearly light that is received. Only a 12% difference in total moles was found between the sunniest and cloudiest years.

Figure 2 displays the entire set of days where light was integrated. The overall shape of the area where data points occurs is a function of the Earths' changing declination over the year. With care, some predictions can be made about the probability of sun on any particular day.

Figure 3 is based on a table (not included) which lists moles per day averaged over the thirteen year set, standard deviation of the yearly values on which the first column is based, and a column where that deviation is normalized. The normalized variation is shown on the Figure 3. This graph provides a means to compare the daily variation for periods of days at different times of the year when different absolute amounts of light were received.

In Table 2 the average daily moles are shown by season. As expected there is more light available during the spring and summer. Two other factors that help explain these can be noted in Figure 4.

Figure 4 shows the total inches of rain for any day of the year, integrated over the whole dataset. Vertical lines on the plot break the year into seasons. The inset numbers are for total number of rainy days during each of the seasons, and total inches of rain received for each season. The values for winter and summer indicate the presence of the minor and major rainy seasons in the local area.

Table 3 shows a breakdown of moles per day and total moles per crop during the time of production (September 1st to May 31st) of tomatoes at the Campus Agricultural Center Hydroponic Greenhouse in North-Central Tucson, which is near the AZMET station where the light data was collected. This production period consists of 74.4% of a full year but the average number of moles per day during this period is 91.1% of the average daily moles for the whole dataset. This means that the times of the year with the most light were included in the production period.

Conclusions

The purpose of this study was to take readily available solar radiation data and convert it into units depicting PAR, the portion of sunlight usable by plants. Also to present it in forms that show how sunlight varies of the course of the year in Tucson. By study of such data, decisions on siting greenhouses for crop production can be made.

References

1. Thimijan, R.W., Royal D. Heins. 1983. Photometric, Radiometric, and Quantum Light Units of Measure: A Review of Procedures for Interconversion. HortScience 18(6):818-822.
2. Ting, K.C., G. A. Giacomelli. 1987. Availability of Solar Photosynthetically Active Radiation. Transactions of the ASAE. 30(5):1453-1457.

Table 1. Average Moles per day of each month, standard deviation of average day Mole totals.

Month (Julian range)	Average Daily Moles	Standard Deviation
January (1 - 31)	25.4	2.90
February (32 - 59)	31.5	3.03
March (60 - 90)	42.3	3.23
April (91 - 120)	52.9	3.90
May (121 - 152)	58.9	4.03
June (153 - 181)	60.0	3.29
July (182 - 212)	52.2	2.77
August (213 - 243)	48.6	1.99
September (244 - 273)	44.6	2.08
October (274 - 304)	37.2	2.99
November (305 - 334)	28.2	1.89
December (335 - 365)	23.4	2.70

Table 2. Average daily moles per day per season.

Season (Julian Range)	Average Moles per Day
Winter, December 22 to March 21 (356 - 80)	30.3
Spring, March 22 to June 21 (81 - 172)	55.9
Summer, June 22 to September 21 (173 - 264)	50.1
Fall, September 22 to December 21 (265 - 355)	31.8

Table 3. Light during CAC Tomato Production season (September to May).

Year	Average Daily Moles during Tomato Production	Total Moles during Tomato Production
1988	37.7	10,244
1989	39.2	10,730
1990	37.9	10,395
1991	37.6	10,312
1992	35.3	9,698
1993	36.1	9,887
1994	37.4	10,245
1995	38.8	10,633
1996	40.3	11,072
1997	38.8	10,639
1998	38.5	10,562
1999	42.1	11,495
2000	39.7	10,909
Overall average:	38.4	10,525

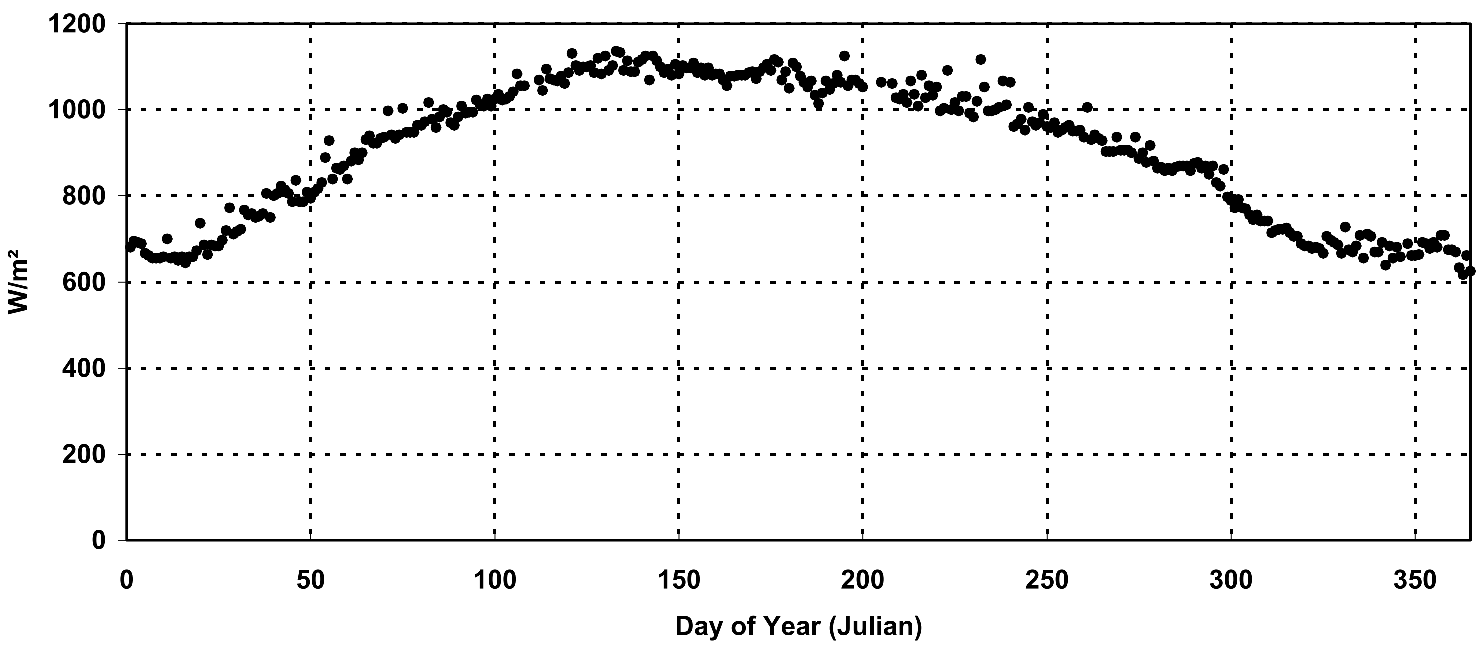

Figure 1. Maximum Solar Intensities in Tucson AZ, from 1988 through 2001. Radiometric units.

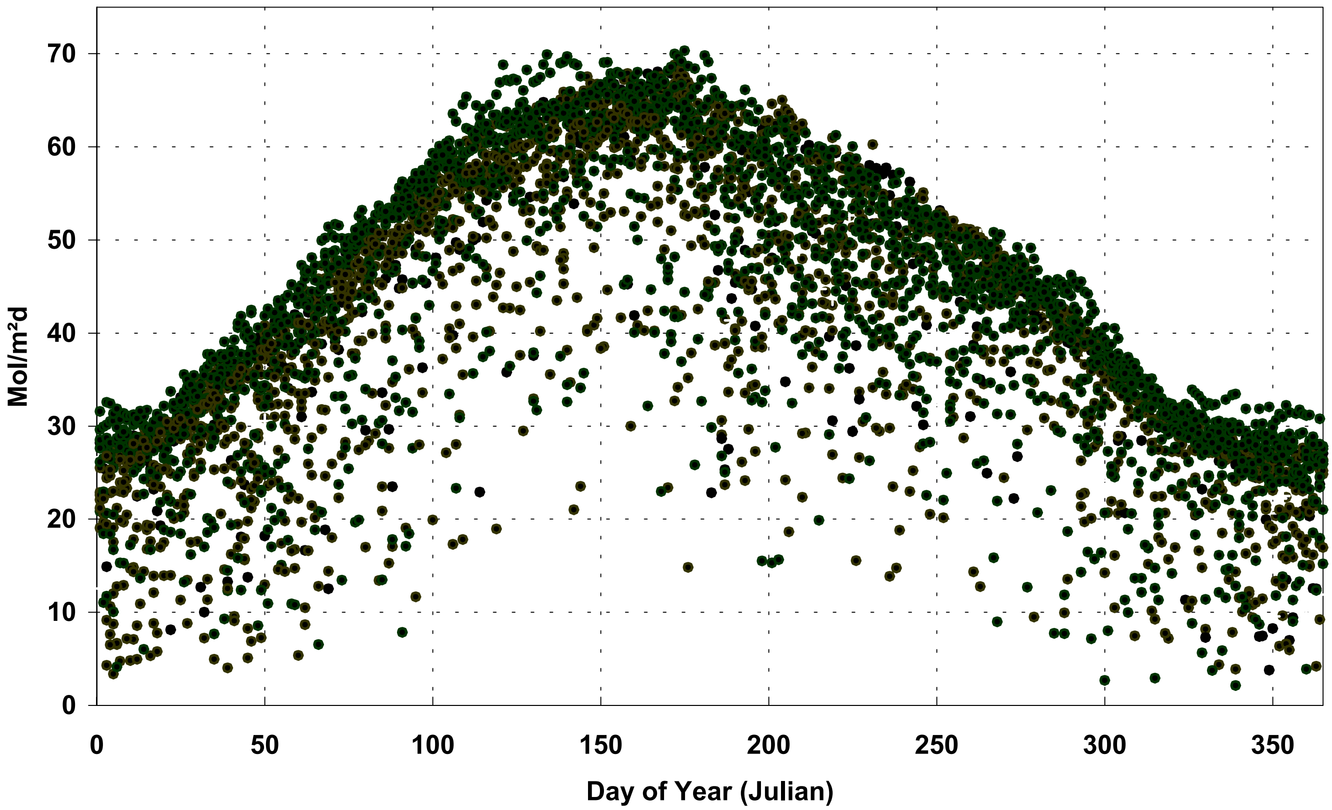

Figure 2. Total Moles per Day for Tucson AZ, 1988 to July, 2001.

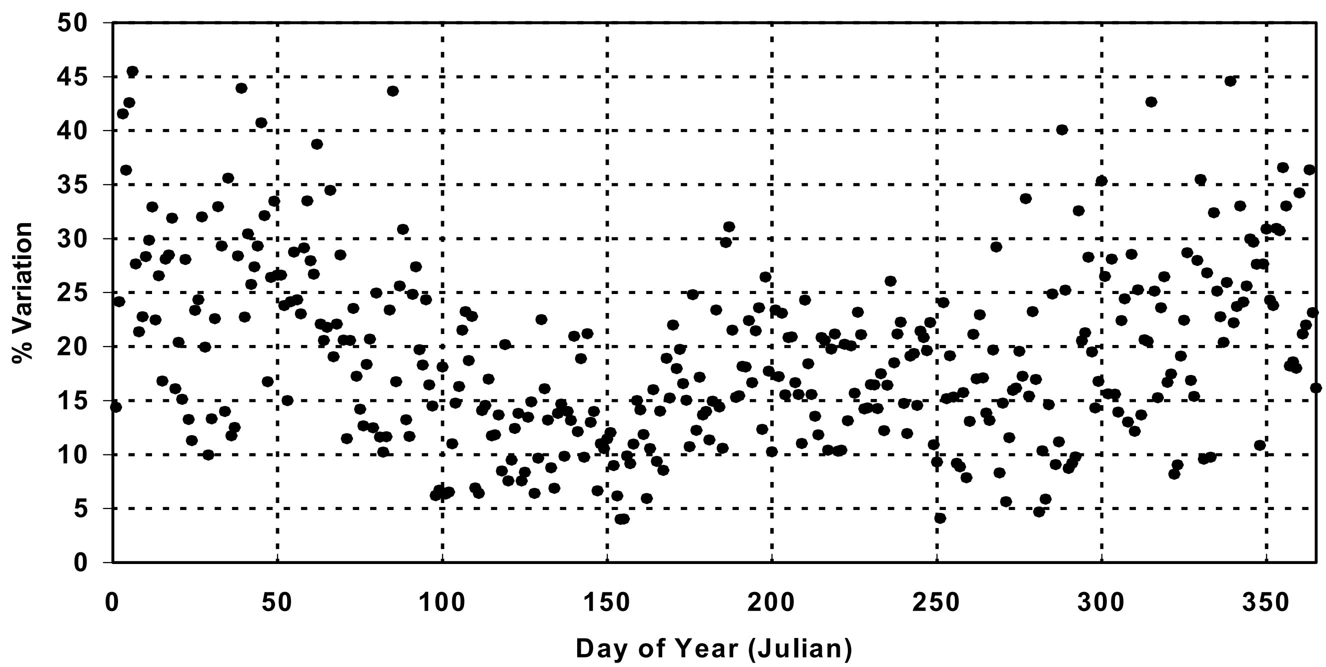

Figure 3. Normalized Variation in Average Daily Moles for Tucson, AZ.

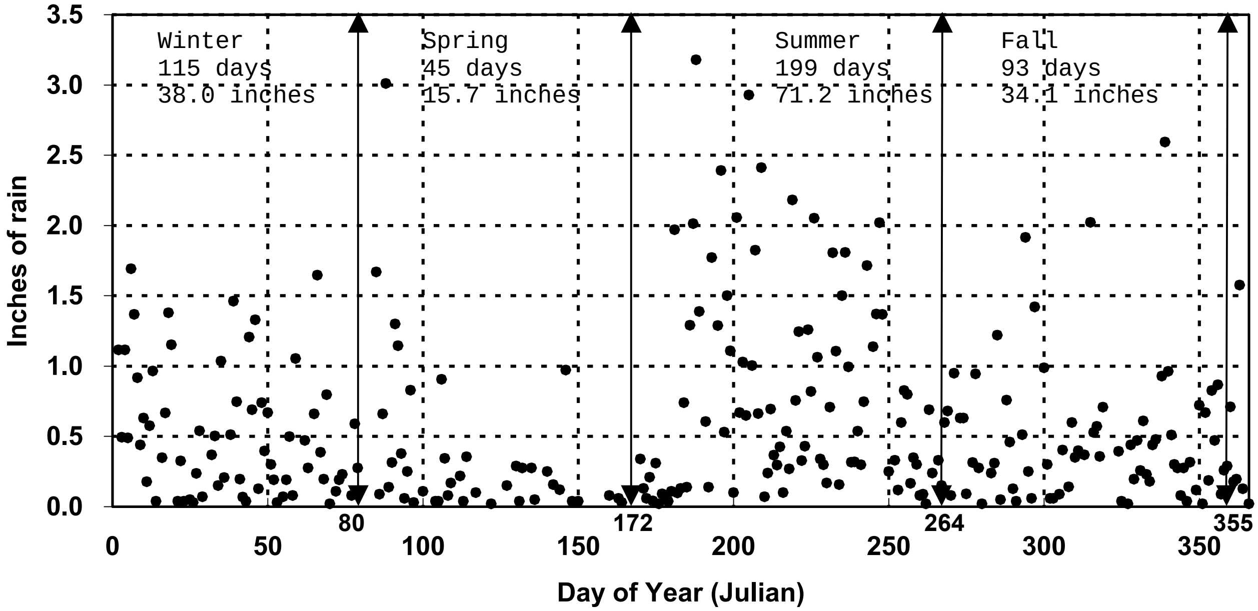

Figure 4. All rainy days from 1988 - July 2001 in Tucson, AZ, including totals of rainy days and amounts by season.

A slightly different version of this paper was presented at the 30th National Agricultural Plastics Congress in San Diego, CA, February 23-26, 2002. The proceedings can be purchased from the American Society for Plasticulture, 1924 N. Second Street, Harrisburg, PA 17102 Phone: 717-238-9762, FAX: 814-238-705, e-mail: info@plasticulture.org, web site: http://www.plasticulture.org. Price: $35 plus $5 for shipping and handling (North America).

One of the research greenhouses at the University of Arizona in Tucson, AZ. Inside, hydroponic tomato research is conducted by members of the Controlled Environment Agriculture Center, which is directed by Prof. Gene Giacomelli. For more information about CEAC, visit the following web site: http://ag.arizona.edu/ceac/